HS-PS1 Matter and Its Interactions

HS-PS1 Matter and Its Interactions

Students who demonstrate understanding can:

HS-PS1-a. Evaluate the merits of different atomic and molecular representations based on their ability to explain a given property of matter or phenomenon. [Clarification Statement: Types of atomic and molecular structural representations can include computer-based simulations, physical, ball and stick, and drawings. Properties of matter can include melting points, boiling points, and polarity. Phenomena can include formation of solutions and phase changes.] [Assessment Boundary: Computational models and advanced conceptual models (e.g., molecular orbital theory) are not assessed.]

HS-PS1-b. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outer energy level of atoms. [Clarification Statement: An example of a pattern that predicts element properties would be Group I of the periodic table. These elements all have one electron in the outermost energy level and as such, are all highly reactive metals. Other properties could include types of bonds formed with other elements, number of bonds formed, and reactions with oxygen.] [Assessment Boundary: Only for main group elements (not transition metals). Ionization energy is not required.]

HS-PS1-c. Analyze and interpret provided data about bulk properties of various substances to support claims about the relative strength of the interactions among particles in the substance. [Clarification Statement: Students should infer the strength of interactions between particles. Bulk properties of substances can include melting point and boiling point, vapor pressure, and surface tension. Only the following types of particles are included in data and explanations: atoms, monatomic ions, and molecules.] [Assessment Boundary: Provided data is limited to the macroscopic scale. Comparisons require understanding of interactions between ions, interactions between atoms to form molecules or networked materials, and interactions between molecules; however, names of specific intermolecular forces (e.g., dipole-dipole) will not be assessed.]

HS-PS1-d. Develop a representation to show that energy is required to separate the atoms in a molecule and that energy is released when atoms at a distance come together to form molecules that are more stable. [Clarification Statement: Examples of representations can include drawings, graphs, chemical equations, and diagrams from data. At times, two representations would be appropriate.] [Assessment Boundary: Representations are only of common substances (e.g., water, carbon dioxide, common hydrocarbons, sodium chloride).]

HS-PS1-e. Construct 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: Evidence will come from temperature, concentration, and rate data; student reasoning should include that the factors that affect reaction rates depend on the number and the energy of the collisions between molecules.] [Assessment Boundary: Limited to simple reactions in which there are only two reactants. The quantitative relationship between rate and temperature is not required.]

HS-PS1-f. Use models to support that the release or absorption of energy from a chemical system depends upon the changes in total bond energy. [Clarification Statement: Examples of using models can include molecular level drawings and diagrams of reactions, and graphs showing the relative energies of reactants and products.] [Assessment Boundary: Calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products is not assessed.]

HS-PS1-g. Refine the design of a chemical system to specify changes in conditions that would produce increased amounts of products at equilibrium.* [Clarification Statement: Examples of designs could include different ways to increase product formation including adding reactants, or removing products. Designs should include descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of chemical systems could be nitrogen plus hydrogen producing ammonia or reactions in which water is produced – such as a simple condensation reaction.] [Assessment Boundary: Limited to simple reactions provided to students, adding or removing one reactant or product at a time. Calculating equilibrium constants and concentrations is not included. The effect of temperature on equilibrium is not included. Quantitative changes are not required.]

HS-PS1-h. Use mathematical expressions to support the explanation that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Models could include ball and stick models, computer simulations, and drawings. Using mathematical expressions includes explaining the meaning of 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. Memorization and rote application of problem-solving techniques alone will not yield successful performance.] [Assessment Boundary: Complex chemical reactions are not included.]

HS-PS1-i. Construct an explanation to support predictions about the outcome of simple chemical reactions, using the structure of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions would include the reaction of sodium and chlorine, or carbon and oxygen, or carbon and hydrogen.] [Assessment Boundary: Chemical reactions not readily predictable from the element's position on the periodic table (i.e., the main group elements) and combustion reactions are not intended. Reactions typically classified by surface level characteristics (e.g., double or single displacement reactions) are not intended.]

HS-PS1-j. Develop representations of 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: Representations should be qualitative.] [Assessment Boundary: Mathematical representations or quantitative calculation of energy released during nuclear processes are not assessed. Radioactive decays limited to alpha, beta, and gamma.]

The performance expectations above were developed using the following elements from the NRC document *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 explain relationships between systems and their components in the natural and designed world.

- Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations. (HS-PS1-d),(HS-PS1-f)
- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-PS1-j)
- Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. (HS-PS1-b)

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of

Disciplinary Core Ideas

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. (HS-PS1-a)
- 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. (HS-PS1-b)
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-a),(HS-PS1-c),*(secondary to HS-PS2-f)*
- Stable forms of matter are those in which the electric and magnetic field energy is minimized. A stable molecule has less energy, by an amount known as the binding energy, than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-d)

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. (HS-PS1-i)

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
- 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.
- Systems can be designed to cause a desired effect.
- Changes in systems may have various causes that may not have equal effects. (HS-PS1-b),(HS-PS1-d)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

data sets for consistency, and the use of models to generate and analyze data.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS1-c)

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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. (HS-PS1-h)
- Apply techniques of algebra and functions to represent and solve scientific and engineering problems. (HS-PS1-h)

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.

- Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. (HS-PS1-e)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulation) and peer review. (HS-PS1-e),(HS-PS1-i)
- 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. (HS-PS1-g)

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds from 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. Arguments may also come from current scientific or historical episodes in science.

- Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. (HS-PS1-a)

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 total binding energy (i.e., the sum of all bond energies in the set of molecules) that are matched by changes in kinetic energy. (HS-PS1-e),(HS-PS1-f)
- 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. (HS-PS1-g)
- 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. (HS-PS1-h),(HS-PS1-i)

PS1.C: Nuclear Processes

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve changes in nuclear binding energies. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-j)

PS3.A: Definitions of Energy

- "Chemical energy" generally is used to mean the energy that can be released or stored in chemical processes. *(secondary to HS-PS1-f)*

  - Clarification Statement for HS-PS1-b: The likelihood of interactions between elements is caused by the number of electrons in their valence shell; thus, the arrangement of the periodic table.
  - Clarification Statement for HS-PS1-d: Stability is caused by minimization of energy.

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. (HS-PS1-a)

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-j)
- The total amount of energy and matter in closed systems is conserved. (HS-PS1-h)
- 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. (HS-PS1-f)

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. (HS-PS1-c)
  - Clarification Statement for HS-PS1-c: The relative strength of interactions among particles causes different bulk properties.

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-g)
- Change and rates of change can be quantified and modeled over very short or very long periods of time. (HS-PS1-e),(HS-PS1-g)

Connections to Nature of Science

Science is a Way of Knowing

- Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time. (HS-PS1-b)

Connections to other DCIs in this grade-level: will be added in future version.

Articulation to DCIs across grade-levels: will be added in future version.

Common Core State Standards Connections:
ELA/Literacy –

RST.9-10.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. *(HS-PS1-e),(HS-PS1-i)*
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-PS1-a)*,(HS-PS1-c)
RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. *(HS-PS1-a)*,(HS-PS1-c),(HS-PS1-d),(HS-PS1-j)
RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. *(HS-PS1-a)*
RST.9-10.9	Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. *(HS-PS1-e),(HS-PS1-i)*
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-PS1-e),(HS-PS1-i)
WHST.11-12.1	Write arguments focused on discipline-specific content. *(HS-PS1-a)*
WHST.11-12. 2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. (HS-PS1-e),(HS-PS1-i)
WHST.11-12.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. *(HS-PS1-a)*,(HS-PS1-e),(HS-PS1-i)
WHST.9-10.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *(HS-PS1-g)*
WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation. *(HS-PS1-a)*
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS1-e),(HS-PS1-i)
WHST.11-12.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS1-a)

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SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. *(HS-PS1-a)*,(HS-PS1-c),(HS-PS1-e),(HS-PS1-i)
Mathematics –	
MP.2	Reason abstractly and quantitatively. (HS-PS1-b),(HS-PS1-c),(HS-PS1-e),(HS-PS1-h)
MP.3	Construct viable arguments and critique the reasoning of others. (HS-PS1-a)
MP.4	Model with mathematics. *(HS-PS1-b)*,(HS-PS1-h)
8.SP	Investigate patterns of association in bivariate data. (HS-PS1-b),(HS-PS1-e)
F.LE	Construct and compare linear, quadratic, and exponential models and solve problems. *(HS-PS1-c)*
S.ID	Summarize, represent, and interpret data on two categorical and quantitative variables. (HS-PS1-c), (HS-PS1-e),(HS-PS1-h)
S.IC.B	Make inferences and justify conclusions from sample surveys, experiments, and observational studies. (HS-PS1-b),(HS-PS1-e),(HS-PS1-h),(HS-PS1-i)
A-CED.1	Create equations that describe numbers or relationships. (HS-PS1-h)

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HS-PS2 Motion and Stability: Forces and Interactions

HS-PS2 Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

HS-PS2-a. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on macroscopic objects, their mass, and acceleration.* [Assessment Boundary: Restricted to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

HS-PS2-b. Use mathematical expressions 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: Conservation of momentum is the focus. Using mathematical expressions includes explaining the meaning of those expressions. Desired quantities are the total momentum of the system before and after interaction.] [Assessment Boundary: Systems are restricted to two macroscopic bodies moving in one dimension.]

HS-PS2-c. Design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.* [Clarification Statement: Evaluation and refinement could consist of determining the success of the device at protecting the object from harm, and modifying the design to improve it. Examples include an egg drop investigation and design of a football helmet.] [Assessment Boundary: Evaluations are qualitative only.]

HS-PS2-d. Use mathematical expressions to represent the relationship between the variables in both Newton's Law of Gravitation and Coulomb's Law, and use these expressions to predict the gravitational and electrostatic forces between objects. [Clarification Statement: Using mathematical expressions includes specifying relationships in both quantitative and conceptual terms.] [Assessment Boundary: Only systems with two objects are considered.]

HS-PS2-e. Design and conduct an investigation to support claims about how electric and magnetic fields are created. [Clarification Statement: An example investigation would be experiments to determine the effect of an electrical current on a compass, or the effect of a moving magnet on a nearby conductor.] [Assessment Boundary: Qualitative observations only. In-depth understanding of fields is not intended—understanding is limited to the concept that a field is a way for objects to exert forces without touching. Students are only assessed on designing and conducting investigations with provided materials and tools.]

HS-PS2-f. Produce technical writing and/or oral presentations about why the molecular-level structure is important in the functioning of designed materials. [Clarification Statement: Descriptions could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, hard durable materials are made of cross-linked long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Memorization of specific structures of designed molecules is not intended.]

The performance expectations above were developed using the following elements from the NRC document *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 build, test, and revise conceptual, mathematical, physical and empirical models.

- Design and conduct an investigation individually and collaboratively, 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. (HS-PS2-e)

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.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS2-a)

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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. (HS-PS2-b),(HS-PS2-d)
- Apply techniques of algebra and functions to represent and solve scientific and engineering problems. (HS-PS2-b),(HS-PS2-d)

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, 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. (HS-PS2-c)

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Newton's second law accurately predicts changes in the motion of macroscopic objects, but it requires revision for subatomic scales or for speeds close to the speed of light. (HS-PS2-a)
- Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-b)
- In any system, total momentum is always conserved. (HS-PS2-b)
- 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. (HS-PS2-b),(HS-PS2-c)

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-d)
- Forces at a distance are explained by fields permeating space that can transfer energy through space. Magnets or changing electric fields cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-e),*(secondary to HS-PS3-e)*
- 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. (HS-PS2-f),*(secondary to HS-PS1-a)*,*(secondary to HS-PS1-c)*

PS3.A: Definitions of Energy

- …and "electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary to HS-PS2-e)*

ETS1.A: Defining and Delimiting an Engineering Problem

- Design criteria and constraints, which typically reflect the needs of the end-user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability, and limits on its size and cost. *(secondary to HS-PS2-c)*
- 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 to HS-PS2-c)*

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 to HS-PS2-c)*
- Testing should lead to improvements in the design through an iterative procedure. *(secondary to HS-PS2-c)*
- Both physical models and computer models can be used in various

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-a),(HS-PS2-e)
- 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. (HS-PS2-d)
- Systems can be designed to cause a desired effect. (HS-PS2-c)
- Changes in systems may have various causes that may not have equal effects. (HS-PS2-a)

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. (HS-PS2-b)

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. (HS-PS2-f)

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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. ▪ Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. (HS-PS2-f) --- ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ Theories and laws provide explanations in science, but theories do not with time become laws or facts. (HS-PS2-a),(HS-PS2-d) ▪ Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-a),(HS-PS2-d)	ways to aid in the engineering design process. Physical models, or prototypes, are helpful in testing product ideas or the properties of different materials. *(secondary to HS-PS2-a)* ▪ Computer models are useful for a variety of purposes, such as in representing a design in 3-D through CAD software; in troubleshooting to identify and describe a design problem; in 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 to HS-PS2-a)* **ETS1.C: Optimizing the Design Solution** ▪ The aim of engineering design is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. *(secondary to HS-PS2-a)* ▪ Testing should lead to design improvements through an iterative process, and computer simulations are one useful way of running such tests. *(secondary to HS-PS2-a)*	

Connections to other DCIs in this grade-level: will be added in future version.

Articulation to DCIs across grade-levels: will be added in future version.

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.3	Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text. (HS-PS2-a),(HS-PS2-e)
RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-PS2-b),(HS-PS2-d)
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS2-c)
WHST.11-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-PS2-f)*
WHST.11-12.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. (HS-PS2-f)
WHST.11-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS2-a),(HS-PS2-e)
WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation. (HS-PS2-f)
SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. *(HS-PS2-f)*
SL.9-10.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-PS2-f)*

Mathematics –

MP.2	Reason abstractly and quantitatively (HS-PS2-a),(HS-PS2-b),(HS-PS2-d)
MP.4	Model with Mathematics (HS-PS2-d)
8.F	Define, evaluate, and compare functions. *(HS-PS2-a)*,(HS-PS2-b),(HS-PS2-d)
S.ID	Summarize, represent, and interpret data on a single count or measurement variable (HS-PS2-b),(HS-PS2-d)
A.CED.1	Create equations that describe numbers or relationships. (HS-PS2-b),(HS-PS2-d)
F.BF	Build a function that models a relationship between two quantities (HS-PS2-a),(HS-PS2-b),(HS-PS2-d)
F.IF	Interpret functions that arise in applications in terms of the context. (HS-PS2-a),(HS-PS2-b),(HS-PS2-d)
S.IC.B	Make inferences and justify conclusions from sample surveys, experiments, and observational studies. (HS-PS1-b),(HS-PS2-f)

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HS-PS3 Energy

HS-PS3 Energy

Students who demonstrate understanding can:

HS-PS3-a. Use mathematical expressions to describe, model, or simulate the change energy in the energy of one component within a closed system when the change in the energy of the other component(s) is known. [Clarification Statement: Using mathematical expressions includes explaining the meaning of those expressions.] [Assessment Boundary: Computational accounting for energy in a system is limited to systems of two or three components.]

HS-PS3-b. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Clarification Statement: Examples of devices can include roller coasters, Rube Goldberg devices, wind turbines, solar cells, and generators. Examples of constraints can include use of renewable energy forms and efficiency. Qualitative evaluations could include a wide range of energy conversions (e.g., from electrical to kinetic and from electromagnetic to thermal) that go beyond the expectation for quantitative evaluations.] [Assessment Boundary: Quantitative evaluation is limited to potential and kinetic conversions. Devices are limited to those constructed with materials provided to students.]

HS-PS3-c. Develop a model that supports the explanation that all forms of energy can be described as either the movement of particles or energy in fields. [Assessment Boundary: Mathematical models representing field energies are not assessed.]

HS-PS3-d. Design and conduct an investigation to support the claim that the transfer of thermal energy between components results in a more uniform energy distribution among the components of a closed system. [Clarification Statement: Investigations could include mixing liquids at different initial temperatures, adding hot objects at different temperatures to water. Evidence stems from analyzing data and using mathematical thinking to describe the energy changes both quantitatively and conceptually.] [Assessment Boundary: Assessment to be based on a given set of materials and tools.]

HS-PS3-e. Develop and use models of two objects interacting through a field to explain the changes in energy and the forces between the objects due to the interaction. [Clarification Statement: The emphasis of the core idea is on the relative position, not mass or charge. Representations could include drawings, diagrams, and texts. An example would be drawings of what happens when two charges of opposite polarity are near each other, including an explanation of how the change in energy of the charges is related to the change in energy of the field.] [Assessment Boundary: Only systems containing two objects are to be assessed.]

HS-PS3-f. Produce written and illustrated texts or oral presentations about how scientific discoveries about the conversion of energy from one form to another have affected human civilization, including the further development of science and technology.*

HS-PS3-g. Evaluate the benefits and drawbacks of nuclear processes compared to other types of energy production. [Clarification Statement: Students are provided with data and information (e.g., input/output data, production, storage costs) about energy production methods (e.g., burning coal or solar energy generation versus using nuclear reactors.] [Assessment Boundary: Students only evaluate data and information provided. Benefits and drawbacks only include economic, safety, and environmental.]

The performance expectations above were developed using the following elements from the NRC document *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 explain relationships between systems and their components in the natural and designed world.

- Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations. (HS-PS3-c)
- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-PS3-e)

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 build, test, and revise conceptual, mathematical, physical, and empirical models.

- Design an investigation individually and collaboratively and test designs as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. (HS-PS3-d)

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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models, or simulations. (HS-PS3-a)

Constructing Explanations and Designing

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. (HS-PS3-a)
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. "Mechanical energy" generally refers to some combination of motion and stored energy in an operating machine. (HS-PS3-b)
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-c)

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. (HS-PS3-a)
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-a),(HS-PS3-d)
- 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. (HS-PS3-a)
- The availability of energy limits what can occur in any system. (HS-PS3-a)
- 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). (HS-PS3-d)

PS3.C: Relationship Between Energy and Forces

- When two objects interacting through a force field change

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS3-e)

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. (HS-PS3-a),(HS-PS3-c),(HS-PS3-d)
- 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. (HS-PS3-a),(HS-PS3-d)
  - Clarification Statement for all PEs: Energy transfer cannot be directly studied – a model must be used. In design for maximal or minimal energy transfer, the boundaries of a system must be defined

Stability and Change

- Feedback (negative or positive) can stabilize or destabilize a system. Systems can be designed for greater or lesser stability. (HS-PS3-g)

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). (HS-PS3-f)
- Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. (HS-PS3-f)

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

- Modern civilization depends on major technological systems such as agriculture, health, water, energy, transportation, manufacturing, construction, and

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

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.

- Apply scientific knowledge and evidence to explain phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS3-b)

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds from 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. Arguments may also come from current scientific or historical episodes in science.

- Evaluate a claim for a design solution to a real-world problem based on scientific knowledge, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). (HS-PS3-g)

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.

- Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. (HS-PS3-f)

relative position, the energy stored in the force field is changed. (HS-PS3-e)

- Each force between the two interacting objects acts in the direction such that motion in that direction would reduce the energy in the force field between the objects. However, prior motion and other forces also affect the actual direction of motion. (HS-PS3-e)

PS3.D: Energy in Chemical Processes

- A variety of multistage physical and chemical processes in living organisms, particularly within their cells, account for the transport and transfer (release or uptake) of energy needed for life functions.) (HS-PS3-f)
- All forms of electricity generation and transportation fuels have associated economic, social, and environmental costs and benefits, both short and long term. (HS-PS3-f),(HS-PS3-g)
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. Machines are judged as efficient or inefficient based on the amount of energy input needed to perform a particular useful task. Inefficient machines are those that produce more waste heat while performing the task and thus require more energy input. It is therefore important to design for high efficiency so as to reduce costs, waste materials, and many environmental impacts. (HS-PS3-b),(HS-PS3-d)

ETS1.A: Defining and Delimiting an Engineering Problem

- Design criteria and constraints, which typically reflect the needs of the end-user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability, and limits on its size and cost. *(secondary to HS-PS3-b)*
- 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 to HS-PS3-b)*
- 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 may also have manifestations in local communities. But, whatever the scale, the first things that engineers do is define the problem and specify the criteria and constraints for potential solutions. (*secondary to HS-PS3-b*),(*secondary to HS-PS3-f*)

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 to HS-PS3-b)*
- Testing should lead to improvements in the design through an iterative procedure. *(secondary to HS-PS3-b)*

ETS1.C: Optimizing the Design Solution

- The aim of engineering design is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. *(secondary to HS-PS3-b)*
- Testing should lead to design improvements through an iterative process, and computer simulations are one useful way of running such tests. *(secondary to HS-PS3-b)*

communications. Engineers continuously modify these systems to increase benefits while decreasing costs and risks. (HS-PS3-b),(HS-PS3-f)

- Widespread adoption of technological innovations often depends on market forces or other societal demands, but it may also be subject to evaluation by scientists and engineers and to eventual government regulation. (HS-PS3-b),(HS-PS3-f)
- 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. (HS-PS3-b),(HS-PS3-f)

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. (HS-PS3-g)
- 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. (HS-PS3-f),(HS-PS3-g)
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. (HS-PS3-f),(HS-PS3-g)

Connections to other DCIs in this grade-level: will be added in future version.

Articulation to DCIs across grade-levels: will be added in future version.

Common Core State Standards Connections:
ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(HS-PS3-g)*
RST.9-10.3	Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text. (HS-PS3-d)
RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. *(HS-PS3-a),*(HS-PS3-c),*(HS-PS3-g)*
RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. *(HS-PS3-g)*
WHST.11-12.1	Write arguments focused on discipline-specific content. *(HS-PS3-g)*
WHST.9-10.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *(HS-PS3-b),*(HS-PS3-d)
WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation. *(HS-PS3-g)*
WHST.11-12.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS3-g)
SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each

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	source. *(HS-PS3-g)*
SL.11-12.2	Integrate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, orally) in order to make informed decisions and solve problems, evaluating the credibility and accuracy of each source and noting any discrepancies among the data. *(HS-PS3-b)*
SL.9-10.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-PS3-c)*
SL.11-12.5	Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. (HS-PS3-e)
Mathematics –	
MP.1	Make sense of problems and persevere in solving them. (HS-PS3-b)(HS-PS3-f)
MP.2	Reason abstractly and quantitatively. (HS-PS3-a),(HS-PS3-b),(HS-PS3-d)
MP.3	Construct viable arguments and critique the reasoning of others. (HS-PS3-g)
MP.6	Attend to precision (HS-PS3-b)
S.ID	Summarize, represent, and interpret data on a single count or measurement variable *(HS-PS3-b),*(HS-PS3-d)
F.BF	Build a function that models a relationship between two quantities (HS-PS3-a)
F.IF	Interpret a functions that arise in applications in terms of the context. (HS-PS3-a)
A-REI.10	Represent and solve equations and inequalities graphically. *(HS-PS3-a)*
A.CED	Create equations that describe numbers or relationships. (HS-PS3-a)
N-Q	Reason quantitatively and use units to solve problems. *(HS-PS3-b)*

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HS-PS4 Waves and Their Applications in Technologies for Information Transfer

HS-PS4 Waves and Their Applications in Technologies for Information Transfer

Students who demonstrate understanding can:

HS-PS4-a. Make quantitative claims using provided data regarding the relationship among frequency and wavelength, and the speed of the wave traveling in various media. [Clarification Statement: Examples of provided 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. Relationships are only expressed algebraically.]

HS-PS4-b. Evaluate a provided experimental design that attempts to determine the extent to which an interface between two materials meets the theoretical prediction for transmission, reflection, and refraction of waves. [Clarification Statement: Theoretical predictions are based on Law of Reflection and/or Snell's Law. Students should be provided relevant information, such as index of refraction of media and angle of incidence.] [Assessment Boundary: Restricted to light and sound waves.]

HS-PS4-c. Ask questions that challenge the relative advantages of analog vs. digital transmission of information in order to determine if the questions are testable and relevant.* [Clarification Statement: An example of different representations could include digital radio signals vs. FM signals. Advantages could include that digital information can be stored reliably in computer memory, but that analog can be easier to understand.] [Assessment Boundary: Questions are provided to students.]

HS-PS4-d. Develop a model to demonstrate that a structure can be modified to change its resonant frequency in a way that improves the structure's performance.* [Clarification Statement: Examples of models can include pictures, diagrams, or physical models. Potentially damaging resonance can involve real world examples of bridges, buildings, fences, or street signs; other examples can include musical instruments.] [Assessment Boundary: Students will be provided a structure to modify. Students are not required to solve a problem – only to apply the concept of resonant frequency to a given problem.]

HS-PS4-e. 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 better than the other. [Clarification Statement: Arguments should include existing experimental evidence. Examples of a phenomenon can include resonance, interference, diffraction, or photoelectric effect.] [Assessment Boundary: Limited to understanding that quantum theory relates the two models, students do not need to know the specifics of the quantum theory.]

HS-PS4-f. Develop and defend a claim about the effectiveness of a particular wavelength of an electromagnetic wave for use in a certain application.* [Clarification Statement: Examples can include infrared light for night vision, x-rays being used for bone imaging, or radio waves being used for long distance communication.] [Assessment Boundary: Only qualitative descriptors in the explanation are assessed.]

HS-PS4-g. Evaluate claims in written materials about the effects that different wavelengths of electromagnetic radiation have when interacting with matter. [Clarification Statement: Examples of written materials can include trade books, magazines, web resources, and other passages that may reflect bias. Evaluations should include the idea that different wavelengths of light have different energies, and that high energy electromagnetic radiation is much more damaging to living tissue than is low energy, which is often converted to thermal energy.] [Assessment Boundary: Only radio, microwaves, infrared, visible, UV, gamma, and x-ray radiation are intended; qualitative descriptions only.]

HS-PS4-h. Construct an explanation, using the particle model of light, of how photovoltaic materials work and describe their application in everyday devices in diverse contexts.* [Clarification Statement: Everyday devices can include solar cells and photosensors.] [Assessment Boundary: Qualitative explanations only. Knowledge of band theory is not required.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

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 solutions using models and simulations.

- Ask and evaluate questions that challenge the premise of an argument, the interpretation of a data set, or the suitability of a design. (HS-PS4-c)

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world.

- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-PS4-d)

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 build, test, and revise conceptual, mathematical, physical, and empirical models.

- Design and conduct an investigation individually and collaboratively, 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. (HS-PS4-b)

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

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 to HS-PS4-h)*

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. The reflection, refraction, and transmission of waves at an interface between two media can be modeled on the basis of these properties. (HS-PS4-a),(HS-PS4-b)
- Combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. (HS-PS4-c)
- 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. (HS-PS4-c)
- Resonance is a phenomenon in which waves add up in phase in a structure, growing in amplitude due to energy input near the natural vibration frequency. Structures have particular frequencies at which they resonate. This phenomenon (e.g., waves in a stretched string, vibrating air in a pipe) is used in speech and in the design of all musical instruments. (HS-PS4-d)

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. Quantum theory relates the two models. (Boundary: Quantum theory is not explained further at this grade level.) (HS-PS4-e)
- Because a wave is not much disturbed by objects that are small compared with its wavelength, visible light cannot be used to see such objects as individual atoms. (HS-PS4-f)
- All electromagnetic radiation travels through a vacuum at the same speed, called the speed of light. Its speed in any other given medium depends on its wavelength and the properties of that medium. (HS-PS4-a)

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. (HS-PS4-a),(HS-PS4-b),(HS-PS4-d),(HS-PS4-e),(HS-PS4-f),(HS-PS4-g),(HS-PS4-h)
  - Clarification Statement for HS-PS4-e: The way something functions, (e.g., visible light) can be best understood through a particular representation of its structure.

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). (HS-PS4-h)

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

- Modern civilization depends on major technological systems, such as agriculture, health, water, energy, transportation, manufacturing, construction, and communications. (HS-PS4-c),(HS-PS4-d),(HS-PS4-f),(HS-PS4-h)
- Engineers continuously modify these systems to increase benefits while

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theories.

- Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. (HS-PS4-a)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-PS4-h)

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds from 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. 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. (HS-PS4-e),(HS-PS4-f)
- Make and defend a claim about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence. (HS-PS4-f)

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.

- Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in scientific and technical texts or media reports, verifying the data when possible. (HS-PS4-g)

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. (HS-PS4-e)

- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). (HS-PS4-g)
- Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. (HS-PS4-g)
- Photovoltaic materials emit electrons when they absorb light of a high-enough frequency. (HS-PS4-h)
- Atoms of each element emit and absorb characteristic frequencies of light, and nuclear transitions have distinctive gamma ray wavelengths. These characteristics allow identification of the presence of an element, even in microscopic quantities. (HS-PS4-h)

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. (HS-PS4-f)
- Knowledge of quantum physics enabled the development of semiconductors, computer chips, and lasers, all of which are now essential components of modern imaging, communication, and information technologies. (Boundary: Details of quantum physics are not formally taught at this grade level.) (HS-PS4-f)

ETS1.A: Defining and Delimiting an Engineering Problem

- Design criteria and constraints, which typically reflect the needs of the end-user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability, and limits on its size and cost. *(secondary to HS-PS4-c),(secondary to HS-PS4-d),(secondary to HS-PS4-f)*
- 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 to HS-PS4-c),(secondary to HS-PS4-d),(secondary to HS-PS4-f)*

ETS1.B: Developing Possible Solutions

- To design something complicated one may need to break the problem into parts and attend to each part separately but must then bring the parts together to test the overall plan. *(secondary to HS-PS4-f)*
- Testing should lead to improvements in the design through an iterative procedure. *(secondary to HS-PS4-d)*
- Both physical models and computer models can be used in various ways to aid in the engineering design process. Physical models, or prototypes, are helpful in testing product ideas or the properties of different materials. *(secondary to HS-PS4-d)*

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 to HS-PS4-f)*
- The comparison of multiple designs can be aided by a trade-off matrix. *(secondary to HS-PS4-f)*

decreasing costs and risks. (HS-PS4-d)

Connections to other DCIs in this grade-level: will be added in future version.

Articulation to DCIs across grade-levels: will be added in future version.

Common Core State Standards Connections:

ELA//Literacy–

RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-PS4-a)
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS4-a)
RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. (HS-PS4-f), (HS-PS4-g)
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. *(HS-PS4-c), (HS-PS4-b),* (HS-PS4-E), (HS-PS4-g),
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. *(HS-PS4-d),*(HS-PS4-f),(HS-PS4-h)
WHST.11-12.1	Write arguments focused on discipline-specific content. *(HS-PS4-f)*
WHST.11-12.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. (HS-PS4-f)
WHST.11-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS4-f)*
SL.9-10.1c	Propel conversations by posing and responding to questions that relate the current discussion to broader themes or larger ideas; actively incorporate others into the discussion; and clarify, verify, or challenge ideas and conclusions. *(HS-PS4-c)*
SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. *(HS-PS4-b),* (HS-PS4-f), (HS-PS4-g), (HS-PS4-h)
SL.9-10.4	Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. (HS-PS4-f), (HS-PS4-h)

Mathematics –

MP.3	Construct viable arguments and critique the reasoning of others. (HS-PS4-e),(HS-PS4-f),(HS-PS4-g)
MP.4	Model with mathematics. *(HS-PS4-a),(HS-PS4-d)*

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HS-PS4 Waves and Their Applications in Technologies for Information Transfer

MP.5	Use appropriate tools strategically. (HS-PS4-b)
N-Q	Reason quantitatively and use units to solve problems (HS-PS4-a)
S.ID	Summarize, represent, and interpret data on a single count or measurement variable (HS-PS4-a)
S.IC	Make inferences and justify conclusions from sample surveys, experiments, and observational studies *(HS-PS4-b)*,(HS-PS4-e),(HS-PS4-f),(HS-PS4-h)
F.IF	Interpret functions that arise in applications in terms of the context. (HS-PS4-a)
F.BF	Build a function that models a relationship between two quantities. (HS-PS4-a)
F.LE	Construct and compare linear, quadratic, and exponential models and solve problems. *(HS-PS4-a)*
A.CED	Create equations that describe numbers or relationships. (HS-PS4-a)
A-REI.10	Represent and solve equations and inequalities graphically. *(HS-PS4-a)*

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-LS1 From Molecules to Organisms: Structures and Processes

HS-LS1 From Molecules to Organisms: Structures and Processes

Students who demonstrate understanding can:

HS-LS1-a. Critically read scientific literature and produce scientific writing and/or oral presentations that communicate how the structure and function of systems of specialized cells within organisms help perform the essential functions of life. [Clarification Statement: Emphasis is on identifying systems of specialized cells or tissues (e.g., nervous, muscular, connective, epithelial) and specialized structures that these cells possess that are vital to their functioning in carrying out essential life processes (e.g., transmission of neural impulses, muscle contraction, maintenance of blood glucose levels). Students should be able to determine information that is relevant to how the structure and function of these systems are related to chemical reactions that take place between different types of molecules (e.g., water, proteins, carbohydrates, lipids, nucleic acids).] [Assessment Boundary: The assessment should measure students' understanding of the hierarchical and structural organization of cells. Emphasis is not on whole body systems or biochemistry.]

HS-LS1-b. Critically read scientific literature and produce scientific writing and/or oral presentations that communicate how DNA sequences determine the structure and function of proteins, which carry out most of the work of the cell. [Clarification Statement: Emphasis is on the conceptual understanding that DNA sequences determine the amino acid sequence; thus, protein structure and function.] [Assessment Boundary: The assessment should provide evidence of students' abilities to read critically and identify key ideas and major conceptual ideas of the relationship between structure and the processes that lead to protein synthesis. The specific steps of transcription and translation or actual protein structure are not assessed.]

HS-LS1-c. Develop and use a model to support explanations about the hierarchical organization of interacting systems working together to provide specific functions within multicellular organisms. [Clarification Statement: Emphasis is on the levels of organization including cells, tissues, organs, and systems of an organism.] [Assessment Boundary: The assessment should provide evidence of students' abilities to develop and use models to explain how each level is dependent on the next to operate as a system carrying out specific functions necessary for life.]

HS-LS1-d. Design and conduct an investigation to gather evidence in supporting explanations for the function of feedback mechanisms to maintain homeostasis. [Clarification Statement: The emphasis is on investigations (e.g., heart rate response to exercise, blood vessels response to temperature changes) that students use to provide evidence to support explanations of types of feedback.] [Assessment Boundary: The assessment should provide evidence that students can distinguish between evidence supporting the feedback mechanism and evidence that does not include a feedback mechanism. Additionally, students should be able to determine whether or not an investigation is safe and ethical. The assessment should provide evidence of students' abilities to distinguish between supporting and irrelevant data. Cellular operations involved in the feedback mechanism are not assessed.]

HS-LS1-e. Use a model to support the explanation of how mitotic cell division results in daughter cells with identical patterns of genetic material essential for producing and maintaining a complex organism. [Clarification Statement: Emphasis is on conceptual understanding that mitosis passes on genetically identical materials via replication, not on the phases of mitosis.] [Assessment Boundary: The assessment should provide evidence of students' abilities to explain from a model (e.g., diagrams, computer simulations) how cells may have differentiated within an organism but are genetically identical.]

HS-LS1-f. Construct an explanation using evidence for how cell differentiation is the result of activation or inactivation of specific genes and small differences in the immediate environment of the cells; relate these concepts to potential solutions in biomedical engineering and research.* [Clarification Statement: Emphasis is limited to the concept that a single cell develops into a variety of differentiated cells and thus, a complex organism.] [Assessment Boundary: The assessment should provide evidence of students' abilities to construct an explanation about the conditions necessary for cell differentiation as well as the applications for biomedical research (e.g., cancer treatment, replacing damaged organs, engineering tissues to test drugs).]

HS-LS1-g. Develop and revise a model to support explanations about the role of cellular division and differentiation in producing and maintaining complex organisms composed of systems of tissues and organs that work together to meet the needs of the entire organism. [Clarification Statement: Emphasis is on the concept that genetically identical cells produced from a single cell during embryological development differentiate and become tissues that make up organs within organ systems working together to meet the needs of the organism.] [Assessment Boundary: The assessment should provide evidence of students' abilities to show strengths and/or limitations of a model to demonstrate the development of differentiated cells with specific functions necessary for the organism to survive. Assessments could use a computer simulation. Emphasis is not on recalling the steps of mitosis or specific gene control mechanisms.]

HS-LS1-h. Develop a model to support explanations for how photosynthesis transforms light energy into stored chemical energy. [Clarification Statement: Emphasis is on model development within the context of explaining the process of photosynthesis. Models may include diagrams and chemical equations. The focus should be on the flow of matter and energy through plants and other photosynthesizing organisms.] [Assessment Boundary: The assessment should provide evidence of students' abilities to describe the inputs and outputs of photosynthesis, not the specific biochemical steps.]

HS-LS1-i. Construct an explanation that carbon, hydrogen, and oxygen from sugar molecules produced through photosynthesis may combine with other elements to form amino acids and other large carbon-based molecules. [Clarification Statement: Emphasis is on students constructing explanations for how sugar molecules are formed through photosynthesis and the components of the reaction (i.e., carbon, hydrogen, oxygen). This hydrocarbon backbone is used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA).] [Assessment Boundary: The assessment should provide evidence of students' abilities to explain the relationship between the products of photosynthesis and their role as building blocks for the formation of macromolecules. Limited to the conceptual understanding of how the products of photosynthesis are utilized to build macromolecules. The details of the various chemical reactions are not assessed.]

HS-LS1-j. Use a model to represent and support the explanation 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 metabolism, not the specific steps.] [Assessment Boundary: The assessment should provide evidence of students' abilities to use conceptual models or diagrams to explain the inputs and outputs of metabolism. Students are not expected to identify the steps in cellular respiration.]

HS-LS1-k. Produce technical writing to communicate information about the evidence from technologies that supports explanations for the integrated functioning of various regions of the brain.* [Clarification Statement: Emphasis is on evaluating evidence about the integrated functioning of various regions of the brain and the technologies (e.g., MRI, CAT scan) used to gather the evidence about how the brain functions.] [Assessment Boundary: The assessment should provide evidence of students' abilities to determine which explanations are supported by valid and reliable data and the sources of the data. Emphasis is on physiological function, not the value of the behavior to the organism.]

HS-LS1-l. Ask questions to establish the strength of evidence supporting scientific arguments for the patterns of behavior in organisms related seeking rewards, avoiding punishments, and/or forming attachments to members of their own species and, in some cases, to members of other species. [Clarification Statement: Emphasis is on the strength of arguments explaining the relationship between brain circuits and motivation of behaviors. Emphasis is on the strength of evidence used to support an argument.] [Assessment Boundary: The assessment should provide evidence of students' abilities to recognize patterns of behaviors and relate those patterns to information processing regions of the brain and

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whether the organisms are seeking rewards, avoiding punishments, and/or forming attachments. The assessment will provide evidence of students' abilities to recognize patterns of behaviors and relate those patterns to the integrated functioning of the brain and whether the organism is seeking rewards, avoiding punishments, and/or forming attachments.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Asking Questions and Defining Problems
Asking questions and defining problems in grades 9–12 builds on grades K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design solutions using models and simulations.
- Ask questions that arise from careful observation of phenomena, models, theory, or unexpected results. (HS-LS1-l)
- Ask and evaluate questions that challenge the premise of an argument, the interpretation of a data set, or the suitability of a design. (HS-LS1-l)

Developing and Using Models
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world.
- Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations. (HS-LS1-c),(HS-LS1-e),(HS-LS1-g),(HS-LS1-h),(HS-LS1-j)
- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-LS1-c),(HS-LS1-h),(HS-LS1-j)
- Evaluate merits and limitations of two different models of the same proposed tool, process, or system in order to select or revise a model that best fits the evidence or design criteria. (HS-LS1-g)

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 build, test, and revise conceptual, mathematical, physical, and empirical models.
- Design and conduct an investigation individually and collaboratively, 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. (HS-LS1-d)
- Select appropriate tools to collect, record, analyze, and evaluate data. (HS-LS1-d)
- Design and conduct investigations and test design solutions in a safe and ethical manner including considerations of environmental, social, and personal impacts. (HS-LS1-d)

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.
- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-LS1-f)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-LS1-f)
- Apply scientific knowledge and evidence to explain phenomena and solve design problems, taking into account possible unanticipated effects. (HS-LS1-i)
- 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. (HS-LS1-f)

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on 6–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.
- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (HS-LS1-a),(HS-LS1-b),(HS-LS1-k)
- Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in

Disciplinary Core Ideas

LS1.A: Structure and Function
- Systems of specialized cells within organisms help them perform the essential functions of life, which involve chemical reactions that take place between different types of molecules, such as water, proteins, carbohydrates, lipids, and nucleic acids. (HS-LS1-a)
- All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells. (HS-LS1-b)
- Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-c)
- Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Outside that range (e.g. at too high or too low external temperature, with too little food or water available) the organism cannot survive. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. (HS-LS1-d)

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

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. (HS-LS1-h)
- 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. (HS-LS1-i)
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-i),(HS-LS1-j)
  As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. For example, aerobic (in the presence of oxygen) cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Anaerobic (without oxygen) cellular respiration follows a different and less efficient chemical pathway to provide energy in cells. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy loss to the surrounding environment. (HS-LS1-j),*(secondary to HS-LS2-d),(secondary to HS-LS2-c)*

LS1.D: Information Processing
- In complex animals, the brain is divided into several distinct regions and circuits, each of which primarily serves dedicated functions, such as visual perception,

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. (HS-LS1-e),(HS-LS1-l)

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. (HS-LS1-i)
- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. (HS-LS1-h),(HS-LS1-j)

Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS1-f)

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. (HS-LS1-c), (HS-LS1-g)

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. (HS-LS1-a)
- 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. (HS-LS1-b)

Stability and Change
- Feedback (negative or positive) can stabilize or destabilize a system. (HS-LS1-d)

Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology
- Science and engineering complement each other in the cycle of research and development. (HS-LS1-k)

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scientific and technical texts or media reports, verifying the data when possible. (HS-LS1-a),(HS-LS1-k)
- Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. (HS-LS1-a), (HS-LS1-b)

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems. (HS-LS1-l)
- Science includes the process of coordinating patterns of evidence with current theory. (HS-LS1-l)
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-LS1-l)

auditory perception, interpretation of perceptual information, guidance of motor movement, and decision making about actions to take in the event of certain inputs. (HS-LS1-k)
- In addition, some circuits give rise to emotions and memories that motivate organisms to seek rewards, avoid punishments, develop fears, or form attachments to members of their own species and, in some cases, to individuals of other species (e.g., mixed herds of mammals, mixed flocks of birds). (HS-LS1-l)
- The integrated functioning of all parts of the brain is important for successful interpretation of inputs and generation of behaviors in response to them. (HS-LS1-k)

PS1.B: Chemical Reactions
- Chemical processes and properties of materials underlie many important biological and geophysical phenomena. *(secondary to HS-LS1-j)*

PS3.D: Energy in Chemical Processes
- A variety of multistage physical and chemical processes in living organisms, particularly within their cells, account for the transport and transfer (release or uptake) of energy needed for life functions.) *(secondary to HS-LS1-i)*

ETS1.A: Defining and Delimiting an Engineering Problem
- Design criteria and constraints, which typically reflect the needs of the end-user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability, and limits on its size and cost. *(secondary to HS-LS1-f)*

Connections to other topics in this grade-level: will be added in future version.

Articulation across grade-levels: will be added in future version.

Common Core State Standards Connections:

ELA/Literacy –

RST.9-10.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. *(HS-LS1-a), (HS-LS1-k)*
RST.9-10.3	Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text. *(HS-LS1-d)*
RI.9-10.8	Delineate and evaluate the argument and specific claims in a text, assessing whether the reasoning is valid and the evidence is relevant and sufficient; identify false statements and fallacious reasoning. (HS-LS1-a), (HS-LS1-b)
RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. *(HS-LS1-a),(HS-LS1-k)*
RST.9-10.9	Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. *(HS-LS1-a), (HS-LS1-k)*
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-LS1-f),(HS-LS1-g),(HS-LS1-i)
WHST.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS1-a),(HS-LS1-b), (HS-LS1-g), (HS-LS1-k)
WHST.11-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS1-i)
WHST.9-10.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. (HS-LS1-a),(HS-LS1-b),(HS-LS1-k)
WHST.11-12.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. (HS-LS1-i)
WHST.9-10.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *(HS-LS1-g)*
WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation. (HS-LS1-a),(HS-LS1-b),(HS-LS1-k)
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS1-a),(HS-LS1-b)
WHST.11-12.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS1-i)
SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. (HS-LS1-a),(HS-LS1-b), (HS-LS1-g), (HS-LS1-i),(HS-LS1-k)
SL.9-10.1c	Propel conversations by posing and responding to questions that relate the current discussion to broader themes or larger ideas; actively incorporate others into the discussion; and clarify, verify, or challenge ideas and conclusions. (HS-LS1-l)
SL.9-10.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with pertinent descriptions, facts, details, and examples; use appropriate eye contact, adequate volume, and clear pronunciation. (HS-LS1-a), (HS-LS1-b),(HS-LS1-k)

Mathematics –

MP.4	Model with mathematics *(HS-LS1-f)*
S.ID	Summarize, represent, and interpret data on two categorical and quantitative variables. (HS-LS1-l)
S.IC	Make inferences and justify conclusions from sample surveys, experiments, and observational studies. (HS-LS1-l)

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HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Students who demonstrate understanding can:

HS-LS2-a. Design and conduct an investigation to generate mathematical comparisons of factors that affect carrying capacity and biodiversity of similar ecosystems at different scales. [Clarification Statement: Emphasis is on qualitative comparison of biodiversity and carrying capacity of ecosystems (e.g., wooded lot to a forest, a small pond to a large lake).] [Assessment Boundary: The assessment should provide evidence of students' abilities to make mathematical comparisons and determine which of the factors (e.g., boundaries, resources, climate, competition) affect carrying capacity and biodiversity. Assessments should include mathematical comparisons (e.g., graphs, charts, density, dispersion, histograms, population distributions) taken from simulations or historical data sets. Students should not be expected to derive mathematical equations to make comparisons.]

HS-LS2-b. Apply concepts of statistics and probability as mathematical evidence for population changes in ecosystems to support assertions about the tentative nature of scientific explanations and the role of new evidence in revising explanations. [Clarification Statement: Emphasis is on the difference in historical and contemporary quantitative analysis that demonstrates the changes in explanations about population fluctuations and how explanations for a change at one scale may not explain changes at another scale. Emphasis is not on students only completing mathematical calculations, but using the outcomes to reach a conclusion.] [Assessment Boundary: The assessments should provide evidence of students' abilities to analyze and interpret the effect new information has on explanations (e.g., DDT effects on raptor populations, effects of water temperature below reservoirs on fish spawning, invasive species effects when spread to larger scale).]

HS-LS2-c. Evaluate the impact of new data on a working explanation for cycling of matter and flow of energy in anaerobic respiration and revision of the explanations in light of new data.* [Clarification Statement: Emphasis is on identifying the impact of new data on scientific explanations about the cycling of matter and flow of energy.] [Assessment Boundary: The assessment should provide evidence of students' abilities to explain how new data (e.g., observations and data of organisms living near deep ocean vents–chemosynthesis) have resulted in revisions of explanations in light of new evidence. Conceptual understanding of the cycling of matter and flow of energy in anaerobic respiration is the emphases of the assessment. The emphasis is not on the specific chemical processes of either aerobic or anaerobic respiration.]

HS-LS2-d. Develop a mathematical model that generates data to support explanations about the flow of matter and energy among organisms in an ecosystem. [Clarification Statement: Emphasis is on data derived from models of energy stored in biomass that is transferred from one trophic level to another. The model should also account for students understanding that most of the energy is not transferred between organisms but is dissipated into the environment.] [Assessment Boundary: The assessment should provide evidence of students' abilities to develop energy pyramids, food chains, food webs, and other models from data sets.]

HS-LS2-e. Apply scientific knowledge and evidence to explain that elements and energy are conserved as matter cycles and energy flows through ecosystems. [Clarification Statement: Emphasis is on molecules such as carbon, oxygen, hydrogen, and nitrogen and their conservation in, for example, the water cycle or carbon cycle.] [Assessment Boundary: The assessment should provide evidence of students' abilities to present evidence-based explanations for conservation through the process of cycling of matter and flow of energy.]

HS-LS2-f. Ask questions to define a problem caused by changes in population, resources, and/or the environment that can be solved through environmental engineering of solutions specific to the competition of organisms for matter and energy.* [Clarification Statement: Emphasis is on students understanding that competition between organisms is for matter and energy to survive, grow, and reproduce.] [Assessment Boundary: The assessment should provide evidence of students' abilities to identify questions that define the problems when conditions (e.g., invasive species, predator removal, extreme weather, land use) are altered. The questions should be scientific in nature and useful in defining a problem that has an environmental engineering solution.]

HS-LS2-g. Apply concepts of statistical data to develop an explanation for variations in rates of photosynthesis and cellular respiration and the resulting influence on the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. [Clarification Statement: Emphasis is on determining the data that supports the role of photosynthesis and cellular respiration in the cycling of carbon (e.g., seasonal fluctuations in carbon dioxide, sinks, and sources of carbon).] [Assessment Boundary: The assessment should provide evidence of students' abilities to explain the influence of different rates of photosynthesis and cellular respiration on the carbon cycle. The emphasis is not on the specific chemical steps of photosynthesis and respiration.]

HS-LS2-h. Develop, revise, and use a mathematical model to support an explanation of how complex sets of interactions in ecosystems maintain relatively consistent numbers and types of organisms for long periods of time when conditions are stable. [Clarification Statement: Emphasis is on mathematical models that support stability in populations through cycles and trends.] [Assessment Boundary: The assessment should provide evidence of students' abilities to derive trends from graphical representations of population trends. The models will be used to support explanations of the nature of interactions that occur in an ecosystem and relate these interactions to the stability and change. The assessment should only use mathematical analysis of the model appropriate to the grade level.]

HS-LS2-i. Use scientific reasoning, theory, and models to link evidence to claims about the effects of modest and extreme biological or physical changes to ecosystems on the natural capacity to reestablish an ecosystem with more or less stable conditions. [Clarification Statement: Emphasis is on using evidence to support arguments for the mechanisms leading to either a more stable ecosystem or less stable ecosystem. Computational models may be used as evidence to support the argument.] [Assessment Boundary: The assessment should provide evidence of students' abilities to distinguish between evidence supporting the capacity of ecosystems to respond to modest changes (e.g., hunting, fertilizer run-off) and extreme changes (e.g., fire, flood).]

HS-LS2-j. Design, evaluate, and refine a solution for reducing negative impact of human activities on the environment and ways to sustain biodiversity and maintain the planet's natural capital.* [Clarification Statement: Emphasis is on human activities (e.g., pollution, climate change, making snow at ski areas, controlled burns, dams) that change the way ecosystems operate in terms of potential impacts on biodiversity, as well as populations. The solutions should be based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.] [Assessment Boundary: The assessment should provide evidence of students' abilities to provide reasonable explanations of what might happen as the basis for proposed engineering solutions.]

HS-LS2-k. Evaluate evidence for its merits in supporting the role of group behavior on individual and species' chances to survive and reproduce. [Clarification Statement: Emphasis is on advantages of grouping behaviors (e.g., flocking, schooling, herding) and cooperative behaviors (e.g., hunting, migrating, swarming) on survival and reproduction.] [Assessment Boundary: The assessment should provide evidence of students' abilities to: (1) distinguish between group versus individual behavior, (2) identify evidence supporting the outcomes of group behavior, and (3) develop logical and reasonable arguments based on evidence.]

HS-LS2-l. Design and conduct an investigation to test design solutions for increasing or maintaining the biodiversity of an ecosystem.* [Clarification Statement: Emphasis is on designing solutions for a proposed problem. The investigation may be a simulation or a performance task in the classroom.] [Assessment Boundary: The assessment should provide evidence of the students' abilities to consider environmental, personal, and social impacts as well as designing a solution and developing methods for measuring the effects of the proposed changes on the system in terms of: (1) increasing biodiversity, and (2) maintaining biodiversity.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

Science and Engineering Practices

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 solutions using models and simulations.

- Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations. (HS-LS2-f)

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world.

- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-LS2-h)
- Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. (HS-LS2-h),(HS-LS2-d)

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 build, test, and revise conceptual, mathematical, physical, and empirical models.

- Design an investigation individually and collaboratively and test designs as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. (HS-LS2-a), (HS-LS2-l)
- Design and conduct an investigation individually and collaboratively, 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. (HS-LS2-a),(HS-LS2-l)
- Design and conduct investigations and test design solutions in a safe and ethical manner including considerations of environmental, social, and personal impacts. (HS-LS2-l)

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.

- 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. (HS-LS2-b), (HS-LS2-d)
- Evaluate the impact of new data on a working explanation of a proposed process or system. (HS-LS2-g), (HS-LS2-c)

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9–12 level and 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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. (HS-LS2-h)

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.

- Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. (HS-LS2-j)
- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-LS2-j)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models,

Disciplinary Core Ideas

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

- Matter and energy are conserved in each change. This is true of all biological systems, from individual cells to ecosystems. *(secondary to HS-LS2-e)*

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. (HS-LS2-a),(HS-LS2-b)

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. (HS-LS2-c)
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain. (HS-LS2-d)
- 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; (HS-LS2-e)
- Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. (HS-LS2-d)
- Competition among species is ultimately competition for the matter and energy needed for life. (HS-LS2-f)
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (HS-LS2-g)

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. (HS-LS2-h)
- 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. (HS-LS2-i),(HS-LS2-b)
- 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. (HS-LS2-j)

LS2.D: Social Interactions and Group Behavior

- Animals, including humans, having a strong drive for social affiliation with members of their own species and will suffer, behaviorally as well as physiologically, if reared in isolation, even if all their physical needs are met. Some forms of affiliation arise from the bonds between offspring and parents. Other groups form among peers. Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. (HS-LS2-k)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-k)

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. (HS-LS2-e)

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. (HS-LS2-d),(HS-LS2-f)
- Energy drives the cycling of matter within and between systems. (HS-LS2-g),(HS-LS2-c)

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS2-a)
- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-LS2-b)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-h),(HS-LS2-i)
- Systems can be designed for greater or lesser stability. (HS-LS2-l),(HS-LS2-j)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

theories, simulations) and peer review. (HS-LS2-e)

- 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. (HS-LS2-j)

Engaging in Argument from Evidence

Engaging in argument from evidence in 9–12 builds from 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. 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. (HS-LS2-i),(HS-LS2-k)

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence.

- Scientific explanations can be probabilistic. (HS-LS2-b)
- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-b),(HS-LS2-c)
- 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. (HS-LS2-b)

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. (HS-LS2-c)

LS4.D: Biodiversity and Humans

- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Biological extinction, being irreversible, is a critical factor in reducing the planet's natural capital. *(secondary to HS-LS2-j)*
- 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. These problems have the potential to cause a major wave of biological extinctions—as many species or populations of a given species, unable to survive in changed environments, die out—and the effects may be harmful to humans and other living things. 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 to HS-LS2-i),(secondary to HS-LS2-j)*

PS3.D: Energy in Chemical Processes

- The main way in which that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. *(secondary to HS-LS2-g)*

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 to HS-LS2-j)*

ETS1.C: Optimizing the Design Solution

- The aim of engineering design is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. *(secondary to HS-LS2-l)*

Connections to other topics in this grade-level: will be added in future version.

Articulation across grade-levels: will be added in future version.

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS2-e)

RST.9-10.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text. (HS-LS2-a), (HS-LS2-l)

RST.9-10.7 Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-LS2-b),(HS-LS2-d), (HS-LS2-g)

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address question or solve a problem. *(HS-LS2-e)* , (HS-LS2-c)

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. *(HS-LS2-j), (HS-LS2-k)*

RST.9-10.9 Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. (HS-LS2-c),(HS-LS2-e),*(HS-LS2-i),(HS-LS2-k)*

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-LS2-e),(HS-LS2-j)

WHST.11-12.1 Write arguments focused on *discipline-specific content* (HS-LS2-i),(HS-LS2-k)

WHST.11-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS2-e)

WHST.11-12.4 Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. (HS-LS2-e)

WHST.11-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-LS2-a),(HS-LS2-l)

WHST.11-12.9 Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS2-e),(HS-LS2-i),(HS-LS2-k)

SL.9-10.1c Propel conversations by posing and responding to questions that relate the current discussion to broader themes or larger ideas; actively incorporate others into the discussion; and clarify, verify, or challenge ideas and conclusions. (HS-LS2-f)

SL.11-12.2 Integrate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, orally) in order to make informed decisions and solve problems, evaluating the credibility and accuracy of each source and noting any discrepancies among the data.*(HS-LS2-j)*

SL.9-10.3 Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric, identifying any fallacious reasoning or exaggerated or distorted evidence. (*HS-LS2-e),* (HS-LS2-i), (HS-LS2-k)

SL.9-10.4 Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. (HS-LS2-h)

Mathematics –

MP.1 Make sense of problems and persevere in solving them. (HS-LS2-a)

MP.2 Reason abstractly and quantitatively (HS-LS2-a),(HS-LS2-b),(HS-LS2-d)

MP.4 Model with mathematics. (HS-LS2-d),(HS-LS2-h)

MP.5 Use appropriate tools strategically. (HS-LS2-c)

N-Q Reason quantitatively and use units to solve problems. (HS-LS2-a),(HS-LS2-b)

S.IC Make inferences and justify conclusions from sample surveys, experiments, and observational studies. (HS-LS2-h)

S.ID Summarize, represent, and interpret data on a single count or measurement variable. (HS-LS2-b),(HS-LS2-c),(HS-LS2-d)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

A-CED	Create equations that describe numbers or relationships (HS-LS2-b)
F.BF	Build a function that models a relationship between two quantities. (HS-LS2-d)
N-Q	Reason quantitatively and use units to solve problems. (HS-LS2-d),(HS-LS2-c)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-LS3 Heredity: Inheritance and Variation of Traits

HS-LS3 Heredity: Inheritance and Variation of Traits

Students who demonstrate understanding can:

HS-LS3-a. Ask questions to obtain information about the role of DNA and chromosomes in coding the instructions for forming the characteristic traits of species passed from parents to offspring. [Clarification Statement: Emphasis is on the practice of asking scientific questions and obtaining reliable information to describe roles of chromosomes and DNA in coding instructions for traits in species.] [Assessment Boundary: The assessment should provide evidence of students' abilities to ask questions and obtain relevant information about the coding of instructions for the passing of traits from parent to offspring. Assessments should not include the phases of meiosis.]

HS-LS3-b. Synthesize, communicate, and evaluate the validity and reliability of the claim 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 conceptual and/or simple mathematical understanding of the sources of genetic variation that are heritable. Information on genetic variation should include evidence of understanding the probability of variations and the rarity of mutations.] [Assessment Boundary: The assessment should provide evidence of students' abilities to evaluate and discuss sources of genetic variation in offspring, not the details of the mechanism's variations.]

HS-LS3-c. Evaluate the merits of competing ethical arguments for the research, development, and growth of industries based on the development of technologies that modify the genetic make-up of an organism.* [Clarification Statement: Emphasis is on comparing competing arguments based on ethical as well as scientific principles.] [Assessment Boundary: The assessment should provide evidence of students' abilities to evaluate the merits of genetic modification technologies (e.g., cloning, gene therapy, genetic engineering, selective breeding) in terms of scientific principles as well as ethical considerations and social implications. The assessment should provide evidence of students' abilities to evaluate the merits of genetic modification technologies (e.g., cloning, gene therapy, genetic engineering, selective breeding) in terms of scientific principles as well as cost, safety, and reliability as well as social and environmental impacts.]

HS-LS3-d. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. [Clarification Statement: Emphasis is on distribution and variation of traits in a population and the use of mathematics (e.g., calculations of frequencies in Punnett squares, graphical representations) to describe the distribution.] [Assessment Boundary: The assessment should provide evidence of students' abilities to use mathematical reasoning to explain the variation observed in a population as a combination of genetic and environmental factors. Hardy-Weinberg calculations are beyond the intent.]

The performance expectations above were developed using the following elements from the NRC document, *A Framework for K-12 Science Education*:

Science and Engineering Practices

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 solutions using models and simulations.

- Ask questions that arise from careful observation of phenomena, models, theory, or unexpected results. (HS-LS3-a)

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.

- 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. (HS-LS3-d)

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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. (HS-LS3-d)

Engaging in Argument from Evidence

Engaging in argument from evidence in 9-12 builds from 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. Arguments may also come from current scientific or historical episodes in science.

- Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. (HS-LS3-c)

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9-12 builds on 6-8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (HS-LS3-b)
- Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in scientific and technical texts or media reports, verifying the data when possible. (HS-LS3-b)

Disciplinary Core Ideas

LS1.B: Growth and Development of Organisms

- In sexual reproduction, a specialized type of cell division called meiosis occurs that results in the production of sex cells, such as gametes in animals (sperm and eggs), which contain only one member from each chromosome pair in the parent cell. *(secondary to HS-LS3-b)*

LS3.A: Inheritance of Traits

- In all organisms the genetic instructions for forming species' characteristics are carried in the chromosomes. (HS-LS3-a),(HS-LS3-b)
- 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. (HS-LS3-a),(HS-LS3-c)
- 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. (HS-LS3-d),*(secondary to HS-LS1-g)*

LS3.B: Variation of Traits

- The information passed from parents to offspring is coded in the DNA molecules that form the chromosomes. (HS-LS3-a)
- 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. (HS-LS3-b)
- 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. (HS-LS3-b)
- Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors. (HS-LS3-d),(HS-LS3-b)

ETS1.C: Optimizing the Design Solution

- When evaluating solutions, all relevant considerations, including cost, safety, reliability, and aesthetic, social, cultural, and environmental impacts, should be included. *(secondary to HS-LS3-c)*

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-a),(HS-LS3-b),(HS-LS3-d)

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). (HS-LS3-d)

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 involve scientists, engineers, and others with wide ranges of expertise. (HS-LS3-c)

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. (HS-LS3-c)

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. (HS-LS3-c)
- Science and engineering are influenced by society and society is influenced by science and engineering. (HS-LS3-c)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-LS3 Heredity: Inheritance and Variation of Traits

Connections to other topics in this grave-level: will be added in future version.
Articulation across grade-levels: will be added in future version.

Common Core State Standards Connections:
ELA/Literacy–

RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-LS3-d)
RST.9-10.9	Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. (HS-LS3-c)
WHST.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS3-b)
WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation. (HS-LS3-b)
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS3-b)
SL.9-10.1c	Propel conversations by posing and responding to questions that relate the current discussion to broader themes or larger ideas; actively incorporate others into the discussion; and clarify, verify, or challenge ideas and conclusions. (HS-LS3-a)
SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. *(HS-LS3-b)*
SL.9-10.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-LS3-b)

Mathematics –

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-LS4 Biological Evolution: Unity and Diversity

HS-LS4 Biological Evolution: Unity and Diversity

Students who demonstrate understanding can:

HS-LS4-a. Produce scientific writing that communicates how multiple lines of evidence, such as similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development, contribute to the strength of science theories related to natural selection and biological evolution. [Clarification Statement: Emphasis is on identifying historically reliable sources of scientific evidence contributing to the strength of the theories of natural selection and biological evolution (e.g., DNA sequencing, embryology, anatomy) and evaluating how multiple lines of evidence contribute to an understanding of evolution.] [Assessment Boundary: The assessment should provide evidence of students' abilities to evaluate the strength of the evidence.]

HS-LS4-b. Use a model to support the explanation that the process of natural selection is the result of 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 the interrelationship of the four factors that result in natural selection. Mathematical models and simulations of changes in distribution of traits in a population at different times may be used.] [Assessment Boundary: Assessment should provide evidence of students' abilities to explain natural selection in terms of the number of organisms, behaviors, morphology, or physiology factors having a direct effect on survival and reproduction as well as ability to compete for limited resources. Mathematical models may be used to communicate the explanation.]

HS-LS4-c. Apply concepts of statistics and probability to support explanations for how organisms with an advantageous heritable trait tend to increase in proportion to organisms that lack this trait. [Clarification Statement: Emphasis is on mathematically analyzing changes in the numerical distribution of heritable traits in a population.] [Assessment Boundary: The assessment should provide evidence of students' abilities to analyze shifts in numerical distribution of traits as evidence to support explanations. Analysis is limited to basic statistical and graphical analysis, not gene frequency calculations.]

HS-LS4-d. Construct an explanation based on evidence for how natural selection, genetic drift, gene flow through migration, and co-evolution lead to populations dominated by organisms that are anatomically, behaviorally, and physiologically adapted to survive and reproduce in a specific environment. [Clarification Statement: Emphasis is on quantitative evidence as the basis for clarifying the difference among various processes of adaptation within populations. Data on specific environmental differences and selection for/against traits should be used. Environmental factors may include ranges of seasonal temperature, climate change, acidity, and light.] [Assessment Boundary: The assessment should measure students' abilities to differentiate types of evidence used in explanations.]

HS-LS4-e. Synthesize, communicate, and evaluate technical information that describes how changes in environmental conditions can affect the distribution of traits in a population causing: 1) increases in the population of some species, 2) the emergence of new species over time, and 3) the extinction of other species. [Clarification Statement: Emphasis is on changes in the environment and how these changes affect the distribution of traits in the populations. The rate of change should also be considered in the changes to the environment (e.g., deforestation, fishing, application of fertilizers, drought, flood) and the affect on the distribution of traits.] [Assessment Boundary: The assessment should provide evidence of students' abilities to explain the cause and effect for how changes to the environment affect distribution or disappearance of traits in species.]

HS-LS4-f. Design and conduct an investigation to find patterns in data indicating the relationship between changes in the environment and natural selection. [Clarification Statement: Emphasis is on finding patterns in data that support the cause and effect relationships between changes in the environment and natural selection.] [Assessment Boundary: The assessment should provide evidence of students' abilities to present evidence based conclusions for investigations and limitations of findings in terms of the design of an investigation, identification of relevant data, attributes of reliable and accurate measurements, and presentation of evidence-based conclusions.]

The performance expectations above were developed using the following elements from the NRC document *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 explain relationships between systems and their components in the natural and designed world.

- Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations. (HS-LS4-b)

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 build, test, and revise conceptual, mathematical, physical, and empirical models.

- Design and conduct an investigation individually and collaboratively, 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. (HS-LS4-f)
- Use investigations to gather evidence to support explanations or concepts. (HS-LS4-f)

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.

- 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. (HS-LS4-c)

Constructing Explanations and Designing Solutions

Disciplinary Core Ideas

LS4.A: Evidence of Common Ancestry and Diversity

- Genetic information, like the fossil record, also 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. (HS-LS4-a)

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. (HS-LS4-b),(HS-LS4-c)
- The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. (HS-LS4-d),(HS-LS4-c),(HS-LS4-e)

LS4.C: Adaptation

- Natural selection is the result of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. (HS-LS4-b)
- 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

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. (HS-LS4-c),(HS-LS4-f),(HS-LS4-a)

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-b),(HS-LS4-d),(HS-LS4-e)

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency (Regularity) 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. (HS-LS4-d),(HS-LS4-a)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-LS4 Biological Evolution: Unity and Diversity

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.

- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-LS4-d)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-LS4-d)
- Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. (HS-LS4-d)

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9–12 builds on 6–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (HS-LS4-e),(HS-LS4-a)
- Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. (HS-LS4-e),(HS-LS4-a)

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. (HS-LS4-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. (HS-LS4-d),(HS-LS4-c)

- Adaptation also means that the distribution of traits in a population can change when conditions change. (HS-LS4-e)
- 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. (HS-LS4-e),(HS-LS4-f)
- 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. (HS-LS4-e)

Connections to other topics in this grade-level: will be added in future version.

Articulation across grade-levels: will be added in future version.

Common Core State Standards Connections:

ELA/Literacy–

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS4-c)
RST.9-10.3	Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text. (HS-LS4-f)
RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-LS4-b),(HS-LS4-c)
RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. (HS-LS4-e),(HS-LS4-a)
RI.9-10.8	Delineate and evaluate the argument and specific claims in a text, assessing whether the reasoning is valid and the evidence is relevant and sufficient; identify false statements and fallacious reasoning. (HS-LS4-e), (HS-LS4-a)
WHST.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-LS4-d), (HS-LS4-e), (HS-LS4-a)*
WHST.9-10.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. *(HS-LS4-d), (HS-LS4-e), (HS-LS4-a)*
WHST.9-10.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-LS4-f)
WHST.9-10.8	Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation. *(HS-LS4-e), (HS-LS4-a)*
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-LS4-d), (HS-LS4-e), (HS-LS4-a)*
SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. (HS-LS4-d),(HS-LS4-e),(HS-LS4-a)

Mathematics –

MP.4	Model with mathematics. (HS-LS4-b)
N-Q	Reason quantitatively and use units to solve problems (HS-LS4-c),(HS-LS4-e)
F.LE	Construct and compare linear, quadratic, and exponential models and solve problems. (HS-LS4-b)
S.ID	Summarize, represent, and interpret data on a single count or measurement variable (HS-LS4-c)
S.IC	Make inferences and justify conclusions from sample surveys, experiments, and observational studies (HS-LS4-c),(HS-LS4-e),(HS-LS4-a)
F.BF	Build a function that models a relationship between two quantities. (HS-LS4-c)
A.CED.1	Create equations that describe numbers or relationships (HS-LS4-c)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-ESS1 Earth's Place in the Universe

HS-ESS1 Earth's Place in the Universe

Students who demonstrate understanding can:

HS-ESS1-a. Use models to describe the sun's place in space in relation to the Milky Way galaxy and the distribution of galaxies and galaxy clusters in the Universe. [Clarification Statement: Mathematical models can focus on the logarithmic powers-of-ten relationship among the sun, its solar system, the Milky Way galaxy, the local cluster of galaxies, and the universe; these relationships can also be investigated graphically, using 2D or 3D scaled models, or through computer programs, either pre-made or student-written.] [Assessment Boundary: Details about the mapped distribution of galaxies and clusters are not assessed.]

HS-ESS1-b. Construct explanations based on observable astronomical data as empirical evidence of the Big Bang theory and the role the development of technologies have played in obtaining this data.* [Clarification Statement: Data include 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.]

HS-ESS1-c. Synthesize and communicate technical information about the processes by which stars produce new elements over their changing lifetimes. [Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.]

HS-ESS1-d. Analyze data on the variability of mass and energy outputs from the sun to justify the valid and reliable scientific claim that short-term changes in the sun affect human technologies and societies.* [Clarification Statement: Data span a range of time scales including sudden solar flares and coronal mass ejections referred to as space weather, 11-year "sunspot cycles," and non-cyclic variations over centuries.] [Assessment Boundary: The solar physics of why these variations occur (solar flares, coronal mass ejections, sunspot cycles, and longer-term variations in solar output) is not assessed.]

HS-ESS1-e. Use mathematical and computational representations of natural and human-made solar system objects in order to describe their motions and predict their trajectories and/or collisions.* [Clarification Statement: The same Newtonian gravitational laws governing orbital motions 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.]

HS-ESS1-f. Construct explanations from data for the formation of the solar system based on space exploration and astronomical evidence of the composition, structure, and motions of solar system bodies.* [Clarification Statement: Engineering accomplishments in space have helped to raise and answer questions about our solar system. Evidence that our solar system formed from a disk of dust and gas drawn together by gravity includes: (1) the similarity between the direction of rotation of the sun, the orbits of the planets, and the directions of the rotations of planets, (2) patterns of impact craters on planetary surfaces, (3) the composition of meteorites, some of which show the make-up of the early solar system, and (4) the distribution of matter in the solar system with metal/rock-rich objects close to the sun and ice-rich objects far from the sun.] [Assessment Boundary: Details of the sequence of the evolution of the solar system, such as the timing of the late-heavy bombardment period, are not assessed.]

HS-ESS1-g. Analyze actual or simulated isotope ratios within Earth materials to make valid and reliable scientific claims about the planet's age, the ages of Earth events and rocks, and the overall time scale of Earth's history.* [Clarification Statement: Actual or simulated isotope data can be used (from materials that include igneous rocks, fossils, sedimentary layers, or ice cores) to understand how events in Earth's 4.6-billion-year history have absolute ages that can be quantified.] [Assessment Boundary: Radiometric dating techniques using complex methods such as multiple isotope ratios are not assessed.]

HS-ESS1-h. Construct explanations, using the theory of plate tectonics, for patterns in the general trends of the ages of both continental and oceanic crust. [Clarification Statement: For oceanic crust, trends of crustal ages entail the youngest seafloor rocks located at mid-ocean ridges and the oldest ocean rocks often (but not always) located near continental boundaries, with age bands of rocks parallel across mid-ocean ridges dependent upon spreading rates. For continental crust, continents such as North America contain ancient cores (cratons) with regions of increasingly younger rocks trending toward the edges as a result of subsequent plate interactions.]

HS-ESS1-i. Consider the incomplete nature of Earth's rock record when analyzing and interpreting the events of Earth's distant past. [Clarification Statement: Dynamic Earth processes have destroyed most of Earth's very early rock record (e.g., erosion of land surfaces, subduction of ocean lithosphere), such that very few rocks from Earth's first billions of years remain.] [Assessment Boundary: Specific events are not assessed.]

HS-ESS1-j. Construct and revise explanations about Earth's early history based on data from ancient Earth materials, asteroids, meteorites, and other planetary surfaces. [Clarification Statement: Lunar rocks, asteroids, and meteorites have remained relatively unchanged, and they serve as proxies for conditions during Earth's earliest time periods, which likely involved high levels of volcanic activity and surface impacts, including the formation of the Moon and the Late Heavy Bombardment period.] [Assessment Boundary: Memorization of absolute time periods of Earth's past is not required.]

The performance expectations above were developed using the following elements from the NRC document *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 explain relationships between systems and their components in the natural and designed world.

- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-ESS1-a)

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.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS1-e), (HS-ESS1-g)
- Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- The sun is one of more than 200 billion stars in the Milky Way galaxy, and the Milky Way is just one of hundreds of billions of galaxies in the universe. (HS-ESS1-a)
- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1-b)
- 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. (NRC Framework, p. 173) (HS-ESS1-b)
- 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. The star called the sun is

Crosscutting Concepts

Patterns

- Empirical evidence is needed to identify patterns. (HS-ESS1-h)

Cause and Effect

- Changes in systems may have various causes that may not have equal effects. (HS-ESS1-d)

Scale, Proportion, and Quantity

- Patterns observable at one scale may not be observable or exist at other scales. (HS-ESS1-a), (HS-ESS1-i)
- 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). (HS-ESS1-g)

Systems and System Models

- Models (e.g., physical, mathematical and computer models) can be used to

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and observations. (HS-ESS1-e)
- Consider limitations (e.g., measurement error, sample selection) when analyzing and interpreting data. (HS-ESS1-g),(HS-ESS1-i)

Using Mathematical 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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. (HS-ESS1-f),(HS-ESS1-g)
- Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. (HS-ESS1-f)

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.
- Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. (HS-ESS1-h)
- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-ESS1-j)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-ESS1-b), (HS-ESS1-h),(HS-ESS1-j)
- Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. (HS-ESS1-b)

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on 6–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.
- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (HS-ESS1-c),(HS-ESS1-d)
- Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in scientific and technical texts or media reports, verifying the data when possible. (HS-ESS1-c),(HS-ESS1-d)

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. (HS-ESS1-h)
  Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. (HS-ESS1-h)

changing and will burn out over a lifespan of approximately 10 billion years. (NRC Framework, p. 173) (HS-ESS1-b),(HS-ESS1-c),(HS-ESS1-d),(HS-ESS1-e)

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. (HS-ESS1-e)
- The solar system appears to have formed from a disk of dust and gas, drawn together by gravity. (NRC Framework, p. 175) (HS-ESS1-f)

ESS1.C: The History of Planet Earth
- Radioactive-decay lifetimes and isotopic content in rocks provide a way of dating rock formations and thereby fixing the scale of geologic time. (HS-ESS1-g)
- 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. (HS-ESS1-h)
- 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. (HS-ESS1-i),(HS-ESS1-j)

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 to HS-ESS1-h)*

ESS2.E: Biogeology
- The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it. *(secondary to HS-ESS2-l)*

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 from the isotope ratios present. *(secondary to HS-ESS1-g)*

PS3.B: Conservation of Energy and Energy Transfer
- Any object or system that can degrade with no added energy is unstable. Eventually it will do so, but if the energy releases throughout the transition are small, the process duration can be very long (e.g., long-lived radioactive isotopes). *(secondary to HS-ESS1-g)*

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 to HS-ESS1-c)*

PS4.B: Electromagnetic Radiation
- Atoms of each element emit and absorb characteristic frequencies of light, and nuclear transitions have distinctive gamma ray wavelengths. These characteristics allow identification of the presence of an element, even in microscopic quantities. *(secondary to HS-ESS1-b)*

ETS1.A: Defining and Delimiting an Engineering Problem
- Design criteria and constraints, which typically reflect the needs of the end user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability and limits on its size and cost. *(secondary to HS-ESS1-f)*

ETS1.B: Developing Possible Solutions
- Both physical models and computer models can be used in various ways to aid in the engineering design process. Physical models or prototypes are helpful in testing product ideas or the properties of different materials. *(secondary to HS-ESS1-e),(secondary to HS-ESS1-f)*
- Computer models are useful for a variety of purposes, such as in representing a design in 3-D through CAD software; in troubleshooting to identify or describe a design problem; in 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 to HS-ESS1-*

simulate systems and interactions within and between systems at different scales. (HS-ESS1-e)

Stability and Change
- Change and rates of change can be quantified and modeled over very short or very long periods of time. (HS-ESS1-j)

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. (HS-ESS1-b)
- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-ESS1-c)

Connection 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. (HS-ESS1-b),(HS-ESS1-e),(HS-ESS1-f), (HS-ESS1-g)

Connection to Nature of Science

Science is a Human Endeavor
- Scientific knowledge is a result of human endeavors, imagination, and creativity. (HS-ESS1-f)
- Individuals and teams from many nations and cultures have contributed to science and engineering advances. (HS-ESS1-f)
- Technological advances have influenced the progress of science and science has influenced advances in technology. (HS-ESS1-b),(HS-ESS1-f)

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. (HS-ESS1-g)
- Science assumes the universe is a vast single system in which basic laws are consistent. (HS-ESS1-g)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

	e),(secondary to HS-ESS1-f)	

Connections to other DCIs in this grade-level: will be added in future version.
Articulation to DCIs across grade-levels: will be added in future version.
Common Core State Standards Connections: [Note: these connections will be made available soon.] *ELA/Literacy –* *Mathematics –*

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-ESS2 Earth's Systems

HS-ESS2 Earth's Systems

Students who demonstrate understanding can:

HS-ESS2-a. Use Earth system models to support explanations of how Earth's internal and surface processes operate concurrently at different spatial and temporal scales to form landscapes and sea floor features. [Clarification Statement: The appearance of the land (e.g., mountains, basins, valleys, plateaus, platforms) and sea floor features (e.g., trenches, ridges, fracture zones, seamounts, abyssal plains, continental slopes) are a result of both constructive forces (e.g., volcanism, tectonic uplift, orogeny) and destructive mechanisms (e.g., stream processes, coastal wave action, mass wasting, weathering, erosion, shoreline progressions).] [Assessment Boundary: Details of the formation of major geographic features of Earth's surface are not assessed.]

HS-ESS2-b. Construct an evidence-based argument about how a natural or human-caused change to one part of an Earth system can create feedback that causes changes in that system or other systems.* [Clarification Statement: Modern civilization depends on major technological systems and these are critical aspects of decisions about technology usage. Local real world examples could include how removing ground vegetation causes an increase in water runoff and soil erosion; building reservoirs increases groundwater recharge; installing a coastal rock jetty changes currents and resulting beach erosion patterns; removing wetlands causes a decrease in local humidity that further reduces the wetland extent; diminishing glacial ice reduces the amount of sunlight reflected from Earth's surface, which increases surface temperatures and further reduces the amount of ice.]

HS-ESS2-c. Apply scientific reasoning to show how empirical evidence from Earth observations and laboratory experiments have been used to develop the current model of Earth's interior.* [Clarification Statement: Examples of evidence may include results from drill cores (rock composition with depth), gravity (density with depth), Earth's magnetic field, seismic waves (elastic properties with depth), and laboratory experiments on Earth materials (composition, density, and elastic properties with pressure).]

HS-ESS2-d. Use a model of Earth's interior including the mechanisms of thermal convection to support the explanation for the cycling of matter within the Earth. [Clarification Statement: Explanations of cycling of matter should focus on the plate tectonic process, with ocean lithosphere sinking down into the mantle at subduction zones and new rock coming to the surface at ocean spreading centers, but can also include non-plate tectonic processes such as hot spot mantle plumes. Models of the mechanisms should include the major forces associated with the surface expression of convection, whose impacts on Earth's surface include land formation, volcanic activity and uplift, orogeny, basin formation, crustal deformation, and replenishment of Earth's atmosphere and ocean.]

HS-ESS2-e. Construct a scientific explanation based on evidence from the geoscience record that changes to Earth and Solar System processes can affect global and regional climates over a wide range of time scales.* [Clarification Statement: Examples of evidence include ice core data, tree-ring data, the fossil and sedimentary record, which show the history of surface temperatures, the ice, volume, and sea level fluctuations. Examples of the changes to processes include variations in the sun's energy output, Earth's orbit and axis orientation, tectonic events, ocean circulation, volcanic activity, glacial activity, biosphere interactions, and human activities.] [Assessment Boundary: Use evidence from the geoscience record only.]

HS-ESS2-f. Read scientific literature critically to evaluate and communicate the causes and effects of climate change over 10s-100s of years, 10s-100s of thousands of years, and 10s-100s of millions of years. [Clarification Statement: Examples of causes are changes in solar output, ocean circulation, and volcanic and human activity (which change atmospheric composition and other systems over 10s-100s of years); changes to Earth's orbit and the orientation of its axis (over 10s-100s of thousands of years); or long-term changes in atmospheric composition (over 10s-100s of millions of years).]

HS-ESS2-g. Develop, revise, and use models of atmospheric circulation to support explanations of how air masses redistribute energy from the sun. [Clarification Statement: The absorption of solar radiation by the ocean and the subsequent heat transfer due to evaporation largely drive atmospheric circulation through the generation of high- and low-pressure systems (e.g., the condensation of water vapor over warm ocean surfaces provides the power for hurricanes and typhoons). Models of atmospheric circulation should include the Coriolis effect and the locations of the continents.]

HS-ESS2-h. Design and conduct investigations to model the conditions at which clouds form and precipitation occurs, taking into account the factors of humidity, temperature, and pressure. [Clarification Statement: Weather conditions include the temperature and pressure changes that occur during orographic lifting, frontal wedging, air mass convergence, and localized convective lifting; investigations include cooling of water by adiabatic, conductive, radiational, or evaporative processes.]

HS-ESS2-i. Analyze the physical and chemical properties of water to make valid scientific claims about the impact of water on the flow of energy and the cycling of matter within and among Earth systems.* [Clarification Statement: Claims about the flow of energy should include the role of water in the convective transfer of energy through oceanic and atmospheric circulation; the cycling of matter refers to both the flow of water through the various hydrologic cycles, which connect the ocean with other water reservoirs, and the many roles that water plays in moving mineral and rock materials through Earth's systems.]

HS-ESS2-j. Use models of the flow of energy between the sun and Earth's atmosphere, ocean, and land to support explanations of how Earth's radiative energy balance is affected by the absorption and retention of heat in Earth's atmosphere. [Clarification Statement: Students examine the radiative properties of different atmospheric gases and surface regions, (e.g., ocean, ice, land), and will evaluate variations in the reflection, absorption, storage, and redistribution of solar radiation among the atmosphere, ocean, and land systems.]

HS-ESS2-k. Develop, revise, and use quantitative models to support the explanation of the amount of carbon that cycles among the hydrosphere, atmosphere, geosphere, and biosphere. [Clarification Statement: Biogeochemical cycles involve the cycling of carbon and other elements through the ocean, atmosphere, soil, and biosphere, providing the foundation for living organisms.]

HS-ESS2-l. Apply scientific reasoning, theory, and models to support the claim that dynamic causes, effects, and feedbacks among Earth's systems result in continual coevolution of Earth and the life that exists on it. [Clarification Statement: Students investigate examples of feedbacks among Earth's different systems (e.g., the atmosphere affects the conditions for life, which in turn affects the composition of the atmosphere; or, soil supports life, which in turn increases the rate of development of soil).] [Assessment Boundary: The complete ways that the biosphere interacts with Earth's other systems are not assessed; only examples are necessary.]

The performance expectations above were developed using the following elements from the NRC document *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 explain relationships between systems and their components in the natural and designed world.

- Use multiple types of models to represent and support explanations of phenomena, and move flexibly between

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. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts. (HS-ESS2-a),(HS-ESS2-b)
- Evidence from deep probes and seismic waves, reconstructions of

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS2-h)

Scale, Proportion, and Quantity

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model types based on merits and limitations. (HS-ESS2-j)

- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-ESS2-a),(HS-ESS2-d), (HS-ESS2-g),(HS-ESS2-k)
- Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. (HS-ESS2-d),(HS-ESS2-a)

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.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS2-i)

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 build, test, and revise conceptual, mathematical, physical, and empirical models.

- Design and conduct investigations individually and collaboratively and test designs as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. (HS-ESS2-h)

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.

- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-ESS2-c),(HS-ESS2-l)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-ESS2-b), (HS-ESS2-e)
- Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. (HS-ESS2-e)

Engaging in Argument from Evidence

Engaging in argument from evidence in 9–12 builds from 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. 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. (HS-ESS2-e)

Obtaining, Evaluating, and Communicating Information

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

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (HS-ESS2-f)

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence. (HS-ESS2-c),(HS-ESS2-e)
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems.

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. (HS-ESS2-c)

- 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. (HS-ESS2-d)
- 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. (HS-ESS2-e),(HS-ESS2-f)
- Weather is driven by interactions of the geosphere, hydrosphere, and atmosphere. (NRC Framework, p. 180) (HS-ESS2-g),(HS-ESS2-h)

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. (HS-ESS2-d)
- 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) (HS-ESS2-d)
- 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) (HS-ESS2-a)

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. (HS-ESS2-i)

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. Climate change can occur when certain parts of Earth's systems are altered. (HS-ESS2-j)
- Geologic evidence indicates that past climate changes were either sudden changes caused by alterations in the atmosphere; longer-term changes (e.g., ice ages) due to variations in solar output, Earth's orbit, or the orientation of its axis; or even more gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen. The time scales of these changes varied from a few to millions of years. Human activity causes changes in the atmosphere that include increased carbon dioxide concentrations and thus affect climate (link to ESS3.D). (HS-ESS2-k),(HS-ESS2-e),(HS-ESS2-f)

ESS2.E: Biogeology

- The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it. (HS-ESS2-l)

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. (HS-ESS2-b)

ETS1.C: Optimizing the Design Solution

- The aim of engineering design is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. (HS-ESS2-c)
- When evaluating solutions, all relevant considerations, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts, should be included. (HS-ESS2-i),(HS-ESS2-b)

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-ESS2-a)
- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-ESS2-f)

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. (HS-ESS2-j)

Energy and Matter

- The total amount of energy and matter in closed systems is conserved. (HS-ESS2-k)
- Energy drives the cycling of matter within and between systems. (HS-ESS2-d), (HS-ESS2-g),(HS-ESS2-i)

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. (HS-ESS2-c)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS2-b)
- Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS2-e),(HS-ESS2-l)

Connections to Engineering, Technology, and Applications of Science

Interaction 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. (HS-ESS2-c)

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. (HS-ESS2-b), (HS-ESS2-e)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

(HS-ESS2-c) ▪ Science includes the process of coordinating patterns of evidence with current theory. (HS-ESS2-c) ▪ Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS2-f)		

Connections to other DCIs in this grade-level: will be added in future version.
Articulation to DCIs across grade-levels: will be added in future version.
Common Core State Standards Connections: [Note: these connections will be made available soon.] *ELA/Literacy –* *Mathematics –*

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

HS-ESS3 Earth and Human Activity

HS-ESS3 Earth and Human Activity

Students who demonstrate understanding can:

HS-ESS3-a. Construct explanations based on evidence for how the development of human societies has been influenced by natural resource availability.* [Clarification Statement: Examples can be drawn from the many civilizations across history whose rise, transformation, or fall has been facilitated by the presence or lack of these resources. Examples of key resources include the location of water (rivers, groundwater), coasts, regions of fertile soils such as deltas, and high concentrations of minerals, ores, coal, and hydrocarbons.]

HS-ESS3-b. Analyze and revise solutions for developing, managing, and utilizing resources that would increase economic, social, environmental, and/or cost: benefit ratios.* [Clarification Statement: Examples include best practices for agricultural soil use, retrieving water from aquifers or desalination, mining for coal and minerals, pumping for oil, hydro-fracturing to retrieve natural gas, recovering off-shore methane gas hydrates, extracting petroleum from tar sands and oil shales, and the conservation, recycling, and reuse of resources. 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.]

HS-ESS3-c. Ask questions to construct and revise explanations of the impact that natural hazards and other geoscience events have had on the course of human history at regional and global scales. [Clarification Statement: Natural hazard events (e.g., earthquakes, volcanoes, floods) and changes in regional or global climates can affect populations, drive mass migrations, and influence the rise and fall of civilizations.]

HS-ESS3-d. Construct and evaluate scientific claims based on valid and reliable evidence that human activities can contribute to the frequency and intensity of some natural hazards. [Clarification Statement: Human activities (e.g., building dams and levees, urbanizing ground cover, removing wetlands, managing fires, removing vegetation) can increase the frequency and/or severity of certain natural hazards (floods, droughts, forest fires, landslides, coastal erosion).]

HS-ESS3-e. Identify mathematical relationships between natural resource production and consumption rates in order to assess the global sustainability of humans and the biodiversity that supports them.* [Clarification Statement: Use equations for linear relationships.] [Assessment Boundary: The construction of equations is not expected for non-linear relationships, which can be studied graphically (e.g., with "Hubbert" curves) or computationally.]

HS-ESS3-f. Analyze data regarding the effects of human activities on natural systems to make valid scientific claims for how engineering solutions are designed and implemented to help limit environmental impacts.* [Clarification Statement: Examples of environmental impacts that have been mitigated include water and air pollution, landfill leakage, acid rain, the growth of the Antarctic ozone hole, and agricultural soil erosion. Claims can be qualitative or quantitative, in cases where quantitative data are available. New technologies enhance the ability to construct scientific claims based on evidence.]

HS-ESS3-g. Use geoscience data and the results from global climate models to make evidence-based forecasts of climate change. [Clarification Statement: Geoscience data can include charts, tables, or maps of topography, biomass, precipitation, temperature, or weather-related events.]

HS-ESS3-h. Apply scientific reasoning, theory, and models to construct explanations for how humans may predict and modify their impacts on future global climate systems.* [Clarification Statement: Examples can range from large-scale geoengineering design solutions to alter global temperatures (e.g., seeding the atmosphere with aerosols or seeding the ocean with iron to enhance microbe growth) to more local efforts (e.g., reducing resource consumption and energy use, recycling and reusing, and using renewable energy sources) done by both societies and individuals. 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.]

HS-ESS3-i. Use models of Earth system interactions to support explanations of the relationships among the hydrosphere, atmosphere, cryosphere, geosphere, and biosphere systems and how they are being modified in response to human activities.* [Clarification Statement: Examples include: changes to groundwater levels and recharge rates; ocean acidity and coral health; atmospheric composition and rain acidity and lake life health; deforestation and erosion rates and local biosphere health; agricultural fertilization; stream composition and "dead" zones in offshore regions.] [Assessment Boundary: Students will not be required to model all the ways systems are being modified by human activities, but need to demonstrate how systems can react in response to feedbacks from human activities.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

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 solutions using models and simulations.

- Ask questions that arise from careful observation of phenomena, models, theory, or unexpected results. (HS-ESS3-c)

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world.

- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-ESS3-i)
- Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. (HS-ESS3-g)

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.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS3-f)
- Evaluate the impact of new data on a working explanation of a

Disciplinary Core Ideas

ESS2.D: Weather and Climate

- Global climate models incorporate scientists' best knowledge of physical and chemical processes and of the interactions of relevant systems. They are tested by their ability to fit past climate variations. *(secondary to HS-ESS3-g)*
- 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. Hence the outcomes depend on human behaviors (link to ESS3.D) as well as on natural factors that involve complex feedbacks among Earth's systems (link to ESS3.A). *(secondary to HS-ESS3-h)*

ESS3.A: Natural Resources

- Resource availability has guided the development of human society. (HS-ESS3-a)
- 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. (HS-ESS3-b)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS3-c)
- In complex natural and designed systems, not all of the outcomes can be predicted—but outcomes might be predicted in systems when smaller scale mechanisms are known. (HS-ESS3-g)

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. (HS-ESS3-i)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS3-f)
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-f)
- Feedback (negative or positive) can

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proposed process or system. (HS-ESS3-f)

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.

- Apply techniques of algebra and functions to represent and solve scientific and engineering problems. (HS-ESS3-e)
- Create a simple computational model or simulation of a designed device, process, or system. (HS-ESS3-e)

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.

- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-ESS3-h)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-ESS3-a),(HS-ESS3-c),(HS-ESS3-d)
- Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. (HS-ESS3-a),(HS-ESS3-d)
- Apply scientific knowledge and evidence to explain phenomena and solve design problems, taking into account possible unanticipated effects. (HS-ESS3-h)

Engaging in Argument from Evidence

Engaging in argument from evidence in 9–12 builds from 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. Arguments may also come from current scientific or historical episodes in science.

- Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. (HS-ESS3-b)
- Evaluate a claim for a design solution to a real-world problem based on scientific knowledge, empirical evidence, and logical arguments regarding all relevant factors (e.g. economic, societal, environmental, and ethical considerations). (HS-ESS3-b)

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. (HS-ESS3-g)
- New technologies advance scientific knowledge. (HS-ESS3-g)
- 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.

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence. (HS-ESS3-g)
- Science includes the process of coordinating patterns of evidence with current theory. (HS-ESS3-h)
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS3-h),(HS-ESS3-g)

ESS3.B: Natural Hazards

- Natural hazards and other geologic events have shaped the course of human history by destroying buildings and cities, eroding land, changing the courses of rivers, and reducing the amount of arable land. These events have significantly altered the sizes of human populations and have driven human migrations. (HS-ESS3-c)
- Natural hazards can be local, regional, or global in origin, and their risks increase as populations grow. Human activities can contribute to the frequency and intensity of some natural hazards. (HS-ESS3-d)

ESS3.C: Human Impacts on Earth Systems

- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. (HS-ESS3-e)
- Scientists and engineers can make major contributions [to responsible management]–for example, by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. When the source of an environmental problem is understood and international agreement can be reached, human activities can be regulated to mitigate global impacts (e.g., acid rain and the ozone hole over Antarctica). (HS-ESS3-f)

ESS3.D: Global Climate Change

- Global climate models are often used to understand the process of climate change because these changes are complex and can occur slowly over Earth's history. (HS-ESS3-g)
- 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. (HS-ESS3-g),(HS-ESS3-h)
- 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, as well as changes in human activities. (HS-ESS3-i)
- Thus science and engineering will be essential both to understanding the possible impacts of global climate change and to informing decisions about how to slow its rate and consequences–for humanity as well as for the rest of the planet. (HS-ESS3-g),(HS-ESS3-h)

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. (HS-ESS3-f), (HS-ESS3-h)
- 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 may also have manifestations in local communities. But, whatever the scale, the first things that engineers do is define the problem and specify the criteria and constraints for potential solutions. (HS-ESS3-b),(HS-ESS3-h),(HS-ESS3-i)

ETS1.B: Developing Possible Solutions

- To design something complicated one may need to break the problem into parts and attend to each part separately but must then bring the parts together to test the overall plan. (HS-ESS3-h)
- 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. (HS-ESS3-b),(HS-ESS3-f), (HS-ESS3-h)
- Testing should lead to improvements in the design through an iterative procedure. (HS-ESS3-f)

ETS1.C: Optimizing the Design Solution

- The aim of engineering design is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. (HS-ESS3-b),(HS-ESS3-f)
- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety,

stabilize or destabilize a system. (HS-ESS3-f)

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, such as agriculture, health, water, energy, transportation, manufacturing, construction, and communications. (HS-ESS3-a),(HS-ESS3-e)
- Engineers continuously modify these systems to increase benefits while decreasing costs and risks. (HS-ESS3-b),(HS-ESS3-f)
- New technologies can have deep impacts on society and the environment, including some that were not anticipated. (HS-ESS3-d),(HS-ESS3-h)
- Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS3-h)

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. (HS-ESS3-b)
- 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. (HS-ESS3-b)
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. [HS-ESS3-b]

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	reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ESS3-e),(HS-ESS3-f)	

Connections to other DCIs in this grade-level: will be added in future version.
Articulation to DCIs across grade-levels: will be added in future version.
Common Core State Standards Connections: [Note: these connections will be made available soon.] *ELA/Literacy –* *Mathematics –*

HS.ETS1 Engineering, Technology, and Applications of Science

HS.ETS1 Engineering, Technology, and Applications of Science

[Note: All of these performance expectations can also be found in other standards.]

Students who demonstrate understanding can:

HS-PS2-c. **Design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*** [Clarification Statement: Evaluation and refinement could consist of determining the success of the device at protecting the object from harm, and modifying the design to improve it. Examples include an egg drop investigation and design of a football helmet.] [Assessment Boundary: Evaluations are qualitative only.]

HS-PS3-b. **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** [Clarification Statement: Examples of devices can include roller coasters, Rube Goldberg devices, wind turbines, solar cells, and generators. Examples of constraints can include use of renewable energy forms and efficiency. Qualitative evaluations could include a wide range of energy conversions (e.g., from electrical to kinetic and from electromagnetic to thermal) that go beyond the expectation for quantitative evaluations.] [Assessment Boundary: Quantitative evaluation is limited to potential and kinetic conversions. Devices are limited to those constructed with materials provided to students.]

HS-PS4-c. **Ask questions that challenge the relative advantages of analog vs. digital transmission of information in order to determine if the questions are testable and relevant.*** [Clarification Statement: An example of different representations could include digital radio signals vs. FM signals. Advantages could include that digital information can be stored reliably in computer memory, but that analog can be easier to understand.] [Assessment Boundary: Questions are provided to students.]

HS-PS4-d. **Develop a model to demonstrate that a structure can be modified to change its resonant frequency in a way that improves the structure's performance.*** [Clarification Statement: Examples of models can include pictures, diagrams, or physical models. Potentially damaging resonance can involve real world examples of bridges, buildings, fences, or street signs; other examples can include musical instruments.] [Assessment Boundary: Students will be provided a structure to modify. Students are not required to solve a problem – only to apply the concept of resonant frequency to a given problem.]

HS-PS4-f. **Develop and defend a claim about the effectiveness of a particular wavelength of an electromagnetic wave for use in a certain application.*** [Clarification Statement: Examples can include infrared light for night vision, x-rays being used for bone imaging, or radio waves being used for long distance communication.] [Assessment Boundary: Only qualitative descriptors in the explanation are assessed.]

HS-LS1-f. **Construct an explanation using evidence for how cell differentiation is the result of activation or inactivation of specific genes and small differences in the immediate environment of the cells; relate these concepts to potential solutions in biomedical engineering and research.*** [Clarification Statement: Emphasis is limited to the concept that a single cell develops into a variety of differentiated cells and thus, a complex organism.] [Assessment Boundary: The assessment should provide evidence of students' abilities to construct an explanation about the conditions necessary for cell differentiation as well as the applications for biomedical research (e.g., cancer treatment, replacing damaged organs, engineering tissues to test drugs).]

HS-ESS1-f. **Construct explanations from data for the formation of the solar system based on space exploration and astronomical evidence of the composition, structure, and motions of solar system bodies.*** [Clarification Statement: Engineering accomplishments in space have helped to raise and answer questions about our solar system. Evidence that our solar system formed from a disk of dust and gas drawn together by gravity includes: (1) the similarity between the direction of rotation of the sun, the orbits of the planets, and the directions of the rotations of planets, (2) patterns of impact craters on planetary surfaces, (3) the composition of meteorites, some of which show the make-up of the early solar system, and (4) the distribution of matter in the solar system with metal/rock-rich objects close to the sun and ice-rich objects far from the sun.] [Assessment Boundary: Details of the sequence of the evolution of the solar system, such as the timing of the late-heavy bombardment period, are not assessed.]

HS-ESS3-f. **Analyze data regarding the effects of human activities on natural systems to make valid scientific claims for how engineering solutions are designed and implemented to help limit environmental impacts.*** [Clarification Statement: Examples of environmental impacts that have been mitigated include water and air pollution, landfill leakage, acid rain, the growth of the Antarctic ozone hole, and agricultural soil erosion. Claims can be qualitative or quantitative, in cases where quantitative data are available. New technologies enhance the ability to construct scientific claims based on evidence.]

HS-ESS3-h. **Apply scientific reasoning, theory, and models to construct explanations for how humans may predict and modify their impacts on future global climate systems.*** [Clarification Statement: Examples can range from large-scale geoengineering design solutions to alter global temperatures (e.g., seeding the atmosphere with aerosols or seeding the ocean with iron to enhance microbe growth) to more local efforts (e.g., reducing resource consumption and energy use, recycling and reusing, and using renewable energy sources) done by both societies and individuals. 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.]

HS-PS3-f. **Produce written and illustrated texts or oral presentations about how scientific discoveries about the conversion of energy from one form to another have affected human civilization, including the further development of science and technology.***

HS-ESS3-b. **Analyze and revise solutions for developing, managing, and utilizing resources that would increase economic, social, environmental, and/or cost: benefit ratios.*** [Clarification Statement: Examples include best practices for agricultural soil use, retrieving water from aquifers or desalination, mining for coal and minerals, pumping for oil, hydro-fracturing to retrieve natural gas, recovering off-shore methane gas hydrates, extracting petroleum from tar sands and oil shales, and the conservation, recycling, and reuse of resources. 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.]

HS-ESS3-i. **Use models of Earth system interactions to support explanations of the relationships among the hydrosphere, atmosphere, cryosphere, geosphere, and biosphere systems and how they are being modified in response to human activities.*** [Clarification Statement: Examples include: changes to groundwater levels and recharge rates; ocean acidity and coral health; atmospheric composition and rain acidity and lake life health; deforestation and erosion rates and local biosphere health; agricultural fertilization; stream composition and "dead" zones in offshore regions.] [Assessment Boundary: Students will not be required to model all the ways systems are being modified by human activities, but need to demonstrate how systems can react in response to feedbacks from human activities.]

HS-LS2-j. **Design, evaluate, and refine a solution for reducing negative impact of human activities on the environment and ways to sustain biodiversity and maintain the planet's natural capital.*** [Clarification Statement: Emphasis is on human activities (e.g., pollution, climate change, making snow at ski areas, controlled burns, dams) that change the way ecosystems operate in terms of potential impacts on biodiversity, as well as populations. The solutions should be based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.] [Assessment Boundary: The assessment should provide evidence of students' abilities to provide reasonable explanations of what might happen as the basis for proposed engineering solutions.]

HS-ESS2-b. **Construct an evidence-based argument about how a natural or human-caused change to one part of an Earth system can create feedback that causes changes in that system or other systems.*** [Clarification Statement: Modern

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civilization depends on major technological systems and these are critical aspects of decisions about technology usage. Local real world examples could include how removing ground vegetation causes an increase in water runoff and soil erosion; building reservoirs increases groundwater recharge; installing a coastal rock jetty changes currents and resulting beach erosion patterns; removing wetlands causes a decrease in local humidity that further reduces the wetland extent; diminishing glacial ice reduces the amount of sunlight reflected from Earth's surface, which increases surface temperatures and further reduces the amount of ice.]

HS-PS2-a. **Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on macroscopic objects, their mass, and acceleration.*** [Assessment Boundary: Restricted to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

HS-ESS1-e. **Use mathematical and computational representations of natural and human-made solar system objects in order to describe their motions and predict their trajectories and/or collisions.*** [Clarification Statement: The same Newtonian gravitational laws governing orbital motions 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.]

HS-LS2-l. **Design and conduct an investigation to test design solutions for increasing or maintaining the biodiversity of an ecosystem.*** [Clarification Statement: Emphasis is on designing solutions for a proposed problem. The investigation may be a simulation or a performance task in the classroom.] [Assessment Boundary: The assessment should provide evidence of the students' abilities to consider environmental, personal, and social impacts as well as designing a solution and developing methods for measuring the effects of the proposed changes on the system in terms of: (1) increasing biodiversity, and (2) maintaining biodiversity.]

HS-ESS2-c. **Apply scientific reasoning to show how empirical evidence from Earth observations and laboratory experiments have been used to develop the current model of Earth's interior.*** [Clarification Statement: Examples of evidence may include results from drill cores (rock composition with depth), gravity (density with depth), Earth's magnetic field, seismic waves (elastic properties with depth), and laboratory experiments on Earth materials (composition, density, and elastic properties with pressure).]

HS-LS3-c. **Evaluate the merits of competing ethical arguments for the research, development, and growth of industries based on the development of technologies that modify the genetic make-up of an organism.*** [Clarification Statement: Emphasis is on comparing competing arguments based on ethical as well as scientific principles.] [Assessment Boundary: The assessment should provide evidence of students' abilities to evaluate the merits of genetic modification technologies (e.g., cloning, gene therapy, genetic engineering, selective breeding) in terms of scientific principles as well as ethical considerations and social implications. The assessment should provide evidence of students' abilities to evaluate the merits of genetic modification technologies (e.g., cloning, gene therapy, genetic engineering, selective breeding) in terms of scientific principles as well as cost, safety, and reliability as well as social and environmental impacts.]

HS-ESS2-i. **Analyze the physical and chemical properties of water to make valid scientific claims about the impact of water on the flow of energy and the cycling of matter within and among Earth systems.*** [Clarification Statement: Claims about the flow of energy should include the role of water in the convective transfer of energy through oceanic and atmospheric circulation; the cycling of matter refers to both the flow of water through the various hydrologic cycles, which connect the ocean with other water reservoirs, and the many roles that water plays in moving mineral and rock materials through Earth's systems.]

HS-ESS3-e. **Identify mathematical relationships between natural resource production and consumption rates in order to assess the global sustainability of humans and the biodiversity that supports them.*** [Clarification Statement: Use equations for linear relationships.] [Assessment Boundary: The construction of equations is not expected for non-linear relationships, which can be studied graphically (e.g., with "Hubbert" curves) or computationally.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

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 solutions using models and simulations.

- Ask and evaluate questions that challenge the premise of an argument, the interpretation of a data set, or the suitability of a design. (HS-PS4-c)

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world.

- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-PS4-d),(HS-ESS3-i)

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 build, test, and revise conceptual, mathematical, physical, and empirical models.

- Design an investigation individually and collaboratively and test designs as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. (HS-LS2-l)
- Design and conduct an investigation individually and collaboratively, 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. (HS-LS2-l)
- Design and conduct investigations and test design solutions in a

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting an Engineering Problem

- Design criteria and constraints, which typically reflect the needs of the end user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability and limits on its size and cost. (HS-PS2-c),(HS-PS3-b),(HS-PS4-c),(HS-PS4-d),(HS-PS4-f),(HS-LS1-f),(HS-ESS1-f)
- Criteria and constraints 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. (HS-PS2-c),(HS-PS3-b),(HS-PS4-c),(HS-PS4-d),(HS-PS4-f),(HS-ESS3-f),(HS-ESS3-h)
- 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 may also have manifestations in local communities. But, whatever the scale, the first things that engineers do is define the problem and specify the criteria and constraints for potential solutions. (HS-PS3-b),(HS-PS3-f),(HS-ESS3-b),(HS-ESS3-h),(HS-ESS3-i)

ETS1.B: Developing Possible Solutions

- To design something complicated one may need to break the problem into parts and attend to each part separately but must then bring the parts together to test the overall plan. (HS-PS4-f),(HS-ESS3-h)
- 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. (HS-PS2-c),(HS-PS3-b),(HS-LS2-j),(HS-ESS2-b),(HS-ESS3-f),(HS-ESS3-h)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-a),(HS-LS1-f),(HS-ESS2-h)
- Systems can be designed to cause a desired effect. (HS-PS2-c)
- Changes in systems may have various causes that may not have equal effects. (HS-PS2-a)

Systems and System Models

- Models (e.g., physical, mathematical and computer models) can be used to simulate systems and interactions within and between systems at different scales. (HS-ESS1-e)
- 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. (HS-ESS3-i)

Energy and Matter

- Energy drives the cycling of matter within and between systems. (HS-ESS2-i)

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.

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safe and ethical manner including considerations of environmental, social, and personal impacts. (HS-LS2-l)

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.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS2-a),(HS-ESS2-i),(HS-ESS3-f)
- Evaluate the impact of new data on a working explanation of a proposed process or system. (HS-ESS3-f)

Using Mathematical 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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. (HS-ESS1-e)
- Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. (HS-ESS1-e)
- Apply techniques of algebra and functions to represent and solve scientific and engineering problems. (HS-ESS3-e)
- Create a simple computational model or simulation of a designed device, process, or system. (HS-ESS3-e)

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.

- Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. (HS-LS2-j)
- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-PS3-b),(HS-LS1-f),(HS-LS2-j),(HS-ESS2-c)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-LS1-f),(HS-ESS1-f),(HS-ESS2-b)
- Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. (HS-ESS1-f)
- 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. (HS-PS2-c),(HS-LS1-f),(HS-LS2-j)

Engaging in Argument from Evidence

Engaging in argument from evidence in 9–12 builds from 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. Arguments may also come from current scientific or historical episodes in science.

- Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. (HS-LS3-c),(HS-ESS3-b)
- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-PS4-f)
- Make and defend a claim about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence. (HS-PS4-f)
- Evaluate a claim for a design solution to a real-world problem based on scientific knowledge, empirical evidence, and logical arguments regarding all relevant factors (e.g. economic, societal, environmental, and ethical considerations). (HS-ESS3-b)

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.

- Testing should lead to improvements in the design through an iterative procedure. (HS-PS2-c),(HS-PS3-b),(HS-PS4-d) (HS-ESS3-f)
- Both physical models and computer models can be used in various ways to aid in the engineering design process. Physical models or prototypes are helpful in testing product ideas or the properties of different materials. (HS-PS2-a),(HS-PS4-d),(HS-ESS1-e),(HS-ESS1-f)
- Computer models are useful for a variety of purposes, such as in representing a design in 3-D through CAD software; in troubleshooting to identify or describe a design problem; in 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. (HS-PS2-a),(HS-ESS1-e),(HS-ESS1-f)

ETS1.C: Optimizing the Design Solution

- The aim of engineering design is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. (HS-PS2-a),(HS-PS3-b),(HS-LS2-l),(HS-ESS2-c),(HS-ESS3-b),(HS-ESS3-f)
- When evaluating solutions, all relevant considerations, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts, should be included. (HS-LS3-c),(HS-ESS2-b),(HS-ESS2-i),(HS-ESS3-e),(HS-ESS3-f)
- Testing should lead to design improvements through an iterative process, and computer simulations are one useful way of running such tests. (HS-PS2-a),(HS-PS3-b)
- 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. (HS-PS4-f)
- The comparison of multiple designs can be aided by a trade-off matrix. (HS-PS4-f)

(HS-PS4-d),(HS-PS4-f),(HS-ESS2-c)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS2-b),(HS-ESS3-f)
- Systems can be designed for greater or lesser stability. (HS-LS2-l),(HS-LS2-j)
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-f)
- Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS3-f)

Connection 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. (HS-PS3-f),(HS-LS3-c),(HS-ESS1-e),(HS-ESS1-f),(HS-ESS2-c)

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

- Modern civilization depends on major technological systems, such as agriculture, health, water, energy, transportation, manufacturing, construction, and communications. (HS-PS3-b),(HS-PS3-f),(HS-PS4-c),(HS-PS4-d),(HS-PS4-f),(HS-ESS3-a),(HS-ESS3-e)
- Engineers continuously modify these systems to increase benefits while decreasing costs and risks. (HS-PS4-d),(HS-ESS3-b),(HS-ESS3-f)
- Widespread adoption of technological innovations often depends on market forces or other societal demands, but it may also be subject to evaluation by scientists and engineers and to eventual government regulation. (HS-PS3-b),(HS-PS3-f)
- 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. (HS-PS3-b),(HS-PS3-f),(HS-LS3-c),(HS-ESS2-b),(HS-ESS3-h),(HS-ESS3-d)

Connection to Nature of Science

Science is a Human Endeavor

- Scientific knowledge is a result of human endeavors, imagination, and creativity. (HS-ESS1-f)
- Individuals and teams from many nations and cultures have contributed to science and engineering advances. (HS-ESS1-f)
- Technological advances have influenced the progress of science and science has influenced advances in technology. (HS-LS3-c),(HS-ESS1-f)
- Science and engineering are influenced by society and society is influenced by science and engineering. (HS-LS3-c)

Science Addresses Questions About

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▪ Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. (HS-PS3-f) --- ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** ▪ Science knowledge is based on empirical evidence. (HS-ESS2-c) ▪ Science disciplines share common rules of evidence used to evaluate explanations about natural systems. (HS-ESS2-c) Science includes the process of coordinating patterns of evidence with current theory. (HS-ESS2-c) **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ Theories and laws provide explanations in science, but theories do not with time become laws or facts. (HS-PS2-a) ▪ Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-a)		**the Natural and Material World** ▪ Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. (HS-ESS3-b) ▪ 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. (HS-PS3-f),(HS-ESS3-b),(HS-ESS3-h) ▪ Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. (HS-PS3-f),(HS-ESS3-b)

Connections to other DCIs in this grade-level: will be added in future version.

Articulation to DCIs across grade-levels: will be added in future version.

Common Core State Standards Connections: [Note: these connections will be made available soon.]
ELA/Literacy –
Mathematics –

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