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)

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

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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HS-PS2 Motion and Stability: Forces and Interactions

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)*

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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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