NGSS Evidence Statements

Executive Summary of the Front Matter

Overview

- The NGSS identify assessable performance expectations (PEs), or what students should know and be able to do at the end of instruction.
- Each PE represents the integration of three "dimensions" of science education: scientific and engineering practices, disciplinary core ideas (DCIs), and crosscutting concepts (CCCs). As such, both student learning and assessment around the NGSS should be "three dimensional".
- The evidence statements are meant to show what it looks like for students to fully satisfy the PE.

Purpose

- The evidence statements were designed to articulate how students can use the practices to demonstrate their understanding of the DCIs through the lens of the CCCs, and thus, demonstrate proficiency on each PE. The evidence statements do this by clarifying:
    - How the three dimensions could be assessed together, rather than in independent units
    - The underlying knowledge required for each DCI
    - The detailed approaches to science and engineering practices
    - How crosscutting concepts might be used to deepen content- and practice-driven learning
- Given the shift to three dimensional learning, it is important to note that "minimum proficiency" on the NGSS is higher than for most previous standards, and will not look the same.
- The evidence were **<u>not</u>** created to:
    - Be used as curriculum
    - Limit or dictate instruction

Structure

- The science and engineering practices are used as the organizing structure for the evidence statements (this **<u>does not</u>** mean that the practices are more important than the other dimensions). The proper integration of practices make students' thinking visible.
- As such, there are templates for each practice that contain the categories necessary for students to demonstrate full proficiency on that practice.
- The evidence statements and the associated templates **<u>are not</u>** meant to be used for the following:
    - As a description of teacher prompts, instructional techniques, or steps in a classroom activity
    - As a description of increasing levels of cognitive difficulty, Depth of Knowledge levels, or varying levels of student proficiency
    - As a checklist that denotes the ordering or sequence of steps in a student's performance

How to Use the Evidence Statements

- All users should spend time understanding the NRC's *Framework for K-12 Science Education* and NGSS prior to using the evidence statements
- For assessment: the evidence statements can be used to inform the development of summative assessments, but context would have to be added to the statements to align with the specific examples or prompts used in the assessment.
- For instruction: the evidence statements can be used in support of instructional design, but it is crucial to recognize that there are numerous pathways educators may use across the course of lessons and units to allow students to ultimately be prepared for success on the performance expectations (and thus to be able to demonstrate the evidence statements).
- Although evidence statements are listed individually for each performance expectation, **this does not indicate that they should be measured individually, or that performance expectations should be taught or assessed individually**. Classroom instruction should be focused on helping students build towards several PEs at one time because many concepts and practices are interrelated.

Limitations of the Evidence Statements

- The evidence statements cannot do the following:
  - Provide or proscribe the contexts through which the PEs may be taught or assessed
  - Be the rubrics on which levels of student success would be measured
  - Identify the sequence of instruction or assessment
  - Put limits on student learning or student coursework
  - Replace lesson plans or assessment items
  - Serve as complete scoring rubrics

Development Process & Criteria

- Discipline-based teams of scientists and educators — including many of the writers of the NGSS — worked together to create the evidence statements (starting with high school).
- These authors used the following guiding principles and criteria (among others) to craft the evidence statements:
  - Statements should describe observable evidence that a scorer or assessor could actually see and measure
  - Statements should be written as if they are the "proficient" level
  - Foundation box bullets from all three dimensions must be the focus of the statements and statements must not go beyond the bullets of each dimension's foundation box
  - Specific mathematical formulae should be highlighted when required for student use
  - Concepts that are included in prior grades' DCIs should not be repeated unless they are also in the current grade's DCIs

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-PS1-1

Students who demonstrate understanding can:

HS-PS1-1. **Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.** [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [*Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Use a model to predict the relationships between systems or between components of a system.	**PS1.A: Structure and Properties of Matter** • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From the given model, students identify and describe the components of the model that are relevant for their predictions, including:	
		i.	Elements and their arrangement in the periodic table;
		ii.	A positively-charged nucleus composed of both protons and neutrons, surrounded by negatively-charged electrons;
		iii.	Electrons in the outermost energy level of atoms (i.e., valence electrons); and
		iv.	The number of protons in each element.
2	Relationships		
	a	Students identify and describe the following relationships between components in the given model, including:	
		i.	The arrangement of the main groups of the periodic table reflects the patterns of outermost electrons.
		ii.	Elements in the periodic table are arranged by the numbers of protons in atoms.
3	Connections		
	a	Students use the periodic table to predict the patterns of behavior of the elements based on the attraction and repulsion between electrically charged particles and the patterns of outermost electrons that determine the typical reactivity of an atom.	
	b	Students predict the following patterns of properties:	
		i.	The number and types of bonds formed (i.e. ionic, covalent, metallic) by an element and between elements;
		ii.	The number and charges in stable ions that form from atoms in a group of the periodic table;

		iii.	The trend in reactivity and electronegativity of atoms down a group, and across a row in the periodic table, based on attractions of outermost (valence) electrons to the nucleus; and
		iv.	The relative sizes of atoms both across a row and down a group in the periodic table.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-PS1-2

Students who demonstrate understanding can:

HS-PS1-2. **Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.** [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [*Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and 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.

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

PS1.B: Chemical Reactions

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation of the outcome of the given reaction, including:	
		i.	The idea that the total number of atoms of each element in the reactant and products is the same;
		ii.	The numbers and types of bonds (i.e., ionic, covalent) that each atom forms, as determined by the outermost (valence) electron states and the electronegativity;
		iii.	The outermost (valence) electron state of the atoms that make up both the reactants and the products of the reaction is based on their position in the periodic table; and
		iv.	A discussion of how the patterns of attraction allow the prediction of the type of reaction that occurs (e.g., formation of ionic compounds, combustion of hydrocarbons).
2	Evidence		
	a	Students identify and describe the evidence to construct the explanation, including:	
		i.	Identification of the products and reactants, including their chemical formulas and the arrangement of their outermost (valence) electrons;
		ii.	Identification that the number and types of atoms are the same both before and after a reaction;
		iii.	Identification of the numbers and types of bonds (i.e., ionic, covalent) in both the reactants and the products;
		iv.	The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic

		level as determined by using the periodic table; and
		v. The outermost (valence) electron configuration and the relative electronegativity of the atoms that make up both the reactants and the products of the reaction based on their position in the periodic table.
3	Reasoning	
	a	Students describe their reasoning that connects the evidence, along with the assumption that theories and laws that describe their natural world operate today as they did in the past and will continue to do so in the future, to construct an explanation for how the patterns of outermost electrons and the electronegativity of elements can be used to predict the number and types of bonds each element forms.
	b	In the explanation, students describe the causal relationship between the observable macroscopic patterns of reactivity of elements in the periodic table and the patterns of outermost electrons for each atom and its relative electronegativity.
4	Revising the explanation	
	a	Given new evidence or context, students construct a revised or expanded explanation about the outcome of a chemical reaction and justify the revision.

HS-PS1-3

Students who demonstrate understanding can:

HS-PS1-3. **Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.** [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [*Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • 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.	**PS1.A: Structure and Properties of Matter** • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe the phenomenon under investigation, which includes the following idea: the relationship between the measurable properties (e.g., melting point, boiling point, vapor pressure, surface tension) of a substance and the strength of the electrical forces between the particles of the substance.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data, including bulk properties of a substance (e.g., melting point and boiling point, volatility, surface tension) that would allow inferences to be made about the strength of electrical forces between particles.	
	b	Students describe why the data about bulk properties would provide information about strength of the electrical forces between the particles of the chosen substances, including the following descriptions:	
		i.	The spacing of the particles of the chosen substances can change as a result of the experimental procedure even if the identity of the particles does not change (e.g., when water is boiled the molecules are still present but further apart).
		ii.	Thermal (kinetic) energy has an effect on the ability of the electrical attraction between particles to keep the particles close together. Thus, as more energy is added to the system, the forces of attraction between the particles can no longer keep the particles close together.
		iii.	The patterns of interactions between particles at the molecular scale are reflected in the

		patterns of behavior at the macroscopic scale.
		iv. Together, patterns observed at multiple scales can provide evidence of the causal relationships between the strength of the electrical forces between particles and the structure of substances at the bulk scale.
3	Planning for the investigation	
	a	In the investigation plan, students include:
		i. A rationale for the choice of substances to compare and a description of the composition of those substances at the atomic molecular scale.
		ii. A description of how the data will be collected, the number of trials, and the experimental set up and equipment required.
	b	Students describe how the data will be collected, the number of trials, the experimental set up, and the equipment required.
4	Collecting the data	
	a	Students collect and record data — quantitative and/or qualitative — on the bulk properties of substances.
5	Refining the design	
	a	Students evaluate their investigation, including evaluation of:
		i. Assessing the accuracy and precision of the data collected, as well as the limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the plan to produce more accurate, precise, and useful data.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-PS1-4

Students who demonstrate understanding can:

HS-PS1-4. **Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.** [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [*Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.

PS1.B: Chemical Reactions

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

Crosscutting Concepts

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe the relevant components, including:	
		i.	The chemical reaction, the system, and the surroundings under study;
		ii.	The bonds that are broken during the course of the reaction;
		iii.	The bonds that are formed during the course of the reaction;
		iv.	The energy transfer between the systems and their components or the system and surroundings;
		v.	The transformation of potential energy from the chemical system interactions to kinetic energy in the surroundings (or vice versa) by molecular collisions; and
		vi.	The relative potential energies of the reactants and the products.
2	Relationships		
	a	In the model, students include and describe the relationships between components, including:	
		i.	The net change of energy within the system is the result of bonds that are broken and formed during the reaction (Note: This does not include calculating the total bond energy changes.);
		ii.	The energy transfer between system and surroundings by molecular collisions;
		iii.	The total energy change of the chemical reaction system is matched by an equal but opposite change of energy in the surroundings (Note: This does not include calculating

			the total bond energy changes.); and
		iv.	The release or absorption of energy depends on whether the relative potential energies of the reactants and products decrease or increase.
3	Connections		
	a	Students use the developed model to illustrate:	
		i.	The energy change within the system is accounted for by the change in the bond energies of the reactants and products. (Note: This does not include calculating the total bond energy changes.)
		ii.	Breaking bonds requires an input of energy from the system or surroundings, and forming bonds releases energy to the system and the surroundings.
		iii.	The energy transfer between systems and surroundings is the difference in energy between the bond energies of the reactants and the products.
		iv.	The overall energy of the system and surroundings is unchanged (conserved) during the reaction.
		v.	Energy transfer occurs during molecular collisions.
		vi.	The relative total potential energies of the reactants and products can be accounted for by the changes in bond energy.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-PS1-5

Students who demonstrate understanding can:

HS-PS1-5. **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.** [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [*Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.	**PS1.B: Chemical Reactions** • Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes the idea that as the kinetic energy of colliding particles increases and the number of collisions increases, the reaction rate increases.	
2	Evidence		
	a	Students identify and describe evidence to construct the explanation, including:	
		i.	Evidence (e.g., from a table of data) of a pattern that increases in concentration (e.g., a change in one concentration while the other concentration is held constant) increase the reaction rate, and vice versa; and
		ii.	Evidence of a pattern that increases in temperature usually increase the reaction rate, and vice versa.
3	Reasoning		
	a	Students use and describe the following chain of reasoning that integrates evidence, facts, and scientific principles to construct the explanation:	
		i.	Molecules that collide can break bonds and form new bonds, producing new molecules.
		ii.	The probability of bonds breaking in the collision depends on the kinetic energy of the collision being sufficient to break the bond, since bond breaking requires energy.
		iii.	Since temperature is a measure of average kinetic energy, a higher temperature means that molecular collisions will, on average, be more likely to break bonds and form new bonds.
		iv.	At a fixed concentration, molecules that are moving faster also collide more frequently, so molecules with higher kinetic energy are likely to collide more often.
		v.	A high concentration means that there are more molecules in a given volume and thus more particle collisions per unit of time at the same temperature.

HS-PS1-6

Students who demonstrate understanding can:

HS-PS1-6. **Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*** [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [*Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**PS1.B: Chemical Reactions** • In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary)*	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students identify and describe potential changes in a component of the given chemical reaction system that will increase the amounts of particular species at equilibrium. Students use evidence to describe the relative quantities of a product before and after changes to a given chemical reaction system (e.g., concentration increases, decreases, or stays the same), and will explicitly use Le Chatelier's principle, including:	
		i.	How, at a molecular level, a stress involving a change to one component of an equilibrium system affects other components;
		ii.	That changing the concentration of one of the components of the equilibrium system will change the rate of the reaction (forward or backward) in which it is a reactant, until the forward and backward rates are again equal; and
		iii.	A description of a system at equilibrium that includes the idea that both the forward and backward reactions are occurring at the same rate, resulting in a system that appears stable at the macroscopic level.
2	Describing criteria and constraints, including quantification when appropriate		
	a	Students describe the prioritized criteria and constraints, and quantify each when appropriate. Examples of constraints to be considered are cost, energy required to produce a product, hazardous nature and chemical properties of reactants and products, and availability of resources.	
3	Evaluating potential solutions		
	a	Students systematically evaluate the proposed refinements to the design of the given chemical	

		system. The potential refinements are evaluated by comparing the redesign to the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources).
4	Refining and/or optimizing the design solution	
	a	Students refine the given designed system by making tradeoffs that would optimize the designed system to increase the amount of product, and describe the reasoning behind design decisions.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-PS1-7

Students who demonstrate understanding can:

HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [*Assessment Boundary: Assessment does not include complex chemical reactions.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena to support claims.

Disciplinary Core Ideas

PS1.B: Chemical Reactions

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Crosscutting Concepts

Energy and Matter

- The total amount of energy and matter in closed systems is conserved.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent.

Observable features of the student performance by the end of the course:			
1	Representation		
	a	Students identify and describe the relevant components in the mathematical representations:	
		i.	Quantities of reactants and products of a chemical reaction in terms of atoms, moles, and mass;
		ii.	Molar mass of all components of the reaction;
		iii.	Use of balanced chemical equation(s); and
		iv.	Identification of the claim that atoms, and therefore mass, are conserved during a chemical reaction.
	b	The mathematical representations may include numerical calculations, graphs, or other pictorial depictions of quantitative information.	
	c	Students identify the claim to be supported: that atoms, and therefore mass, are conserved during a chemical reaction.	
2	Mathematical modeling		
	a	Students use the mole to convert between the atomic and macroscopic scale in the analysis.	
	b	Given a chemical reaction, students use the mathematical representations to	
		i.	Predict the relative number of atoms in the reactants versus the products at the atomic molecular scale; and
		ii.	Calculate the mass of any component of a reaction, given any other component.
3	Analysis		
	a	Students describe how the mathematical representations (e.g., stoichiometric calculations to show that the number of atoms or number of moles is unchanged after a chemical reaction where a specific mass of reactant is converted to product) support the claim that atoms, and therefore	

		mass, are conserved during a chemical reaction.
	b	Students describe how the mass of a substance can be used to determine the number of atoms, molecules, or ions using moles and mole relationships (e.g., macroscopic to atomic molecular scale conversion using the number of moles and Avogadro's number).

HS-PS1-8

Students who demonstrate understanding can:

HS-PS1-8. **Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.** [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [*Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

PS1.C: Nuclear Processes

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.

Crosscutting Concepts

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop models in which they identify and describe the relevant components of the models, including:	
		i.	Identification of an element by the number of protons;
		ii.	The number of protons and neutrons in the nucleus before and after the decay;
		iii.	The identity of the emitted particles (i.e., alpha, beta — both electrons and positrons, and gamma); and
		iv.	The scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.
2	Relationships		
	a	Students develop five distinct models to illustrate the relationships between components underlying the nuclear processes of 1) fission, 2) fusion and 3) three distinct types of radioactive decay.	
	b	Students include the following features, based on evidence, in all five models:	
		i.	The total number of neutrons plus protons is the same both before and after the nuclear process, although the total number of protons and the total number of neutrons may be different before and after.
		ii.	The scale of energy changes in a nuclear process is much larger (hundreds of thousands or even millions of times larger) than the scale of energy changes in a chemical process.
3	Connections		
	a	Students develop a fusion model that illustrates a process in which two nuclei merge to form a single, larger nucleus with a larger number of protons than were in either of the two original nuclei.	
	b	Students develop a fission model that illustrates a process in which a nucleus splits into two or more fragments that each have a smaller number of protons than were in the original nucleus.	
	c	In both the fission and fusion models, students illustrate that these processes may release	

		energy and may require initial energy for the reaction to take place.
	d	Students develop radioactive decay models that illustrate the differences in type of energy (e.g., kinetic energy, electromagnetic radiation) and type of particle (e.g., alpha particle, beta particle) released during alpha, beta, and gamma radioactive decay, and any change from one element to another that can occur due to the process.
	e	Students develop radioactive decay models that describe that alpha particle emission is a type of fission reaction, and that beta and gamma emission are not.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-PS2-1

Students who demonstrate understanding can:

HS-PS2-1. **Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.** [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [*Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- 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.

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Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Newton's second law accurately predicts changes in the motion of macroscopic objects.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Organizing data		
	a	Students organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings).	
2	Identifying relationships		
	a	Students use tools, technologies, and/or models to analyze the data and identify relationships within the datasets, including:	
		i.	A more massive object experiencing the same net force as a less massive object has a smaller acceleration, and a larger net force on a given object produces a correspondingly larger acceleration; and
		ii.	The result of gravitation is a constant acceleration on macroscopic objects as evidenced by the fact that the ratio of net force to mass remains constant.
3	Interpreting data		
	a	Students use the analyzed data as evidence to describe that the relationship between the observed quantities is accurately modeled across the range of data by the formula $a = F_{net}/m$ (e.g., double force yields double acceleration, etc.).	
	b	Students use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration.	
	c	Students express the relationship $F_{net}=ma$ in terms of causality, namely that a net force on an object causes the object to accelerate.	

HS-PS2-2

Students who demonstrate understanding can:

HS-PS2-2. **Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.** [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [*Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena to describe explanations.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object.
- If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

Crosscutting Concepts

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students clearly define the system of the two interacting objects that is represented mathematically, including boundaries and initial conditions.
	b	Students identify and describe the momentum of each object in the system as the product of its mass and its velocity, $p = mv$ (p and v are restricted to one-dimensional vectors), using the mathematical representations.
	c	Students identify the claim, indicating that the total momentum of a system of two interacting objects is constant if there is no net force on the system.
2	Mathematical modeling	
	a	Students use the mathematical representations to model and describe the physical interaction of the two objects in terms of the change in the momentum of each object as a result of the interaction.
	b	Students use the mathematical representations to model and describe the total momentum of the system by calculating the vector sum of momenta of the two objects in the system.
3	Analysis	
	a	Students use the analysis of the motion of the objects before the interaction to identify a system with essentially no net force on it.
	b	Based on the analysis of the total momentum of the system, students support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so that momentum of the system is constant.
	c	Students identify that the analysis of the momentum of each object in the system indicates that any change in momentum of one object is balanced by a change in the momentum of the other object, so that the total momentum is constant.

HS-PS2-3

Students who demonstrate understanding can:

HS-PS2-3. **Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*** [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [*Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.	**PS2.A: Forces and Motion** • If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. **ETS1.A: Defining and Delimiting an Engineering Problem** • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary)* **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. *(secondary)*	**Cause and Effect** • Systems can be designed to cause a desired effect.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students design a device that minimizes the force on a macroscopic object during a collision. In the design, students:	
		i.	Incorporate the concept that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t = m\Delta v$); and
		ii.	Explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision.
	b	In the design plan, students describe the scientific rationale for their choice of materials and for the structure of the device.	
2	Describing criteria and constraints, including quantification when appropriate		

	a	Students describe and quantify (when appropriate) the criteria and constraints, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets).
3	Evaluating potential solutions	
	a	Students systematically evaluate the proposed device design or design solution, including describing the rationales for the design and comparing the design to the list of criteria and constraints.
	b	Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits.
4	Refining and/or optimizing the design solution	
	a	Students use the test results to improve the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-PS2-4

Students who demonstrate understanding can:

HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [*Assessment Boundary: Assessment is limited to systems with two objects.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena to describe explanations.

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Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.

Disciplinary Core Ideas

PS2.B: Types of Interactions

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students clearly define the system of the interacting objects that is mathematically represented.
	b	Using the given mathematical representations, students identify and describe the gravitational attraction between two objects as the product of their masses divided by the separation distance squared $\left(F_g = -G\frac{m_1 m_2}{d^2}\right)$, where a negative force is understood to be attractive.
	c	Using the given mathematical representations, students identify and describe the electrostatic force between two objects as the product of their individual charges divided by the separation distance squared $\left(F_e = k\frac{q_1 q_2}{d^2}\right)$, where a negative force is understood to be attractive.
2	Mathematical modeling	
	a	Students correctly use the given mathematical formulas to predict the gravitational force between objects or predict the electrostatic force between charged objects.
3	Analysis	
	a	Based on the given mathematical models, students describe that the ratio between gravitational and electric forces between objects with a given charge and mass is a pattern that is independent of distance.

	b	Students describe that the mathematical representation of the gravitational field $\left(F_g = -G\frac{m_1 m_2}{d^2}\right)$ only predicts an attractive force because mass is always positive.
	c	Students describe that the mathematical representation of the electric field $\left(F_e = k\frac{q_1 q_2}{d^2}\right)$ predicts both attraction and repulsion because electric charge can be either positive or negative.
	d	Students use the given formulas for the forces as evidence to describe that the change in the energy of objects interacting through electric or gravitational forces depends on the distance between the objects.

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-PS2-5

Students who demonstrate understanding can:

HS-PS2-5. **Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.** [*Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models.

- 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.

Disciplinary Core Ideas

PS2.B: Types of Interactions

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

PS3.A: Definitions of Energy

- "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary)*

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe the phenomenon under investigation, which includes the following idea: that an electric current produces a magnetic field and that a changing magnetic field produces an electric current.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data about 1) an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and 2) an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit. Students describe why these effects seen must be causal and not correlational, citing specific cause-effect relationships.	
3	Planning for the investigation		
	a	In the investigation plan, students include:	
		i.	The use of an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, and the types and positions of detectors;
		ii.	A means to indicate or measure when electric current is flowing through the circuit;
		iii.	A means to indicate or measure the presence of a local magnetic field near the circuit; and

		iv. A design of a system to change the magnetic field in a nearby circuit and a means to indicate or measure when the magnetic field is changing.
	b	In the plan, students state whether the investigation will be conducted individually or collaboratively.
4	Collecting the data	
	a	Students measure and record electric currents and magnetic fields.
5	Refining the design	
	a	Students evaluate their investigation, including an evaluation of:
		i. The accuracy and precision of the data collected, as well as limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the investigation plan to produce more accurate, precise, and useful data such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-PS2-6

Students who demonstrate understanding can:

HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [*Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats (including oral, graphical, textual and mathematical).

Disciplinary Core Ideas

PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

Crosscutting Concepts

Structure and Function

- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

Observable features of the student performance by the end of the course:			
1	Communication style and format		
	a	Students use at least two different formats (including oral, graphical, textual and mathematical) to communicate scientific and technical information, including fully describing the structure, properties, and design of the chosen material(s). Students cite the origin of the information as appropriate.	
2	Connecting the DCIs and the CCCs		
	a	Students identify and communicate the evidence for why molecular level structure is important in the functioning of designed materials, including:	
		i.	How the structure and properties of matter and the types of interactions of matter at the atomic scale determine the function of the chosen designed material(s); and
		ii.	How the material's properties make it suitable for use in its designed function.
	b	Students explicitly identify the molecular structure of the chosen designed material(s) (using a representation appropriate to the specific type of communication — e.g., geometric shapes for drugs and receptors, ball and stick models for long-chained molecules).	
	c	Students describe the intended function of the chosen designed material(s).	
	d	Students describe the relationship between the material's function and its macroscopic properties (e.g., material strength, conductivity, reactivity, state of matter, durability) and each of the following:	
		i.	Molecular level structure of the material;
		ii.	Intermolecular forces and polarity of molecules; and
		iii.	The ability of electrons to move relatively freely in metals.
	e	Students describe the effects that attractive and repulsive electrical forces between molecules have on the arrangement (structure) of the chosen designed material(s) of molecules (e.g., solids, liquids, gases, network solid, polymers).	
	f	Students describe that, for all materials, electrostatic forces on the atomic and molecular scale results in contact forces (e.g., friction, normal forces, stickiness) on the macroscopic scale.	

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-PS3-1

Students who demonstrate understanding can:

HS-PS3-1. **Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [*Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.

Crosscutting Concepts

Systems and System Models

- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent.

Observable features of the student performance by the end of the course:			
1	Representation		
	a	Students identify and describe the components to be computationally modeled, including:	
		i.	The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero);
		ii.	The initial energies of the system's components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in

		each component), including a quantification in an algebraic description to calculate the total initial energy of the system;
		iii. The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and
		iv. The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.
2	Computational Modeling	
	a	Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.
	b	Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.
3	Analysis	
	a	Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
	b	Students identify and describe the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

HS-PS3-2

Students who demonstrate understanding can:

HS-PS3-2. **Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).** [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

Crosscutting Concepts

Energy and Matter

- Energy cannot be created or destroyed; it only moves between one place and another place, between objects and/or fields, or between systems.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop models in which they identify and describe the relevant components, including:	
		i.	All the components of the system and the surroundings, as well as energy flows between the system and the surroundings;
		ii.	Clearly depicting both a macroscopic and a molecular/atomic-level representation of the system; and
		iii.	Depicting the forms in which energy is manifested at two different scales:

		a) Macroscopic , such as motion, sound, light, thermal energy, potential energy or energy in fields; and
		b) Molecular/atomic, such as motions (kinetic energy) of particles (e.g., nuclei and electrons), the relative positions of particles in fields (potential energy), and energy in fields.
2	Relationships	
	a	Students describe the relationships between components in their models, including:
		i. Changes in the relative position of objects in gravitational, magnetic or electrostatic fields can affect the energy of the fields (e.g., charged objects moving away from each other change the field energy).
		ii. Thermal energy includes both the kinetic and potential energy of particle vibrations in solids or molecules and the kinetic energy of freely moving particles (e.g., inert gas atoms, molecules) in liquids and gases.
		iii. The total energy of the system and surroundings is conserved at a macroscopic and molecular/atomic level.
		iv. Chemical energy can be considered in terms of systems of nuclei and electrons in electrostatic fields (bonds).
		v. As one form of energy increases, others must decrease by the same amount as energy is transferred among and between objects and fields.
3	Connections	
	a	Students use their models to show that in closed systems the energy is conserved on both the macroscopic and molecular/atomic scales so that as one form of energy changes, the total system energy remains constant, as evidenced by the other forms of energy changing by the same amount or changes only by the amount of energy that is transferred into or out of the system.
	b	Students use their models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles/objects and energy associated with the relative positions of particles/objects on both the macroscopic and microscopic scales.

HS-PS3-3

Students who demonstrate understanding can:

HS-PS3-3. **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Design, evaluate, and/or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

PS3.D: Energy in Chemical Processes

- Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary)*

Crosscutting Concepts

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering and Technology on Society and the Natural World

- Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students design a device that converts one form of energy into another form of energy.	
	b	Students develop a plan for the device in which they:	
		i.	Identify what scientific principles provide the basis for the energy conversion design;
		ii.	Identify the forms of energy that will be converted from one form to another in the designed system;
		iii.	Identify losses of energy by the design system to the surrounding environment;
		iv.	Describe the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and
		v.	Describe that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk.
2	Describing criteria and constraints, including quantification when appropriate		

	a	Students describe and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost and efficiency of energy conversion.
3	Evaluating potential solutions	
	a	Students build and test the device according to the plan.
	b	Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
4	Refining and/or optimizing the design solution	
	a	Students use the results of the tests to improve the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in tradeoffs.

HS-PS3-4

Students who demonstrate understanding can:

HS-PS3-4. **Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).** [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [*Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- 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.

Disciplinary Core Ideas

PS3.B: Conservation of Energy and Energy Transfer

- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

PS3.D: Energy in Chemical Processes

- Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.

Crosscutting Concepts

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe the purpose of the investigation, which includes the following idea, that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data, including:	
		i.	The measurement of the reduction of temperature of the hot object and the increase in temperature of the cold object to show that the thermal energy lost by the hot object is equal to the thermal energy gained by the cold object and that the distribution of thermal energy is more uniform after the interaction of the hot and cold components; and
		ii.	The heat capacity of the components in the system (obtained from scientific literature).
3	Planning for the investigation		
	a	In the investigation plan, students describe:	
		i.	How a nearly closed system will be constructed, including the boundaries and initial

		conditions of the system;
		ii. The data that will be collected, including masses of components and initial and final temperatures; and
		iii. The experimental procedure, including how the data will be collected, the number of trials, the experimental set up, and equipment required.
4	Collecting the data	
	a	Students collect and record data that can be used to calculate the change in thermal energy of each of the two components of the system.
5	Refining the design	
	a	Students evaluate their investigation, including:
		i. The accuracy and precision of the data collected, as well as the limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the plan to produce more accurate, precise, and useful data that address the experimental question.
	c	Students identify potential causes of the apparent loss of energy from a closed system (which should be zero in an ideal system) and adjust the design of the experiment accordingly.

HS-PS3-5

Students who demonstrate understanding can:

HS-PS3-5. **Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.** [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [*Assessment Boundary: Assessment is limited to systems containing two objects.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	**PS3.C: Relationship Between Energy and Forces** • When two objects interacting through a field change relative position, the energy stored in the field is changed.	**Cause and Effect** • Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model in which they identify and describe the relevant components to illustrate the forces and changes in energy involved when two objects interact, including:	
		i.	The two objects in the system, including their initial positions and velocities (limited to one dimension).
		ii.	The nature of the interaction (electric or magnetic) between the two objects.
		iii.	The relative magnitude and the direction of the net force on each of the objects.
		iv.	Representation of a field as a quantity that has a magnitude and direction at all points in space and which contains energy.
2	Relationships		
	a	In the model, students describe the relationships between components, including the change in the energy of the objects, given the initial and final positions and velocities of the objects.	
3	Connections		
	a	Students use the model to determine whether the energy stored in the field increased, decreased, or remained the same when the objects interacted.	
	b	Students use the model to support the claim that the change in the energy stored in the field (which is qualitatively determined to be either positive, negative, or zero) is consistent with the change in energy of the objects.	
	c	Using the model, students describe the cause and effect relationships on a qualitative level between forces produced by electric or magnetic fields and the change of energy of the objects in the system.	

HS-PS4-1

Students who demonstrate understanding can:

HS-PS4-1. **Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.** [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [*Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9-12 level builds on K-8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations.

Disciplinary Core Ideas

PS4.A: Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Representation		
	a	Students identify and describe the relevant components in the mathematical representations:	
		i.	Mathematical values for frequency, wavelength, and speed of waves traveling in various specified media; and
		ii.	The relationships between frequency, wavelength, and speed of waves traveling in various specified media.
2	Mathematical modeling		
	a	Students show that the product of the frequency and the wavelength of a particular type of wave in a given medium is constant, and identify this relationship as the wave speed according to the mathematical relationship $v = f\lambda$.	
	b	Students use the data to show that the wave speed for a particular type of wave changes as the medium through which the wave travels changes.	
	c	Students predict the relative change in the wavelength of a wave when it moves from one medium to another (thus different wave speeds using the mathematical relationship $v = f\lambda$). Students express the relative change in terms of cause (different media) and effect (different wavelengths but same frequency).	
3	Analysis		
	a	Using the mathematical relationship $v = f\lambda$, students assess claims about any of the three quantities when the other two quantities are known for waves travelling in various specified media.	
	b	Students use the mathematical relationships to distinguish between cause and correlation with respect to the supported claims.	

HS-PS4-2

Students who demonstrate understanding can:

HS-PS4-2. **Evaluate questions about the advantages of using a digital transmission and storage of information.** [Clarification Statement: Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in grades 9–12 builds from grades K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set or the suitability of a design.	**PS4.A: Wave Properties** • Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses.	**Stability and Change** • Systems can be designed for greater or lesser stability. - ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Engineering, Technology, and Science on Society and the Natural World** • Modern civilization depends on major technological systems. • Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

Observable features of the student performance by the end of the course:			
1	Addressing phenomena or scientific theories		
	a	Students evaluate the given questions in terms of whether or not answers to the questions would:	
		i.	Provide examples of features associated with digital transmission and storage of information (e.g., can be stored reliably without degradation over time, transferred easily, and copied and shared rapidly; can be easily deleted; can be stolen easily by making a copy; can be broadly accessed); and
	b	In their evaluation of the given questions, students:	
		i.	Describe the stability and importance of the systems that employ digital information as they relate to the advantages and disadvantages of digital transmission and storage of information; and
		ii.	Discuss the relevance of the answers to the question to real-life examples (e.g., emailing your homework to a teacher, copying music, using the internet for research, social media).
2	Evaluating empirical testability		
		Students evaluate the given questions in terms of whether or not answers to the questions would provide means to empirically determine whether given features are advantages or disadvantages.	

HS-PS4-3

Students who demonstrate understanding can:

HS-PS4-3. **Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.** [Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.] [*Assessment Boundary: Assessment does not include using quantum theory.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Disciplinary Core Ideas

PS4.A: Wave Properties

- [From the 3–5 grade band endpoints] Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.)

PS4.B: Electromagnetic Radiation

- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, and computer models) can be used to simulate systems and interactions — including energy, matter and information flows — within and between systems at different scales.

Observable features of the student performance by the end of the course:			
1	Identifying the given explanation and associated claims, evidence, and reasoning		
	a	Students identify the given explanation that is to be supported by the claims, evidence, and reasoning to be evaluated, and that includes the following idea: Electromagnetic radiation can be described either by a wave model or a particle model, and for some situations one model is more useful than the other.	
	b	Students identify the given claims to be evaluated.	
	c	Students identify the given evidence to be evaluated, including the following phenomena:	
		i.	Interference behavior by electromagnetic radiation; and
		ii.	The photoelectric effect.
	d	Students identify the given reasoning to be evaluated.	

2		Evaluating given evidence and reasoning
	a	Students evaluate the given evidence for interference behavior of electromagnetic radiation to determine how it supports the argument that electromagnetic radiation can be described by a wave model.
	b	Students evaluate the phenomenon of the photoelectric effect to determine how it supports the argument that electromagnetic radiation can be described by a particle model.
	c	Students evaluate the given claims and reasoning for modeling electromagnetic radiation as both a wave and particle, considering the transfer of energy and information within and between systems, and why for some aspects the wave model is more useful and for other aspects the particle model is more useful to describe the transfer of energy and information.

HS-PS4-4

Students who demonstrate understanding can:

HS-PS4-4. **Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.** [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [*Assessment Boundary: Assessment is limited to qualitative descriptions.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible.	**PS4.B: Electromagnetic Radiation** • When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.	**Cause and Effect** • Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system.

Observable features of the student performance by the end of the course:		
1	Obtaining information	
	a	Students obtain at least two claims proposed in published material (using at least two sources per claim) regarding the effect of electromagnetic radiation that is absorbed by matter. One of these claims deals with the effect of electromagnetic radiation on living tissue.
2	Evaluating information	
	a	Students use reasoning about the data presented, including the energies of the photons involved (i.e., relative wavelengths) and the probability of ionization, to analyze the validity and reliability of each claim.
	b	Students determine the validity and reliability of the sources of the claims.
	c	Students describe the cause and effect reasoning in each claim, including the extrapolations to larger scales from cause and effect relationships of mechanisms at small scales (e.g., extrapolating from the effect of a particular wavelength of radiation on a single cell to the effect of that wavelength on the entire organism).

HS-PS4-5

Students who demonstrate understanding can:

HS-PS4-5. **Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*** [Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [*Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate 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).

Disciplinary Core Ideas

PS3.D: Energy in Chemical Processes

- Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. *(secondary)*

PS4.A: Wave Properties

- Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses.

PS4.B: Electromagnetic Radiation

- Photoelectric materials emit electrons when they absorb light of a high-enough frequency.

PS4.C: Information Technologies and Instrumentation

- Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

Crosscutting Concepts

Cause and Effect

- Systems can be designed to cause a desired effect.

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Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D).

Influence of Engineering, Technology, and Science on Society and the Natural World

- Modern civilization depends on major technological systems.

Observable features of the student performance by the end of the course:		
1	Communication style and format	
	a	Students use at least two different formats (e.g., oral, graphical, textual, and mathematical) to communicate technical information and ideas, including fully describing at least two devices and the physical principles upon which the devices depend. One of the devices must depend on the photoelectric effect for its operation. Students cite the origin of the information as appropriate.
2	Connecting the DCIs and the CCCs	
	a	When describing how each device operates, students identify the wave behavior utilized by the device or the absorption of photons and production of electrons for devices that rely on the photoelectric effect, and qualitatively describe how the basic physics principles were utilized in

		the design through research and development to produce this functionality (e.g., absorbing electromagnetic energy and converting it to thermal energy to heat an object; using the photoelectric effect to produce an electric current).
	b	For each device, students discuss the real-world problem it solves or need it addresses, and how civilization now depends on the device.
	c	Students identify and communicate the cause and effect relationships that are used to produce the functionality of the device.

HS-LS1-1

Students who demonstrate understanding can:

HS-LS1-1. **Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.** [*Assessment Boundary: Assessment does not include identification of specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct 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.

Disciplinary Core Ideas

LS1.A: Structure and Function

- Systems of specialized cells within organisms help them perform the essential functions of life.
- 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. *(Note: This Disciplinary Core Idea is also addressed by HS-LS3-1.)*

Crosscutting Concepts

Structure and Function

- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

Observable features of the student performance by the end of the course:		
1	Articulating the explanation of phenomena	
	a	Students construct an explanation that includes the idea that regions of DNA called genes determine the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
2	Evidence	
	a	Students identify and describe the evidence to construct their explanation, including that:
		i. All cells contain DNA;
		ii. DNA contains regions that are called genes;
		iii. The sequence of genes contains instructions that code for proteins; and
		iv. Groups of specialized cells (tissues) use proteins to carry out functions that are essential to the organism.
	b	Students use a variety of valid and reliable sources for the evidence (e.g., theories, simulations, peer review, students' own investigations).
3	Reasoning	
	a	Students use reasoning to connect evidence, along with 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, to construct the explanation. Students describe the following chain of reasoning in their explanation:
		i. Because all cells contain DNA, all cells contain genes that can code for the formation of proteins.
		ii. 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.
		iii. Proper function of many proteins is necessary for the proper functioning of the cells.
		iv. Gene sequence affects protein function, which in turn affects the function of body tissues.

HS-LS1-2

Students who demonstrate understanding can:

HS-LS1-2. **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.** [Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] [*Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations

Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- 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.

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Connections to Nature of Science

Scientific Investigations Use a Variety of Methods

- Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.

Disciplinary Core Ideas

LS1.A: Structure and Function

- 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. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system.

Crosscutting Concepts

Stability and Change

- Feedback (negative or positive) can stabilize or destabilize a system.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model in which they identify and describe the relevant parts (e.g., organ system, organs, and their component tissues) and processes (e.g., transport of fluids, motion) of body systems in multicellular organisms.	
2	Relationships		
	a	In the model, students describe the relationships between components, including:	
		i.	The functions of at least two major body systems in terms of contributions to overall function of an organism;
		ii.	Ways the functions of two different systems affect one another; and
		iii.	A system's function and how that relates both to the system's parts and to the overall

		function of the organism.
3	Connections	
	a	Students use the model to illustrate how the interaction between systems provides specific functions in multicellular organisms.
	b	Students make a distinction between the accuracy of the model and actual body systems and functions it represents.

HS-LS1-3

Students who demonstrate understanding can:

HS-LS1-3. **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.** [Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.] [*Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- 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.

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Connections to Nature of Science

Scientific Investigations Use a Variety of Methods

- Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.

Disciplinary Core Ideas

LS1.A: Structure and Function

- 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. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system.

Crosscutting Concepts

Stability and Change

- Feedback (negative or positive) can stabilize or destabilize a system.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon under investigation		
	a	Students describe the phenomenon under investigation, which includes the following idea: that feedback mechanisms maintain homeostasis.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data, including:	
		i.	Changes within a chosen range in the external environment of a living system; and
		ii.	Responses of a living system that would stabilize and maintain the system's internal conditions (homeostasis), even though external conditions change, thus establishing the positive or negative feedback mechanism.
	b	Students describe why the data will provide information relevant to the purpose of the investigation.	
3	Planning for the investigation		
	a	In the investigation plan, students describe:	
		i.	How the change in the external environment is to be measured or identified;
		ii.	How the response of the living system will be measured or identified;

		iii.	How the stabilization or destabilization of the system’s internal conditions will be measured or determined;
		iv.	The experimental procedure, the minimum number of different systems (and the factors that affect them) that would allow generalization of results, the evidence derived from the data, and identification of limitations on the precision of data to include types and amounts; and
		v.	Whether the investigation will be conducted individually or collaboratively.
4	Collecting the data		
	a	Students collect and record changes in the external environment and organism responses as a function of time.	
5	Refining the design		
	a	Students evaluate their investigation, including:	
		i.	Assessment of the accuracy and precision of the data, as well as limitations (e.g., cost, risk, time) of the investigation, and make suggestions for refinement; and
		ii.	Assessment of the ability of the data to provide the evidence required.
	b	If necessary, students refine the investigation plan to produce more generalizable data.	

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-LS1-4

Students who demonstrate understanding can:

HS-LS1-4. **Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.** [*Assessment Boundary: Assessment does not include specific gene control mechanisms or rote memorization of the steps of mitosis.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Use a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

LS1.B: Growth and Development of Organisms

- 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. 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.

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter, and information flows — within and between systems at different scales.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From the given model, students identify and describe the components of the model relevant for illustrating the role of mitosis and differentiation in producing and maintaining complex organisms, including:	
		i.	Genetic material containing two variants of each chromosome pair, one from each parent;
		ii.	Parent and daughter cells (i.e., inputs and outputs of mitosis); and
		iii.	A multi-cellular organism as a collection of differentiated cells.
2	Relationships		
	a	Students identify and describe the relationships between components of the given model, including:	
		i.	Daughter cells receive identical genetic information from a parent cell or a fertilized egg.
		ii.	Mitotic cell division produces two genetically identical daughter cells from one parent cell.
		iii.	Differences between different cell types within a multicellular organism are due to gene expression — not different genetic material within that organism.
3	Connections		
	a	Students use the given model to illustrate that mitotic cell division results in more cells that:	
		i.	Allow growth of the organism;
		ii.	Can then differentiate to create different cell types; and
		iii.	Can replace dead cells to maintain a complex organism.
	b	Students make a distinction between the accuracy of the model and the actual process of cellular division.	

HS-LS1-5

Students who demonstrate understanding can:

HS-LS1-5. **Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.** [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [*Assessment Boundary: Assessment does not include specific biochemical steps.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Use a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.

Crosscutting Concepts

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From the given model, students identify and describe the components of the model relevant for illustrating that photosynthesis transforms light energy into stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen, including:	
		i.	Energy in the form of light;
		ii.	Breaking of chemical bonds to absorb energy;
		iii.	Formation of chemical bonds to release energy; and
		iv.	Matter in the form of carbon dioxide, water, sugar, and oxygen.
2	Relationships		
	a	Students identify the following relationship between components of the given model: Sugar and oxygen are produced by carbon dioxide and water by the process of photosynthesis.	
3	Connections		
	c	Students use the given model to illustrate:	
		i.	The transfer of matter and flow of energy between the organism and its environment during photosynthesis; and
		ii.	Photosynthesis as resulting in the storage of energy in the difference between the energies of the chemical bonds of the inputs (carbon dioxide and water) and outputs (sugar and oxygen).

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-LS1-6

Students who demonstrate understanding can:

HS-LS1-6. **Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.** [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [*Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • 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.	**LS1.C: Organization for Matter and Energy Flow in Organisms** • 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 new cells. • As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes:	
		i.	The relationship between the carbon, hydrogen, and oxygen atoms from sugar molecules formed in or ingested by an organism and those same atoms found in amino acids and other large carbon-based molecules; and
		ii.	That larger carbon-based molecules and amino acids can be a result of chemical reactions between sugar molecules (or their component atoms) and other atoms.
2	Evidence		
	a	Students identify and describe the evidence to construct the explanation, including:	
		i.	All organisms take in matter (allowing growth and maintenance) and rearrange the atoms in chemical reactions.
		ii.	Cellular respiration involves chemical reactions between sugar molecules and other molecules in which energy is released that can be used to drive other chemical reactions.
		iii.	Sugar molecules are composed of carbon, oxygen, and hydrogen atoms.
		iv.	Amino acids and other complex carbon-based molecules are composed largely of carbon, oxygen, and hydrogen atoms.
		v.	Chemical reactions can create products that are more complex than the reactants.
		vi.	Chemical reactions involve changes in the energies of the molecules involved in the reaction.
	b	Students use a variety of valid and reliable sources for the evidence (e.g., theories, simulations,	

		students' own investigations).
3	Reasoning	
	a	Students use reasoning to connect the evidence, along with 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, to construct the explanation that atoms from sugar molecules may combine with other elements via chemical reactions to form other large carbon-based molecules. Students describe the following chain of reasoning for their explanation:
		i. The atoms in sugar molecules can provide most of the atoms that comprise amino acids and other complex carbon-based molecules.
		ii. The energy released in respiration can be used to drive chemical reactions between sugars and other substances, and the products of those reactions can include amino acids and other complex carbon-based molecules.
		iii. The matter flows in cellular processes are the result of the rearrangement of primarily the atoms in sugar molecules because those are the molecules whose reactions release the energy needed for cell processes.
4	Revising the explanation	
	a	Given new evidence or context, students revise or expand their explanation about the relationships between atoms in sugar molecules and atoms in large carbon-based molecules, and justify their revision.

HS-LS1-7

Students who demonstrate understanding can:

HS-LS1-7. **Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.**[Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [*Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Use a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

LS1.C: Organization for Matter and Energy Flow in Organisms

- 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. 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. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.

Crosscutting Concepts

Energy and Matter

- Energy cannot be created or destroyed; it only moves between one place and another place, between objects and/or fields, or between systems.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From a given model, students identify and describe the components of the model relevant for their illustration of cellular respiration, including:	
		i.	Matter in the form of food molecules, oxygen, and the products of their reaction (e.g., water and CO_2);
		ii.	The breaking and formation of chemical bonds; and
		iii.	Energy from the chemical reactions.
2	Relationships		
	a	From the given model, students describe the relationships between components, including:	
		i.	Carbon dioxide and water are produced from sugar and oxygen by the process of cellular respiration; and
		ii.	The process of cellular respiration releases energy because the energy released when the bonds that are formed in CO_2 and water is greater than the energy required to break the bonds of sugar and oxygen.
3	Connections		
	a	Students use the given model to illustrate that:	
		i.	The chemical reaction of oxygen and food molecules releases energy as the matter is rearranged, existing chemical bonds are broken, and new chemical bonds are formed, but matter and energy are neither created nor destroyed.
		ii.	Food molecules and oxygen transfer energy to the cell to sustain life's processes, including the maintenance of body temperature despite ongoing energy transfer to the surrounding environment.

HS-LS2-1

Students who demonstrate understanding can:

HS-LS2-1. **Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.** [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [*Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical and/or computational representations of phenomena or design solutions to support explanations.

Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems

- 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 such 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.

Crosscutting Concepts

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

Observable features of the student performance by the end of the course:

1	Representation		
	a	Students identify and describe the components in the given mathematical and/or computational representations (e.g., trends, averages, histograms, graphs, spreadsheets) that are relevant to supporting given explanations of factors that affect carrying capacities of ecosystems at different scales. The components include:	
		i.	The population changes gathered from historical data or simulations of ecosystems at different scales; and
		ii.	Data on numbers and types of organisms as well as boundaries, resources, and climate.
	b	Students identify the given explanation(s) to be supported, which include the following ideas: Factors (including boundaries, resources, climate, and competition) affect carrying capacity of an ecosystem, and:	
		i.	Some factors have larger effects than do other factors.
		ii.	Factors are interrelated.
		iii.	The significance of a factor is dependent on the scale (e.g., a pond vs. an ocean) at which it occurs.
2	Mathematical and/or computational modeling		
	a	Students use given mathematical and/or computational representations (e.g., trends, averages, histograms, graphs, spreadsheets) of ecosystem factors to identify changes over time in the numbers and types of organisms in ecosystems of different scales.	

3	Analysis	
	a	Students analyze and use the given mathematical and/or computational representations
		i. To identify the interdependence of factors (both living and nonliving) and resulting effect on carrying capacity; and
		ii. As evidence to support the explanation and identify the factors that have the largest effect on the carrying capacity of an ecosystem for a given population.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-LS2-2

Students who demonstrate understanding can:

HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] [*Assessment Boundary: Assessment is limited to provided data.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to support and revise explanations.

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Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.

Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems

- 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 such 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.C: Ecosystem Dynamics, Functioning, and Resilience

- 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.

Crosscutting Concepts

Scale, Proportion, and Quantity

- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students identify and describe the components in the given mathematical representations (which include trends, averages, and graphs of the number of organisms per unit of area in a stable system) that are relevant to supporting and revising the given explanations about factors affecting biodiversity and ecosystems, including:

		i. Data on numbers and types of organisms are represented.
		ii. Interactions between ecosystems at different scales are represented.
	b	Students identify the given explanation(s) to be supported of factors affecting biodiversity and population levels, which include the following ideas:
		i. The populations and number of organisms in ecosystems vary as a function of the physical and biological dynamics of the ecosystem.
		ii. The response of an ecosystem to a small change might not significantly affect populations, whereas the response to a large change can have a large effect on populations that then feeds back to the ecosystem at a range of scales.
		iii. Ecosystems can exist in the same location on a variety of scales (e.g., plants and animals vs. microbes), and these populations can interact in ways that significantly change these ecosystems (e.g., interactions among microbes, plants, and animals can be an important factor in the resources available to both a microscopic and macroscopic ecosystem).
2	Mathematical Modeling	
	a	Students use the given mathematical representations (including trends, averages, and graphs) of factors affecting biodiversity and ecosystems to identify changes over time in the numbers and types of organisms in ecosystems of different scales.
3	Analysis	
	a	Students use the analysis of the given mathematical representations of factors affecting biodiversity and ecosystems
		i. To identify the most important factors that determine biodiversity and population numbers of an ecosystem.
		ii. As evidence to support explanation(s) for the effects of both living and nonliving factors on biodiversity and population size, as well as the interactions of ecosystems on different scales.
		iii. To describe how, in the model, factors affecting ecosystems at one scale can cause observable changes in ecosystems at a different scale.
	b	Students describe the given mathematical representations in terms of their ability to support explanation(s) for the effects of modest to extreme disturbances on an ecosystems' capacity to return to original status or become a different ecosystem.
4	Revision	
	a	Students revise the explanation(s) based on new evidence about any factors that affect biodiversity and populations (e.g., data illustrating the effect of a disturbance within the ecosystem).

HS-LS2-3

Students who demonstrate understanding can:

HS-LS2-3. **Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.** [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [*Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and 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.

- -

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.

Disciplinary Core Ideas

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

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

Crosscutting Concepts

Energy and Matter

- Energy drives the cycling of matter within and between systems.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes that:	
		i.	Energy from photosynthesis and respiration drives the cycling of matter and flow of energy under aerobic or anaerobic conditions within an ecosystem.
		ii.	Anaerobic respiration occurs primarily in conditions where oxygen is not available.
2	Evidence		
	a	Students identify and describe the evidence to construct the explanation, including:	
		i.	All organisms take in matter and rearrange the atoms in chemical reactions.
		ii.	Photosynthesis captures energy in sunlight to create chemical products that can be used as food in cellular respiration.
		iii.	Cellular respiration is the process by which the matter in food (sugars, fats) reacts chemically with other compounds, rearranging the matter to release energy that is used by the cell for essential life processes.

	b	Students use a variety of valid and reliable sources for the evidence, which may include theories, simulations, peer review, and students' own investigations.
3	Reasoning	
	a	Students use reasoning to connect evidence, along with 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, to construct their explanation. Students describe the following chain of reasoning used to construct their explanation:
		i. Energy inputs to cells occur either by photosynthesis or by taking in food.
		ii. Since all cells engage in cellular respiration, they must all produce products of respiration.
		iii. The flow of matter into and out of cells must therefore be driven by the energy captured by photosynthesis or obtained by taking in food and released by respiration.
		iv. The flow of matter and energy must occur whether respiration is aerobic or anaerobic.
4	Revising the explanation	
	a	Given new data or information, students revise their explanation and justify the revision (e.g., recent discoveries of life surrounding deep sea ocean vents have shown that photosynthesis is not the only driver for cycling matter and energy in ecosystems).

HS-LS2-4

Students who demonstrate understanding can:

HS-LS2-4. **Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.** [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [*Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematical and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to support claims.

Disciplinary Core Ideas

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

- 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. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.

Crosscutting Concepts

Energy and Matter

- Energy cannot be created or destroyed; it only moves between one place and another place, between objects and/or fields, or between systems.

Observable features of the student performance by the end of the course:

1	Representation	
	a	Students identify and describe the components in the mathematical representations that are relevant to supporting the claims. The components could include relative quantities related to organisms, matter, energy, and the food web in an ecosystem.
	b	Students identify the claims about the cycling of matter and energy flow among organisms in an ecosystem.
2	Mathematical modeling	
	a	Students describe how the claims can be expressed as a mathematical relationship in the mathematical representations of the components of an ecosystem
	b	Students use the mathematical representation(s) of the food web to:
		i. Describe the transfer of matter (as atoms and molecules) and flow of energy upward between organisms and their environment;

		ii. Identify the transfer of energy and matter between tropic levels; and
		iii. Identify the relative proportion of organisms at each trophic level by correctly identifying producers as the lowest trophic level having the greatest biomass and energy and consumers decreasing in numbers at higher trophic levels.
3	Analysis	
	a	Students use the mathematical representation(s) to support the claims that include the idea that matter flows between organisms and their environment.
	b	Students use the mathematical representation(s) to support the claims that include the idea that energy flows from one trophic level to another as well as through the environment.
	c	Students analyze and use the mathematical representation(s) to account for the energy not transferred to higher trophic levels but which is instead used for growth, maintenance, or repair, and/or transferred to the environment, and the inefficiencies in transfer of matter and energy.

HS-LS2-5

Students who demonstrate understanding can:

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. [Clarification Statement: Examples of models could include simulations and mathematical models.] [*Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or components of a system.

Disciplinary Core Ideas

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

PS3.D: Energy in Chemical Processes

- The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. *(secondary)*

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter and information flows — within and between systems at different scales.

Observable features of the student performance by the end of the course:

1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe the relevant components, including:	
		i.	The inputs and outputs of photosynthesis;
		ii.	The inputs and outputs of cellular respiration; and
		iii.	The biosphere, atmosphere, hydrosphere, and geosphere.
2	Relationships		
	a	Students describe relationships between components of their model, including:	
		i.	The exchange of carbon (through carbon-containing compounds) between organisms and the environment; and
		ii.	The role of storing carbon in organisms (in the form of carbon-containing compounds) as part of the carbon cycle.
3	Connections		
	a	Students describe the contribution of photosynthesis and cellular respiration to the exchange of carbon within and among the biosphere, atmosphere, hydrosphere, and geosphere in their model.	
	b	Students make a distinction between the model's simulation and the actual cycling of carbon via photosynthesis and cellular respiration.	

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-LS2-6

Students who demonstrate understanding can:

HS-LS2-6. **Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.** [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.

Disciplinary Core Ideas

LS2.C: Ecosystem Dynamics, Functioning, and Resilience

- 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.

Crosscutting Concepts

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:			
1	Identifying the given explanation and the supporting claims, evidence, and reasoning.		
	a	Students identify the given explanation that is supported by the claims, evidence, and reasoning to be evaluated, and which includes the following idea: The complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.	
	b	From the given materials, students identify:	
		i.	The given claims to be evaluated;
		ii.	The given evidence to be evaluated; and
		iii.	The given reasoning to be evaluated.
2	Identifying any potential additional evidence that is relevant to the evaluation		
	a	Students identify and describe additional evidence (in the form of data, information, or other appropriate forms) that was not provided but is relevant to the explanation and to evaluating the given claims, evidence, and reasoning:	
		i.	The factors that affect biodiversity;
		ii.	The relationships between species and the physical environment in an ecosystem; and
		iii.	Changes in the numbers of species and organisms in an ecosystem that has been

		subject to a modest or extreme change in ecosystem conditions.
3	Evaluating and critiquing	
	a	Students describe the strengths and weaknesses of the given claim in accurately explaining a particular response of biodiversity to a changing condition, based on an understanding of the factors that affect biodiversity and the relationships between species and the physical environment in an ecosystem.
	b	Students use their additional evidence to assess the validity and reliability of the given evidence and its ability to support the argument that resiliency of an ecosystem is subject to the degree of change in the biological and physical environment of an ecosystem.
	c	Students assess the logic of the reasoning, including the relationship between degree of change and stability in ecosystems, and the utility of the reasoning in supporting the explanation of how:
		i. Modest biological or physical disturbances in an ecosystem result in maintenance of relatively consistent numbers and types of organisms.
		ii. Extreme fluctuations in conditions or the size of any population can challenge the functioning of ecosystems in terms of resources and habitat availability, and can even result in a new ecosystem.

HS-LS2-7

Students who demonstrate understanding can:

HS-LS2-7. **Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*** [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

LS2.C: Ecosystem Dynamics, Functioning, and Resilience

- 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: Biodiversity and Humans

- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). *(secondary)*
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. 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. *(secondary) (Note: This Disciplinary Core Idea is also addressed by HS-LS4-6.)*

ETS1.B: Developing Possible Solutions

- When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. *(secondary)*

Crosscutting Concepts

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:		
1	Using scientific knowledge to generate the design solution	
	a	Students design a solution that involves reducing the negative effects of human activities on the environment and biodiversity, and that relies on scientific knowledge of the factors affecting changes and stability in biodiversity. Examples of factors include but are not limited to:
		i. Overpopulation;
		ii. Overexploitation;
		iii. Habitat destruction;
		iv. Pollution;
		v. Introduction of invasive species; and
		vi. Changes in climate.
	b	Students describe the ways the proposed solution decreases the negative effects of human activity on the environment and biodiversity.
2	Describing criteria and constraints, including quantification when appropriate	
	a	Students describe and quantify (when appropriate) the criteria (amount of reduction of impacts and human activities to be mitigated) and constraints (for example, cost, human needs, and environmental impacts) for the solution to the problem, along with the tradeoffs in the solution.
3	Evaluating potential solutions	
	a	Students evaluate the proposed solution for its impact on overall environmental stability and changes.
	b	Students evaluate the cost, safety, and reliability, as well as social, cultural, and environmental impacts, of the proposed solution for a select human activity that is harmful to an ecosystem.
4	Refining and/or optimizing the design solution	
	a	Students refine the proposed solution by prioritizing the criteria and making tradeoffs as necessary to further reduce environmental impact and loss of biodiversity while addressing human needs.

HS-LS2-8

Students who demonstrate understanding can:

HS-LS2-8. **Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.** [Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate the evidence behind currently accepted explanations to determine the merits of arguments.

- -

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.

Disciplinary Core Ideas

LS2.D: Social Interactions and Group Behavior

- Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:		
1	Identifying the given explanation and the supporting evidence	
	a	Students identify the given explanation that is supported by the evidence to be evaluated, and which includes the following idea: Group behavior can increase the chances for an individual and a species to survive and reproduce.
	b	Students identify the given evidence to be evaluated.
2	Identifying any potential additional evidence that is relevant to the evaluation	
	a	Students identify additional evidence (in the form of data, information, or other appropriate forms) that was not provided but is relevant to the explanation and to evaluating the given evidence, and which includes evidence for causal relationships between specific group behaviors (e.g., flocking, schooling, herding, cooperative hunting, migrating, swarming) and individual survival and reproduction rates.
3	Evaluating and critiquing	
	a	Students use their additional evidence to assess the validity, reliability, strengths, and weaknesses of the given evidence along with its ability to support logical and reasonable arguments about the outcomes of group behavior.
	b	Students evaluate the given evidence for the degree to which it supports a causal claim that group behavior can have a survival advantage for some species, including how the evidence

		allows for distinguishing between causal and correlational relationships, and how it supports cause and effect relationships between various kinds of group behavior and individual survival rates (for example, the relationship between moving in a group and individual survival rates, compared to the survival rate of individuals of the same species moving alone or outside of the group).

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-LS3-1

Students who demonstrate understanding can:

HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. [*Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in 9-12 builds on K-8 experiences and progresses to formulating, refining and evaluating empirically testable questions and design problems using models and simulations. • Ask questions that arise from examining models or a theory to clarify relationships.	**LS1.A: Structure and Function** • 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. *(secondary) (Note: This Disciplinary Core Idea is also addressed by HS-LS1-1.)* **LS3.A: Inheritance of Traits** • 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.	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Addressing phenomena or scientific theories		
	a	Students use models of DNA to formulate questions, the answers to which would clarify:	
		i.	The cause and effect relationships (including distinguishing between causal and correlational relationships) between DNA, the proteins it codes for, and the resulting traits observed in an organism;
		ii.	That the DNA and chromosomes that are used by the cell can be regulated in multiple ways; and
		iii.	The relationship between the non-protein coding sections of DNA and their functions (e.g., regulatory functions) in an organism.
2	Evaluating empirical testability		
	a	Students' questions are empirically testable by scientists.	

HS-LS3-2

Students who demonstrate understanding can:

HS-LS3-2. **Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.** [Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.] [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • Make and defend a claim based on evidence about the natural world that reflects scientific knowledge and student-generated evidence.	**LS3.B: Variation of Traits** • 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 mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. • 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 depends on both genetic and environmental factors.	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:		
1	Developing a claim	
	a	Students make a claim that includes the idea that inheritable genetic variations may result from:
		i. New genetic combinations through meiosis;
		ii. Viable errors occurring during replication; and
		iii. Mutations caused by environmental factors.
2	Identifying scientific evidence	
	a	Students identify and describe evidence that supports the claim, including:
		i. Variations in genetic material naturally result during meiosis when corresponding sections of chromosome pairs exchange places.
		ii. Genetic mutations can occur due to:
		a) errors during replication; and/or
		b) environmental factors.
		iii. Genetic material is inheritable.
	b	Students use scientific knowledge, literature, student-generated data, simulations and/or other sources for evidence.
3	Evaluating and critiquing evidence	
	a	Students identify the following strengths and weaknesses of the evidence used to support the claim:

		i. Types and numbers of sources;
		ii. Sufficiency to make and defend the claim, and to distinguish between causal and correlational relationships; and
		iii. Validity and reliability of the evidence.
4	Reasoning and synthesis	
	a	Students use reasoning to describe links between the evidence and claim, such as:
		i. Genetic mutations produce genetic variations between cells or organisms.
		ii. Genetic variations produced by mutation and meiosis can be inherited.
	b	Students use reasoning and valid evidence to describe that new combinations of DNA can arise from several sources, including meiosis, errors during replication, and mutations caused by environmental factors.
	c	Students defend a claim against counter-claims and critique by evaluating counter-claims and by describing the connections between the relevant and appropriate evidence and the strongest claim.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-LS3-3

Students who demonstrate understanding can:

HS-LS3-3. **Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.** [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.] [*Assessment Boundary: Assessment does not include Hardy-Weinberg calculations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9-12 builds on K-8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.

Disciplinary Core Ideas

LS3.B: Variation of Traits

- 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 depends on both genetic and environmental factors.

Crosscutting Concepts

Scale, Proportion, and Quantity
Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

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Connections to Nature of Science

Science is a Human Endeavor

- Technological advances have influenced the progress of science and science has influenced advances in technology.
- Science and engineering are influenced by society and society is influenced by science and engineering.

Observable features of the student performance by the end of the course:			
1	Organizing data		
	a	Students organize the given data by the frequency, distribution, and variation of expressed traits in the population.	
2	Identifying relationships		
	a	Students perform and use appropriate statistical analyses of data, including probability measures, to determine the relationship between a trait's occurrence within a population and environmental factors.	
3	Interpreting data		
	a	Students analyze and interpret data to explain the distribution of expressed traits, including:	
		i.	Recognition and use of patterns in the statistical analysis to predict changes in trait distribution within a population if environmental variables change; and
		ii.	Description of the expression of a chosen trait and its variations as causative or correlational to some environmental factor based on reliable evidence.

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-LS4-1

Students who demonstrate understanding can:

HS-LS4-1. **Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.** [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate scientific information (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).

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Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Disciplinary Core Ideas

LS4.A: Evidence of Common Ancestry and Diversity

- Genetic information, like the fossil record, 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.

Crosscutting Concepts

Patterns
Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.

Observable features of the student performance by the end of the course:			
1	Communication style and format		
	a	Students use at least two different formats (e.g., oral, graphical, textual and mathematical), to communicate scientific information, including that common ancestry and biological evolution are supported by multiple lines of empirical evidence. Students cite the origin of the information as appropriate.	
2	Connecting the DCIs and the CCCs		
	a	Students identify and communicate evidence for common ancestry and biological evolution, including:	
		i.	Information derived from DNA sequences, which vary among species but have many similarities between species;
		ii.	Similarities of the patterns of amino acid sequences, even when DNA sequences are slightly different, including the fact that multiple patterns of DNA sequences can code for

			the same amino acid;
		iii.	Patterns in the fossil record (e.g., presence, location, and inferences possible in lines of evolutionary descent for multiple specimens); and
		iv.	The pattern of anatomical and embryological similarities.
	b	Students identify and communicate connections between each line of evidence and the claim of common ancestry and biological evolution.	
	c	Students communicate that together, the patterns observed at multiple spatial and temporal scales (e.g., DNA sequences, embryological development, fossil records) provide evidence for causal relationships relating to biological evolution and common ancestry.	

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-LS4-2

Students who demonstrate understanding can:

HS-LS4-2. **Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.** [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on the number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [*Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct 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.

Disciplinary Core Ideas

LS4.B: Natural Selection

- 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.

LS4.C: Adaptation

- Evolution is a consequence of the interaction 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.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:		
1	Articulating the explanation of phenomena	
	a	Students construct an explanation that includes a description that evolution is caused primarily by one or more of the four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
2	Evidence	
	a	Students identify and describe evidence to construct their explanation, including that:
		i. As a species grows in number, competition for limited resources can arise.

		ii.	Individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring.
		iii.	Individuals can have specific traits that give them a competitive advantage relative to other individuals in the species.
	b	Students use a variety of valid and reliable sources for the evidence (e.g., data from investigations, theories, simulations, peer review).	
3	Reasoning		
	a	Students use reasoning to connect the evidence, along with 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, to construct the explanation. Students describe the following chain of reasoning for their explanation:	
		i.	Genetic variation can lead to variation of expressed traits in individuals in a population.
		ii.	Individuals with traits that give competitive advantages can survive and reproduce at higher rates than individuals without the traits because of the competition for limited resources.
		iii.	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.
		iv.	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.
	b	Students use the evidence to describe the following in their explanation:	
		i.	The difference between natural selection and biological evolution (natural selection is a process, and biological evolution can result from that process); and
		ii.	The cause and effect relationship between genetic variation, the selection of traits that provide comparative advantages, and the evolution of populations that all express the trait.

HS-LS4-3

Students who demonstrate understanding can:

HS-LS4-3. **Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.** [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [*Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.

Disciplinary Core Ideas

LS4.B: Natural Selection

- 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: Adaptation

- 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 the 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.

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:		
1	Organizing data	
	a	Students organize data (e.g., using tables, graphs and charts) by the distribution of genetic traits over time.
	b	Students describe what each dataset represents
2	Identifying relationships	
	a	Students perform and use appropriate statistical analyses of data, including probability measures, to determine patterns of change in numerical distribution of traits over various time and

		population scales.
3	Interpreting data	
	a	Students use the data analyses as evidence to support explanations about the following:
		i. Positive or negative effects on survival and reproduction of individuals as relating to their expression of a variable trait in a population;
		ii. Natural selection as the cause of increases and decreases in heritable traits over time in a population, but only if it affects reproductive success; and
		iii. The changes in distribution of adaptations of anatomical, behavioral, and physiological traits in a population.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-LS4-4

Students who demonstrate understanding can:

HS-LS4-4. **Construct an explanation based on evidence for how natural selection leads to adaptation of populations.** [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct 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.

Disciplinary Core Ideas

LS4.C: Adaptation

- 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 the trait and to a decrease in the proportion of individuals that do not.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

- -

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that identifies the cause and effect relationship between natural selection and adaptation.	
2	Evidence		
	a	Students identify and describe the evidence to construct their explanation, including:	
		i.	Changes in a population when some feature of the environment changes;
		ii.	Relative survival rates of organisms with different traits in a specific environment;
		iii.	The fact that individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring; and
		iv.	The fact that individuals can have specific traits that give them a competitive advantage relative to other individuals in the species.
	b	Students use a variety of valid and reliable sources for the evidence (e.g., theories, simulations, peer review, students' own investigations)	
3	Reasoning		
	a	Students use reasoning to synthesize the valid and reliable evidence to distinguish between cause and correlation to construct the explanation about how natural selection provides a mechanism for species to adapt to changes in their environment, including the following elements:	
		i.	Biotic and abiotic differences in ecosystems contribute to changes in gene frequency over time through natural selection.
		ii.	Increasing gene frequency in a population results in an increasing fraction of the

			population in each successive generation that carries a particular gene and expresses a particular trait.
		iii.	Over time, this process leads to a population that is adapted to a particular environment by the widespread expression of a trait that confers a competitive advantage in that environment.

HS-LS4-5

Students who demonstrate understanding can:

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence

Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current or historical episodes in science.

- Evaluate the evidence behind currently accepted explanations or solutions to determine the merits of arguments.

Disciplinary Core Ideas

LS4.C: Adaptation

- 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 drastic, the opportunity for the species' evolution is lost.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Identifying the given claims and evidence to be evaluated		
	a	Students identify the given claims, which include the idea that changes in environmental conditions may result in:	
		i.	Increases in the number of individuals of some species;
		ii.	The emergence of new species over time; and
		iii.	The extinction of other species.
	b	Students identify the given evidence to be evaluated.	
2	Identifying any potential additional evidence that is relevant to the evaluation		
	a	Students identify and describe additional evidence (in the form of data, information, models, or other appropriate forms) that was not provided but is relevant to the claims and to evaluating the given evidence, including:	
		i.	Data indicating the change over time in:
			a) The number of individuals in each species;
			b) The number of species in an environment; and
			c) The environmental conditions.
		ii.	Environmental factors that can determine the ability of individuals in a species to survive and reproduce.

3	Evaluating and critiquing	
	a	Students use their additional evidence to assess the validity, reliability, strengths, and weaknesses of the given evidence, along with its ability to support logical and reasonable arguments about the outcomes of group behavior.
	b	Students assess the ability of the given evidence to be used to determine causal or correlational effects between environmental changes, the changes in the number of individuals in each species, the number of species in an environment, and/or the emergence or extinction of species.
4	Reasoning and synthesis	
	a	Students evaluate the degree to which the given empirical evidence can be used to construct logical arguments that identify causal links between environmental changes and changes in the number of individuals or species based on environmental factors that can determine the ability of individuals in a species to survive and reproduce

HS-LS4-6

Students who demonstrate understanding can:

HS-LS4-6. **Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*** [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create or revise a simulation of a phenomenon, designed device, process, or system.

Disciplinary Core Ideas

LS4.C: Adaptation

- 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.

LS4.D: Biodiversity and Humans

- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. 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. *(Note: This Disciplinary Core Idea is also addressed by HS-LS2-7.)*

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)*
- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. *(secondary)*

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students create or revise a simulation that:
		i. Models effects of human activity (e.g., overpopulation, overexploitation, adverse habitat alterations, pollution, invasive species, changes in climate) on a threatened or endangered species or to the genetic variation within a species; and
		ii. Provides quantitative information about the effect of the solutions on threatened or endangered species.
	b	Students describe the components that are modeled by the computational simulation, including human activity (e.g., overpopulation, overexploitation, adverse habitat alterations, pollution, invasive species, changes in climate) and the factors that affect biodiversity.
	c	Students describe the variables that can be changed by the user to evaluate the proposed solutions, tradeoffs, or other decisions.
2	Computational modeling	
	a	Students use logical and realistic inputs for the simulation that show an understanding of the reliance of ecosystem function and productivity on biodiversity, and that take into account the constraints of cost, safety, and reliability as well as cultural, and environmental impacts.
	b	Students use the simulation to identify possible negative consequences of solutions that would outweigh their benefits.
3	Analysis	
	a	Students compare the simulation results to expected results.
	b	Students analyze the simulation results to determine whether the simulation provides sufficient information to evaluate the solution.
	c	Students identify the simulation's limitations.
	d	Students interpret the simulation results, and predict the effects of the specific design solutions on biodiversity based on the interpretation.
4	Revision	
	a	Students revise the simulation as needed to provide sufficient information to evaluate the solution.

HS-ESS1-1

Students who demonstrate understanding can:

HS-ESS1-1. Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation. [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [*Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.]*

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.

PS3.D: Energy in Chemical Processes and Everyday Life

- Nuclear fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. *(secondary)*

Crosscutting Concepts

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe the relevant components, including:	
		i.	Hydrogen as the sun's fuel;
		ii.	Helium and energy as the products of fusion processes in the sun; and
		iii.	That the sun, like all stars, has a life span based primarily on its initial mass, and that the sun's lifespan is about 10 billion years.
2	Relationships		
	a	In the model, students describe relationships between the components, including a description of the process of radiation, and how energy released by the sun reaches Earth's system.	
3	Connections		
	a	Students use the model to predict how the relative proportions of hydrogen to helium change as the sun ages.	
	b	Students use the model to qualitatively describe the scale of the energy released by the fusion process as being much larger than the scale of the energy released by chemical processes.	
	c	Students use the model to explicitly identify that chemical processes are unable to produce the amount of energy flowing out of the sun over long periods of time, thus requiring fusion processes as the mechanism for energy release in the sun.	

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-ESS1-2

Students who demonstrate understanding can:

HS-ESS1-2. Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe. [Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, 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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Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
- The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.

PS4.B: Electromagnetic Radiation

- Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. *(secondary)*

Crosscutting Concepts

Energy and Matter

- Energy cannot be created or destroyed–only moved between one place and another place, between objects and/or fields, or between systems.

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Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.
- Science assumes the universe is a vast single system in which basic laws are consistent.

Observable features of the student performance by the end of the course:		
1	Articulating the explanation of phenomena	
	a	Students construct an explanation that includes a description of how astronomical evidence from numerous sources is used collectively to support the Big Bang theory, which states that the universe is expanding and that thus it was hotter and denser in the past, and that the entire visible universe emerged from a very tiny region and expanded.
2	Evidence	
	a	Students identify and describe the evidence to construct the explanation, including:
		i. The composition (hydrogen, helium and heavier elements) of stars;
		ii. The hydrogen-helium ratio of stars and interstellar gases;
		iii. The redshift of the majority of galaxies and the redshift vs. distance relationship; and
		iv. The existence of cosmic background radiation.
	b	Students use a variety of valid and reliable sources for the evidence, which may include students' own investigations, theories, simulations, and peer review.
	c	Students describe the source of the evidence and the technology used to obtain that evidence.
3	Reasoning	
	a	Students use reasoning to connect evidence, along with 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, to construct the explanation for the early universe (the Big Bang theory). Students describe the following chain of reasoning for their explanation:
		i. Redshifts indicate that an object is moving away from the observer, thus the observed redshift for most galaxies and the redshift vs. distance relationship is evidence that the universe is expanding.
		ii. The observed background cosmic radiation and the ratio of hydrogen to helium have been shown to be consistent with a universe that was very dense and hot a long time ago and that evolved through different stages as it expanded and cooled (e.g., the formation of nuclei from colliding protons and neutrons predicts the hydrogen-helium ratio [numbers not expected from students], later formation of atoms from nuclei plus electrons, background radiation was a relic from that time).
		iii. An expanding universe must have been smaller in the past and can be extrapolated back in time to a tiny size from which it expanded.

HS-ESS1-3

Students who demonstrate understanding can:

HS-ESS1-3. Communicate scientific ideas about the way stars, over their life cycle, produce elements. [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [*Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate scientific 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).

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.

Crosscutting Concepts

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Observable features of the student performance by the end of the course:			
1	Communication style and format		
	a	Students use at least two different formats (e.g., oral, graphical, textual, and mathematical) to communicate scientific information, and cite the origin of the information as appropriate.	
2	Connecting the DCIs and the CCCs		
	a	Students identify and communicate the relationships between the life cycle of the stars, the production of elements, and the conservation of the number of protons plus neutrons in stars. Students identify that atoms are not conserved in nuclear fusion, but the total number of protons plus neutrons is conserved.	
	b	Students describe that:	
		i.	Helium and a small amount of other light nuclei (i.e., up to lithium) were formed from high-energy collisions starting from protons and neutrons in the early universe before any stars existed.
		ii.	More massive elements, up to iron, are produced in the cores of stars by a chain of processes of nuclear fusion, which also releases energy.
		iii.	Supernova explosions of massive stars are the mechanism by which elements more massive than iron are produced.
		iv.	There is a correlation between a star's mass and stage of development and the types of elements it can create during its lifetime.
		v.	Electromagnetic emission and absorption spectra are used to determine a star's composition, motion and distance to Earth.

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-ESS1-4

Students who demonstrate understanding can:

HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system. [Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.] [*Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's laws of orbital motions should not deal with more than two bodies, nor involve calculus.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematical and Computational Thinking

Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical or computational representations of phenomena to describe explanations.

Disciplinary Core Ideas

ESS1.B: Earth and the Solar System

- Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.

Crosscutting Concepts

Scale, Proportion, and Quantity

- Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

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Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students identify and describe the following relevant components in the given mathematical or computational representations of orbital motion: the trajectories of orbiting bodies, including planets, moons, or human-made spacecraft; each of which depicts a revolving body's eccentricity e = f/d, where f is the distance between foci of an ellipse, and d is the ellipse's major axis length (Kepler's first law of planetary motion).
2	Mathematical or computational modeling	
	a	Students use the given mathematical or computational representations of orbital motion to depict that the square of a revolving body's period of revolution is proportional to the cube of its distance to a gravitational center ($T^2 \propto R^3$, where T is the orbital period and R is the semi-major axis of the orbit — Kepler's third law of planetary motion).
3	Analysis	
	a	Students use the given mathematical or computational representation of Kepler's second law of planetary motion (an orbiting body sweeps out equal areas in equal time) to predict the relationship between the distance between an orbiting body and its star, and the object's orbital velocity (i.e., that the closer an orbiting body is to a star, the larger its orbital velocity will be).
	b	Students use the given mathematical or computational representation of Kepler's third law of

		planetary motion ($T^2 \propto R^3$, where T is the orbital period and R is the semi-major axis of the orbit) to predict how either the orbital distance or orbital period changes given a change in the other variable.
	c	Students use Newton's law of gravitation plus his third law of motion to predict how the acceleration of a planet towards the sun varies with its distance from the sun, and to argue qualitatively about how this relates to the observed orbits.

HS-ESS1-5

Students who demonstrate understanding can:

HS-ESS1-5. **Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.** [Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages of oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust decreasing with distance away from a central ancient core of the continental plate (a result of past plate interactions).]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments.	**ESS1.C: The History of Planet Earth** • Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old. **ESS2.B: Plate Tectonics and Large-Scale System Interactions** • Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. *(ESS2.B Grade 8 GBE) (secondary)* **PS1.C: Nuclear Processes** • Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. *(secondary)*	**Patterns** • Empirical evidence is needed to identify patterns.

Observable features of the student performance by the end of the course:			
1	Identifying the given explanation and the supporting evidence		
	a	Students identify the given explanation, which includes the following idea: that crustal materials of different ages are arranged on Earth's surface in a pattern that can be attributed to plate tectonic activity and formation of new rocks from magma rising where plates are moving apart.	
	b	Students identify the given evidence to be evaluated.	
2	Identifying any potential additional evidence that is relevant to the evaluation		
	a	Students identify and describe additional relevant evidence (in the form of data, information, models, or other appropriate forms) that was not provided but is relevant to the explanation and to evaluating the given evidence, including:	
		i.	Measurement of the ratio of parent to daughter atoms produced during radioactive decay as a means for determining the ages of rocks;
		ii.	Ages and locations of continental rocks;
		iii.	Ages and locations of rocks found on opposite sides of mid-ocean ridges; and

		iv. The type and location of plate boundaries relative to the type, age, and location of crustal rocks.
3	Evaluating and critiquing	
	a	Students use their additional evidence to assess and evaluate the validity of the given evidence.
	b	Students evaluate the reliability, strengths, and weaknesses of the given evidence along with its ability to support logical and reasonable arguments about the motion of crustal plates.
4	Reasoning/synthesis	
	a	Students describe how the following patterns observed from the evidence support the explanation about the ages of crustal rocks:
		i. The pattern of the continental crust being older than the oceanic crust;
		ii. The pattern that the oldest continental rocks are located at the center of continents, with the ages decreasing from their centers to their margin; and
		iii. The pattern that the ages of oceanic crust are greatest nearest the continents and decrease in age with proximity to the mid-ocean ridges.
	b	Students synthesize the relevant evidence to describe the relationship between the motion of continental plates and the patterns in the ages of crustal rocks, including that:
		i. At boundaries where plates are moving apart, such as mid-ocean ridges, material from the interior of the Earth must be emerging and forming new rocks with the youngest ages.
		ii. The regions furthest from the plate boundaries (continental centers) will have the oldest rocks because new crust is added to the edge of continents at places where plates are coming together, such as subduction zones.
		iii. The oldest crustal rocks are found on the continents because oceanic crust is constantly being destroyed at places where plates are coming together, such as subduction zones.

HS-ESS1-6

Students who demonstrate understanding can:

HS-ESS1-6. **Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.** [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.
- Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory.

Disciplinary Core Ideas

ESS1.C: The History of Planet Earth

- Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.

PS1.C: Nuclear Processes

- Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. *(secondary)*

Crosscutting Concepts

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an account of Earth's formation and early history that includes that:	
		i.	Earth formed along with the rest of the solar system 4.6 billion years ago.
		ii.	The early Earth was bombarded by impacts just as other objects in the solar system were bombarded.
		iii.	Erosion and plate tectonics on Earth have destroyed much of the evidence of this bombardment, explaining the relative scarcity of impact craters on Earth.

2	Evidence		
	a	Students include and describe the following evidence in their explanatory account:	
		i.	The age and composition of Earth's oldest rocks, lunar rocks, and meteorites as determined by radiometric dating;
		ii.	The composition of solar system objects;
		iii.	Observations of the size and distribution of impact craters on the surface of Earth and on the surfaces of solar system objects (e.g., the moon, Mercury, and Mars); and
		iv.	The activity of plate tectonic processes, such as volcanism, and surface processes, such as erosion, operating on Earth.
3	Reasoning		
	a	Students use reasoning to connect the evidence to construct the explanation of Earth's formation and early history, including that:	
		i.	Radiometric ages of lunar rocks, meteorites and the oldest Earth rocks point to an origin of the solar system 4.6 billion years ago, with the creation of a solid Earth crust about 4.4 billion years ago.
		ii.	Other planetary surfaces and their patterns of impact cratering can be used to infer that Earth had many impact craters early in its history.
		iii.	The relative lack of impact craters and the age of most rocks on Earth compared to other bodies in the solar system can be attributed to processes such as volcanism, plate tectonics, and erosion that have reshaped Earth's surface, and that this is why most of Earth's rocks are much younger than Earth itself.

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-ESS2-1

Students who demonstrate understanding can:

HS-ESS2-1. **Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.** [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [*Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. *(ESS2.B Grade 8 GBE)*

Crosscutting Concepts

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe the following components:	
		i.	Descriptions and locations of specific continental features and specific ocean-floor features;
		ii.	A geographic scale, showing the relative sizes/extents of continental and/or ocean-floor features;
		iii.	Internal processes (such as volcanism and tectonic uplift) and surface processes (such as weathering and erosion); and
		iv.	A temporal scale showing the relative times over which processes act to produce continental and/or ocean-floor features.
2	Relationships		
	a	In the model, students describe the relationships between components, including:	
		i.	Specific internal processes, mainly volcanism, mountain building or tectonic uplift, are identified as causal agents in building up Earth's surface over time.
		ii.	Specific surface processes, mainly weathering and erosion, are identified as causal agents in wearing down Earth's surface over time.
		iii.	Interactions and feedbacks between processes are identified (e.g., mountain-building

			changes weather patterns that then change the rate of erosion of mountains).
		iv.	The rate at which the features change is related to the time scale on which the processes operate. Features that form or change slowly due to processes that act on long time scales (e.g., continental positions due to plate drift) and features that form or change rapidly due to processes that act on short time scales (e.g., volcanic eruptions) are identified.
3	Connections		
	a	Students use the model to illustrate the relationship between 1) the formation of continental and ocean floor features and 2) Earth's internal and surface processes operating on different temporal or spatial scales.	

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-ESS2-2

Students who demonstrate understanding can:

HS-ESS2-2. **Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.** [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- 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.

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.

Crosscutting Concepts

Stability and Change

- Feedback (negative or positive) can stabilize or destabilize a system.

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Connections to Engineering, Technology, and Applications of Science

Influence of Engineering, Technology, and Science on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:			
1	Organizing data		
	a	Students organize data that represent measurements of changes in hydrosphere, cryosphere, atmosphere, biosphere, or geosphere in response to a change in Earth's surface.	
	b	Students describe what each data set represents.	
2	Identifying relationships		
	a	Students use tools, technologies, and/or models to analyze the data and identify and describe relationships in the datasets, including:	
		i.	The relationships between the changes in one system and changes in another (or within the same) Earth system; and
		ii.	Possible feedbacks, including one example of feedback to the climate.
	b	Students analyze data to identify effects of human activity and specific technologies on Earth's systems if present.	
3	Interpreting data		
	a	Students use the analyzed data to describe a mechanism for the feedbacks between two of Earth's systems and whether the feedback is positive or negative, increasing (destabilizing) or decreasing (stabilizing) the original changes.	

	b	Students use the analyzed data to describe a particular unanticipated or unintended effect of a selected technology on Earth's systems if present.
	c	Students include a statement regarding how variation or uncertainty in the data (e.g., limitations, accuracy, any bias in the data resulting from choice of sample, scale, instrumentation, etc.) may affect the interpretation of the data.

HS-ESS2-3

Students who demonstrate understanding can:

HS-ESS2-3. **Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.** [Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth's three-dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure laboratory experiments.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

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Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence.
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems.
- Science includes the process of coordinating patterns of evidence with current theory.

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.

Crosscutting Concepts

Energy and Matter
Energy drives the cycling of matter within and between systems.

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Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model (i.e., graphical, verbal, or mathematical) in which they identify and describe the components based on both seismic and magnetic evidence (e.g., the pattern of the geothermal gradient or heat flow measurements) from Earth's interior, including:	
		i.	Earth's interior in cross-section and radial layers (crust, mantle, liquid outer core, solid inner core) determined by density;
		ii.	The plate activity in the outer part of the geosphere;
		iii.	Radioactive decay and residual thermal energy from the formation of the Earth as a

			source of energy;
		iv.	The loss of heat at the surface of the earth as an output of energy; and
		v.	The process of convection that causes hot matter to rise (move away from the center) and cool matter to fall (move toward the center).
2	Relationships		
	a	Students describe the relationships between components in the model, including:	
		i.	Energy released by radioactive decay in the Earth's crust and mantle and residual thermal energy from the formation of the Earth provide energy that drives the flow of matter in the mantle.
		ii.	Thermal energy is released at the surface of the Earth as new crust is formed and cooled.
		iii.	The flow of matter by convection in the solid mantle and the sinking of cold, dense crust back into the mantle exert forces on crustal plates that then move, producing tectonic activity.
		iv.	The flow of matter by convection in the liquid outer core generates the Earth's magnetic field.
		v.	Matter is cycled between the crust and the mantle at plate boundaries. Where plates are pushed together, cold crustal material sinks back into the mantle, and where plates are pulled apart, mantle material can be integrated into the crust, forming new rock.
3	Connections		
	a	Students use the model to describe the cycling of matter by thermal convection in Earth's interior, including:	
		i.	The flow of matter in the mantle that causes crustal plates to move;
		ii.	The flow of matter in the liquid outer core that generates the Earth's magnetic field, including evidence of polar reversals (e.g., seafloor exploration of changes in the direction of Earth's magnetic field);
		iii.	The radial layers determined by density in the interior of Earth; and
		iv.	The addition of a significant amount of thermal energy released by radioactive decay in Earth's crust and mantle.

HS-ESS2-4

Students who demonstrate understanding can:

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [*Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Use a model to provide mechanistic accounts of phenomena.

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Disciplinary Core Ideas

ESS1.B: Earth and the Solar System

- Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. *(secondary)*

ESS2.A: Earth Materials and System

- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.

ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Components of the model:		
	a	From the given model, students identify and describe the components of the model relevant for their mechanistic descriptions. Given models include at least one factor that affects the input of energy, at least one factor that affects the output of energy, and at least one factor that affects the storage and redistribution of energy. Factors are derived from the following list:	
		i.	Changes in Earth’s orbit and the orientation of its axis;
		ii.	Changes in the sun’s energy output;
		iii.	Configuration of continents resulting from tectonic activity;
		iv.	Ocean circulation;
		v.	Atmospheric composition (including amount of water vapor and CO_2);
		vi.	Atmospheric circulation;
		vii.	Volcanic activity;
		viii.	Glaciation;
		ix.	Changes in extent or type of vegetation cover; and
		x.	Human activities.
	b	From the given model, students identify the relevant different time scales on which the factors operate.	
2	Relationships		
	a	Students identify and describe the relationships between components of the given model, and organize the factors from the given model into three groups:	
		i.	Those that affect the input of energy;
		ii.	Those that affect the output of energy; and
		iii.	Those that affect the storage and redistribution of energy
	b	Students describe the relationships between components of the model as either causal or correlational.	
3	Connections		
	a	Students use the given model to provide a mechanistic account of the relationship between energy flow in Earth’s systems and changes in climate, including:	
		i.	The specific cause and effect relationships between the factors and the effect on energy flow into and out of Earth’s systems; and
		ii.	The net effect of all of the competing factors in changing the climate.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-ESS2-5

Students who demonstrate understanding can:

HS-ESS2-5. **Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- 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.

Disciplinary Core Ideas

ESS2.C: The Roles of Water in Earth's Surface Processes

- The abundance of liquid water on Earth’s surface and its unique combination of physical and chemical properties are central to the planet’s dynamics. These properties include water’s exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.

Crosscutting Concepts

Structure and Function

- The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe the phenomenon under investigation, which includes the following idea: a connection between the properties of water and its effects on Earth materials and surface processes.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data, including:	
		i.	Properties of water, including:
			a) The heat capacity of water;
			b) The density of water in its solid and liquid states; and
			c) The polar nature of the water molecule due to its molecular structure.
		ii.	The effect of the properties of water on energy transfer that causes the patterns of temperature, the movement of air, and the movement and availability of water at Earth’s surface.
		iii.	Mechanical effects of water on Earth materials that can be used to infer the effect of water on Earth’s surface processes. Examples can include:
			a) Stream transportation and deposition using a stream table, which can be used to infer the ability of water to transport and deposit materials;
			b) Erosion using variations in soil moisture content, which can be used to infer the ability of water to prevent or facilitate movement of Earth materials; and

		c) The expansion of water as it freezes, which can be used to infer the ability of water to break rocks into smaller pieces.
		iv. Chemical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. Examples can include:
		a) The solubility of different materials in water, which can be used to infer chemical weathering and recrystallization;
		b) The reaction of iron to rust in water, which can be used to infer the role of water in chemical weathering;
		c) Data illustrating that water lowers the melting temperature of most solids, which can be used to infer melt generation; and
		d) Data illustrating that water decreases the viscosity of melted rock, affecting the movement of magma and volcanic eruptions.
	b	In their investigation plan, students describe how the data collected will be relevant to determining the effect of water on Earth materials and surface processes.
3	Planning for the Investigation	
	a	In their investigation plan, students include a means to indicate or measure the predicted effect of water on Earth's materials or surface processes. Examples include:
		i. The role of the heat capacity of water to affect the temperature, movement of air and movement of water at the Earth's surface;
		ii. The role of flowing water to pick up, move and deposit sediment;
		iii. The role of the polarity of water (through cohesion) to prevent or facilitate erosion;
		iv. The role of the changing density of water (depending on physical state) to facilitate the breakdown of rock;
		v. The role of the polarity of water in facilitating the dissolution of Earth materials;
		vi. Water as a component in chemical reactions that change Earth materials; and
		vii. The role of the polarity of water in changing the melting temperature and viscosity of rocks.
	b	In the plan, students state whether the investigation will be conducted individually or collaboratively.
4	Collecting the data	
	a	Students collect and record measurements or indications of the predicted effect of a property of water on Earth's materials or surface.
5	Refining the design	
	a	Students evaluate the accuracy and precision of the collected data.
	b	Students evaluate whether the data can be used to infer the effect of water on processes in the natural world.
	c	If necessary, students refine the plan to produce more accurate and precise data.

HS-ESS2-6

Students who demonstrate understanding can:

HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models

Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

ESS2.D: Weather and Climate

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Crosscutting Concepts

Energy and Matter

- The total amount of energy and matter in closed systems is conserved.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students use evidence to develop a model in which they:	
		i.	Identify the relative concentrations of carbon present in the hydrosphere, atmosphere, geosphere and biosphere; and
		ii.	Represent carbon cycling from one sphere to another.
2	Relationships		
	a	In the model, students represent and describe the following relationships between components of the system, including:	
		i.	The biogeochemical cycles that occur as carbon flows from one sphere to another;
		ii.	The relative amount of and the rate at which carbon is transferred between spheres;
		iii.	The capture of carbon dioxide by plants; and
		iv.	The increase in carbon dioxide concentration in the atmosphere due to human activity and the effect on climate.
3	Connections		
	a	Students use the model to explicitly identify the conservation of matter as carbon cycles through various components of Earth's systems.	
	b	Students identify the limitations of the model in accounting for all of Earth's carbon.	

HS-ESS2-7

Students who demonstrate understanding can:

HS-ESS2-7. **Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.** [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [*Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • Construct an oral and written argument or counter-arguments based on data and evidence.	**ESS2.D: Weather and Climate** • Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. **ESS2.E Biogeology** • The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual coevolution of Earth's surface and the life that exists on it.	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:			
1	Developing the claim		
	a	Students develop a claim, which includes the following idea: that there is simultaneous coevolution of Earth's systems and life on Earth. This claim is supported by generalizing from multiple sources of evidence.	
2	Identifying scientific evidence		
	a	Students identify and describe evidence supporting the claim, including:	
		i.	Scientific explanations about the composition of Earth's atmosphere shortly after its formation;
		ii.	Current atmospheric composition;
		iii.	Evidence for the emergence of photosynthetic organisms;
		iv.	Evidence for the effect of the presence of free oxygen on evolution and processes in other Earth systems;
		v.	In the context of the selected example(s), other evidence that changes in the biosphere affect other Earth systems.
3	Evaluating and critiquing		
	a	Students evaluate the evidence and include the following in their evaluation:	
		i.	A statement regarding how variation or uncertainty in the data (e.g., limitations, low signal-to-noise ratio, collection bias, etc.) may affect the usefulness of the data as

			sources of evidence; and
		ii.	The ability of the data to be used to determine causal or correlational effects between changes in the biosphere and changes in Earth's other systems.
4	Reasoning and synthesis		
	a	Students use at least two examples to construct oral and written logical arguments. The examples:	
		i.	Include that the evolution of photosynthetic organisms led to a drastic change in Earth's atmosphere and oceans in which the free oxygen produced caused worldwide deposition of iron oxide formations, increased weathering due to an oxidizing atmosphere and the evolution of animal life that depends on oxygen for respiration; and
		ii.	Identify causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems.

HS-ESS3-1

Students who demonstrate understanding can:

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories.

- Construct 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.

Disciplinary Core Ideas

ESS3.A: Natural Resources

- Resource availability has guided the development of human society.

ESS3.B: Natural Hazards

- Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- Modern civilization depends on major technological systems.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes:	
		i.	Specific cause and effect relationships between environmental factors (natural hazards, changes in climate, and the availability of natural resources) and features of human societies including population size and migration patterns; and
		ii.	That technology in modern civilization has mitigated some of the effects of natural hazards, climate, and the availability of natural resources on human activity.
2	Evidence		
	a	Students identify and describe the evidence to construct their explanation, including:	
		i.	Natural hazard occurrences that can affect human activity and have significantly altered the sizes and distributions of human populations in particular regions;
		ii.	Changes in climate that affect human activity (e.g., agriculture) and human populations, and that can drive mass migrations;
		iii.	Features of human societies that have been affected by the availability of natural resources; and
		iv.	Evidence of the dependence of human populations on technological systems to acquire natural resources and to modify physical settings.

	b	Students use a variety of valid and reliable sources for the evidence, potentially including theories, simulations, peer review, or students' own investigations.
3	Reasoning	
	a	Students use reasoning that connects the evidence, along with 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, to describe:
		i. The effect of natural hazards, changes in climate, and the availability of natural resources on features of human societies, including population size and migration patterns; and
		ii. How technology has changed the cause and effect relationship between the development of human society and natural hazards, climate, and natural resources.
	b	Students describe reasoning for how the evidence allows for the distinction between causal and correlational relationships between environmental factors and human activity.

HS-ESS3-2

Students who demonstrate understanding can:

HS-ESS3-2. **Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*** [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence

Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).

Disciplinary Core Ideas

ESS3.A: Natural Resources

- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)*

Crosscutting Concepts

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.
- Analysis of costs and benefits is a critical aspect of decisions about technology.

- -

Connections to Nature of Science

Science Addresses Questions About the Natural and Material World

- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Science knowledge indicates what can happen in natural systems — not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

Observable features of the student performance by the end of the course:		
1	Supported claims	
	a	Students describe the nature of the problem each design solution addresses.
	b	Students identify the solution that has the most preferred cost-benefit ratios.
2	Identifying scientific evidence	
	a	Students identify evidence for the design solutions, including:
		i. Societal needs for that energy or mineral resource;
		ii. The cost of extracting or developing the energy reserve or mineral resource;
		iii. The costs and benefits of the given design solutions; and
		iv. The feasibility, costs, and benefits of recycling or reusing the mineral resource, if applicable.
3	Evaluation and critique	
	a	Students evaluate the given design solutions, including:
		i. The relative strengths of the given design solutions, based on associated economic, environmental, and geopolitical costs, risks, and benefits;
		ii. The reliability and validity of the evidence used to evaluate the design solutions; and
		iii. Constraints, including cost, safety, reliability, aesthetics, cultural effects environmental effects.
4	Reasoning/synthesis	
	a	Students use logical arguments based on their evaluation of the design solutions, costs and benefits, empirical evidence, and scientific ideas to support one design over the other(s) in their evaluation.
	b	Students describe that a decision on the “best” solution may change over time as engineers and scientists work to increase the benefits of design solutions while decreasing costs and risks.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-ESS3-3

Students who demonstrate understanding can:

HS-ESS3-3. **Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.** [Clarification Statement: Examples of factors that affect the management of natural resources include costs of resource extraction and waste management, per-capita consumption, and the development of new technologies. Examples of factors that affect human sustainability include agricultural efficiency, levels of conservation, and urban planning.] [*Assessment Boundary: Assessment for computational simulations is limited to using provided multi-parameter programs or constructing simplified spreadsheet calculations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

Disciplinary Core Ideas

ESS3.C: Human Impacts on Earth Systems

- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.

Crosscutting Concepts

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- Modern civilization depends on major technological systems.
- New technologies can have deep impacts on society and the environment, including some that were not anticipated.

- -

Connections to Nature of Science

Science is a Human Endeavor

- Science is a result of human endeavors, imagination, and creativity.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students create a computational simulation (using a spreadsheet or a provided multi-parameter program) that contains representations of the relevant components, including:
	i.	A natural resource in a given ecosystem;
	ii.	The sustainability of human populations in a given ecosystem;
	iii.	Biodiversity in a given ecosystem; and
	iv.	The effect of a technology on a given ecosystem.

2	Computational modeling		
	a	Students describe simplified realistic (corresponding to real-world data) relationships between simulation variables to indicate an understanding of the factors (e.g., costs, availability of technologies) that affect the management of natural resources, human sustainability, and biodiversity. *(For example, a relationship could be described that the amount of a natural resource does not affect the sustainability of human populations in a given ecosystem without appropriate technology that makes use of the resource; or a relationship could be described that if a given ecosystem is not able to sustain biodiversity, its ability to sustain a human population is also small.)*	
	b	Students create a simulation using a spreadsheet or provided multi-parameter program that models each component and its simplified mathematical relationship to other components. Examples could include:	
		i.	S=C*B*R*T, where S is sustainability of human populations, C is a constant, B is biodiversity, R is the natural resource, and T is a technology used to extract the resource so that if there is zero natural resource, zero technology to extract the resource, or zero biodiversity, the sustainability of human populations is also zero; and
		ii.	B=B1+C*T, where B is biodiversity, B1 is a constant baseline biodiversity, C is a constant that expresses the effect of technology, and T is a given technology, so that a given technology could either increase or decrease biodiversity depending on the value chosen for C.
	c	The simulation contains user-controlled variables that can illustrate relationships among the components (e.g., technology having either a positive or negative effect on biodiversity).	
3	Analysis		
	a	Students use the results of the simulation to:	
		i.	Illustrate the effect on one component by altering other components in the system or the relationships between components;
		ii.	Identify the effects of technology on the interactions between human populations, natural resources, and biodiversity; and
		iii.	Identify feedbacks between the components and whether or not the feedback stabilizes or destabilizes the system.
	b	Students compare the simulation results to a real world example(s) and determine if the simulation can be viewed as realistic.	
	c	Students identify the simulation's limitations relative to the phenomenon at hand.	

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-ESS3-4

Students who demonstrate understanding can:

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles and theories.

- Design or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

ESS3.C: Human Impacts on Earth Systems

- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)*

Crosscutting Concepts

Stability and Change

- Feedback (negative or positive) can stabilize or destabilize a system.

- -

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students use scientific information to generate a number of possible refinements to a given technological solution. Students:	
		i.	Describe the system being impacted and how the human activity is affecting that system;
		ii.	Identify the scientific knowledge and reasoning on which the solution is based;
		iii.	Describe how the technological solution functions and may be stabilizing or destabilizing the natural system;
		iv.	Refine a given technological solution that reduces human impacts on natural systems; and
		v.	Describe that the solution being refined comes from scientists and engineers in the real world who develop technologies to solve problems of environmental degradation.
2	Describing criteria and constraints, including quantification when appropriate		
	a	Students describe and quantify (when appropriate):	
		i.	Criteria and constraints for the solution to the problem; and
		ii.	The tradeoffs in the solution, considering priorities and other kinds of research-driven tradeoffs in explaining why this particular solution is or is not needed.
3	Evaluating potential refinements		
	a	In their evaluation, students describe how the refinement will improve the solution to increase benefits	

		and/or decrease costs or risks to people and the environment.
	b	Students evaluate the proposed refinements for:
		i. Their effects on the overall stability of and changes in natural systems; and
		ii. Cost, safety, aesthetics, and reliability, as well as cultural and environmental impacts.

HS-ESS3-5

Students who demonstrate understanding can:

HS-ESS3-5. **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.** [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [*Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using computational models in order to make valid and reliable scientific claims.

- -

Connections to Nature of Science

Scientific Investigations Use a Variety of Methods

- Science investigations use diverse methods and do not always use the same set of procedures to obtain data.
- New technologies advance scientific knowledge.

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence.
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Disciplinary Core Ideas

ESS3.D: Global Climate Change

- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.

Crosscutting Concepts

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

Observable features of the student performance by the end of the course:		
1	Organizing data	
	a	Students organize data (e.g., with graphs) from global climate models (e.g., computational simulations) and climate observations over time that relate to the effect of climate change on the physical parameters or chemical composition of the atmosphere, geosphere, hydrosphere, or cryosphere.
	b	Students describe what each data set represents.
2	Identifying relationships	
	a	Students analyze the data and identify and describe relationships within the datasets, including:
		i. Changes over time on multiple scales; and
		ii. Relationships between quantities in the given data.
3	Interpreting data	
	a	Students use their analysis of the data to describe a selected aspect of present or past climate and the associated physical parameters (e.g., temperature, precipitation, sea level) or chemical

		composition (e.g., ocean pH) of the atmosphere, geosphere, hydrosphere or cryosphere.
	b	Students use their analysis of the data to predict the future effect of a selected aspect of climate change on the physical parameters (e.g., temperature, precipitation, sea level) or chemical composition (e.g., ocean pH) of the atmosphere, geosphere, hydrosphere or cryosphere.
	c	Students describe whether the predicted effect on the system is reversible or irreversible.
	d	Students identify one source of uncertainty in the prediction of the effect in the future of a selected aspect of climate change.
	e	In their interpretation of the data, students:
		i. Make a statement regarding how variation or uncertainty in the data (e.g., limitations, accuracy, any bias in the data resulting from choice of sample, scale, instrumentation, etc.) may affect the interpretation of the data; and
		ii. Identify the limitations of the models that provided the simulation data and ranges for their predictions.

NEXT GENERATION SCIENCE STANDARDS
For States, By States

HS-ESS3-6

Students who demonstrate understanding can:

HS-ESS3-6. **Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.** [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [*Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations.

Disciplinary Core Ideas

ESS2.D: Weather and Climate

- Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. *(secondary)*

ESS3.D: Global Climate Change

- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

Crosscutting Concepts

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students identify and describe the relevant components of each of the Earth systems modeled in the given computational representation, including system boundaries, initial conditions, inputs and outputs, and relationships that determine the interaction (e.g., the relationship between atmospheric CO_2 and production of photosynthetic biomass and ocean acidification).
2	Computational modeling	
	a	Students use the given computational representation of Earth systems to illustrate and describe relationships among at least two of Earth's systems, including how the relevant components in each individual Earth system can drive changes in another, interacting Earth system.
3	Analysis	
	b	Students use evidence from the computational representation to describe how human activity could affect the relationships between the Earth's systems under consideration.

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-ETS1-1

Students who demonstrate understanding can:

HS-ETS1-1. **Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.**

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Asking Questions and Defining Problems
Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions.

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

Crosscutting Concepts

- -

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:		
1	Identifying the problem to be solved	
	a	Students analyze a major global problem. In their analysis, students:
		i. Describe the challenge with a rationale for why it is a major global challenge;
		ii. Describe, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and
		iii. Document background research on the problem from two or more sources, including research journals.
2	Defining the process or system boundaries, and the components of the process or system	
	a	In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem.
	b	In their analysis, students describe societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy).
3	Defining the criteria and constraints	
	a	Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem.

HS-ETS1-2

Students who demonstrate understanding can:

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. • Design a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.	

Observable features of the student performance by the end of the course:		
1	Using scientific knowledge to generate the design solution	
	a	Students restate the original complex problem into a finite set of two or more sub-problems (in writing or as a diagram or flow chart).
	b	For at least one of the sub-problems, students propose two or more solutions that are based on student-generated data and/or scientific information from other sources.
	c	Students describe how solutions to the sub-problems are interconnected to solve all or part of the larger problem.
2	Describing criteria and constraints, including quantification when appropriate	
	a	Students describe criteria and constraints for the selected sub-problem.
	b	Students describe the rationale for the sequence of how sub-problems are to be solved, and which criteria should be given highest priority if tradeoffs must be made.

HS-ETS1-3

Students who demonstrate understanding can:

HS-ETS1-3. **Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.**

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories.

- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

Crosscutting Concepts

- -

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:			
1	Evaluating potential solutions		
	a	In their evaluation of a complex real-world problem, students:	
		i.	Generate a list of three or more realistic criteria and two or more constraints, including such relevant factors as cost, safety, reliability, and aesthetics that specifies an acceptable solution to a complex real-world problem;
		ii.	Assign priorities for each criterion and constraint that allows for a logical and systematic evaluation of alternative solution proposals;
		iii.	Analyze (quantitatively where appropriate) and describe the strengths and weaknesses of the solution with respect to each criterion and constraint, as well as social and cultural acceptability and environmental impacts;
		iv.	Describe possible barriers to implementing each solution, such as cultural, economic, or other sources of resistance to potential solutions; and
		v.	Provide an evidence-based decision of which solution is optimum, based on prioritized criteria, analysis of the strengths and weaknesses (costs and benefits) of each solution, and barriers to be overcome.
2	Refining and/or optimizing the design solution		
	a	In their evaluation, students describe which parts of the complex real-world problem may remain even if the proposed solution is implemented.	

NEXT GENERATION SCIENCE STANDARDS For States, By States

HS-ETS1-4

Students who demonstrate understanding can:

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.	**ETS1.B: Developing Possible Solutions** • Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.	**Systems and System Models** • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter, and information flows — within and between systems at different scales.

Observable features of the student performance by the end of the course:			
1	Representation		
	a	Students identify the following components from a given computer simulation:	
		i.	The complex real-world problem with numerous criteria and constraints;
		ii.	The system that is being modeled by the computational simulation, including the boundaries of the systems;
		iii.	What variables can be changed by the user to evaluate the proposed solutions, tradeoffs, or other decisions; and
		iv.	The scientific principle(s) and/or relationship(s) being used by the model.
2	Computational Modeling		
	a	Students use the given computer simulation to model the proposed solutions by:	
		i.	Selecting logical and realistic inputs; and
		ii.	Using the model to simulate the effects of different solutions, tradeoffs, or other decisions.
3	Analysis		
	a	Students compare the simulated results to the expected results.	
	b	Students interpret the results of the simulation and predict the effects of the proposed solutions within and between systems relevant to the problem based on the interpretation.	
	c	Students identify the possible negative consequences of solutions that outweigh their benefits.	
	d	Students identify the simulation's limitations.	