Science Standard-Specific Supports

Physical Science

Revised October 2022

Contents

Science Standard-Specific Supports

Overview

The West Virginia College- and Career-Readiness Standards for Science[1] identify what students should know and be able to do at the end of science instruction. Each standard represents the integration of three "dimensions" of science education: practices of scientists and engineers, core science content, and science connecting concepts. As such, both student learning and assessment around the standards should be "three dimensional." The Science Standard-Specific Supports in this document are intended to show what it looks like for students to fully satisfy the intent of the standard.

The Science Standard-Specific Supports are adapted from the Evidence Statements of the Next Generation Science Standards (NGSS)[2], created when West Virginia was a lead state during the NGSS writing process, and the Framework for K-12 Science Instruction[3], created prior to the development of the NGSS. For more information on the Evidence Statements, please refer to them in their original form.

Purpose

The Science Standard-Specific Supports were designed to articulate how students can use the practices of scientists and engineers to demonstrate their understanding of the core science content through the lens of the science connecting concepts, and thus, demonstrate proficiency on each standard. The Science Standard-Specific Supports do this by clarifying:

- how the three dimensions could be assessed together, rather than in independent units;
- the underlying knowledge required for each core science content;
- the detailed approaches to the practices of scientists and engineers; and
- how science connecting concepts might be used to deepen content- and practice-driven learning.

The Science Standard-Specific Supports are not intended to be used as curriculum or limit or dictate instruction.

Structure

The practices of scientists and engineers are used as the organizing structure for the Science Standard-Specific Supports. However, this does not mean that the practices are more important than the other dimensions. The practices of scientists and engineers form the activities through which students demonstrate understanding of the science content. The proper integration of the practices makes students' thinking visible.

---

[1] *West Virginia College- and Career-Readiness Standards for Science* (Policy 2520.3C) https://apps.sos.wv.gov/adlaw/csr/readfile.aspx?DocId=54673&Format=PDF

[2] NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press.

[3] National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press.

How to Use the Science Standard-Specific Supports

- For instruction:
  - The Science Standard-Specific Supports can be used to aid instructional design, but it is crucial to recognize there are numerous pathways educators may use throughout the sequence of lessons and units to allow students to ultimately be prepared to demonstrate mastery of the standards.
- For assessment:
  - The Science Standard-Specific Supports can be used to inform the development of formative and summative assessments by the classroom educator.

Although supports are listed individually for each standard, this does not indicate that they should be measured individually, or that standards should be taught or assessed individually. Best practices in classroom instruction should be focused on helping students build towards several standards at one time because many concepts and practices are interrelated.

Limitations of the Science Standard-Specific Supports

The science standard supports cannot do the following:

- Provide or prescribe the contexts through which the standards may be taught or assessed.
- Be the rubrics on which levels of student success would be measured.
- Identify the sequence of instruction or assessment.
- Put limits on student learning or student coursework.
- Replace lesson plans or assessment items.
- Serve as complete scoring rubrics.

*Only the standards for which specific Science Standard-Specific Supports exist are included in this document. Please refer to the complete standards policy (*West Virginia College- and Career-Readiness Standards for Science* (Policy 2520.3C)) when planning instruction.

Physical Science Introduction

The Physical Science course develops understandings of the central concepts from chemistry and physics: Structure and Properties of Matter; Chemical Reactions; Energy; Forces and Interactions; Waves and Electromagnetic Radiation. The topics in Physical Science allow high school students to explain more in-depth phenomena central not only to the physical sciences but to life and earth and space sciences, as well. The standards blend the central ideas with the practices of scientists and engineers and science connecting concepts to support students in developing useable knowledge to explain ideas across the science disciplines. There is a focus on multiple indicators, including developing and using models, planning and conducting investigations, analyzing and interpreting data, using mathematical and computational thinking, and constructing explanations. Students are expected to use these practices to demonstrate understanding of the central ideas and demonstrate understanding of several engineering practices, including design and evaluation. Students will engage in active inquiries, investigations, and hands-on activities at least 50% of the instructional time as they develop and demonstrate conceptual understandings along with research and laboratory skills described in the standards and indicators for science. Safety instruction is integrated into all activities, and students will implement safe procedures and practices when manipulating equipment, materials, organisms, and models. Standards followed by an asterisk (*) denote the integration of traditional science content with an engineering practice.

College- and Career-Readiness Indicators for Science Grades 9-12

Nature of Science

- Scientific knowledge is simultaneously reliable and subject to change based on empirical evidence and interpretation.
- Scientific knowledge is obtained through a combination of observations of the natural world and inferences based on those observations.
- Science is a creative human endeavor which is influenced by social and cultural biases.
- A primary goal of science is the formation of theories and laws. Theories are inferred explanations of some aspect of the natural world based on successfully tested information from evidence and evaluated phenomena. Laws describe relationships among what has been observed in the natural world.
- Scientific investigations use a variety of methods to address questions about the natural and material world.

Practices of Scientists and Engineers

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematical and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Science Connecting Concepts

- Observing patterns
- Investigating and explaining cause and effect
- Recognizing scale, proportion, and quantity
- Defining systems and system models
- Tracking energy and matter flows, into, out of, and within systems to understand system behavior
- Determining the relationships between structure and function
- Studying stability and change

Science Literacy

- Producing clear and coherent technical writing in which the development, organization and style are appropriate for the science topic
- Correctly utilizing and explaining visually expressed information (e.g., flowchart, diagram, model, graph, table, or digital mapping technology) in a science narrative.
- Appropriately using technical terminology or scientific concepts and processes to create visually expressed information
- Reading with understanding articles about science in the popular press and engaging in social conversation about the validity of the conclusions
- Identifying scientific issues underlying national and local decisions and expressing positions that are scientifically and technologically informed
- Evaluating the quality and validity of scientific information on the basis of its source and the methods used to generate it.

Science Lab Safety

- Requiring student lab safety training and demonstrating appropriate proficiency before participating in lab activities
- Archiving signed student safety contracts documenting lab safety training and medical contraindications (e.g., allergies, contact lenses, medical conditions)
- Wearing proper protective gear as needed (e.g., goggles, apron, and gloves)
- Requiring grade appropriate lab equipment operation and safety training
- Using and following SDS protocols
- Storing and disposing of chemical/biological materials properly
- Following ethical classroom uses of living materials/organisms
- Displaying proper safety signage and laboratory rules in the classroom and lab

Physical Science

Topic: Structure and Properties of Matter

S.PS.8. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. * [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

Practices of Scientists and Engineers	Core Science Content
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. Students will communicate scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats (including oral, graphical, textual and mathematical).	**Types of Interaction** 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.
Science Connecting Concepts	
Structure and Function Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.	

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

1) Communication style and format
   a) Students use at least two different formats (including oral, graphical, textual and mathematical) to communicate scientific and technical information, including fully describing the structure, properties, and design of the chosen material(s). Students cite the origin of the information as appropriate.
2) Connecting the content and the science connecting concepts
   a) Students identify and communicate the evidence for why molecular level structure is important in the functioning of designed materials, including:
      i) How the structure and properties of matter and the types of interactions of matter at the atomic scale determine the function of the chosen designed material(s); and
      ii) How the material's properties make it suitable for use in its designed function
   b) Students explicitly identify the molecular structure of the chosen designed material(s) (using a representation appropriate to the specific type of communication—e.g., geometric shapes for drugs and receptors, ball and stick models for long-chained molecules).
   c) Students describe the intended function of the chosen designed material(s).
   d) Students describe the relationship between the material's function and its macroscopic properties (e.g., material strength, conductivity, reactivity, state of matter, durability) and each of the following:
      i) Molecular level structure of the material;
      ii) Intermolecular forces and polarity of molecules; and
      iii) The ability of electrons to move relatively freely in metals.

e) Students describe the effects that attractive and repulsive electrical forces between molecules have on the arrangement (structure) of the chosen designed material(s) of molecules (e.g., solids, liquids, gases, network solid, polymers).
f) Students describe that, for all materials, electrostatic forces on the atomic and molecular scale results in contact forces (e.g., friction, normal forces, stickiness) on the macroscopic scale.

S.PS.10. Use mathematical representations to support the claim that atoms, mass, energy, and charge are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.]

Practices of Scientists and Engineers	Core Science Content
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. Students will use mathematical representations of phenomena to support claims.	Chemical Reactions The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
Science Connecting Concepts	
Energy and Matter The total amount of energy and matter in closed systems is conserved. Scientific Knowledge Assumes an Order and Consistency in Natural Systems Science assumes the universe is a vast single system in which basic laws are consistent.	

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

1) Representation
   a) Students identify and describe* the relevant components in the mathematical representations:
      i) Quantities of reactants and products of a chemical reaction in terms of atoms, moles, and mass;
      ii) Molar mass of all components of the reaction;
      iii) Use of balanced chemical equation(s); and
      iv) Identification of the claim that atoms, and therefore mass, are conserved during a chemical reaction.
   b) The mathematical representations may include numerical calculations, graphs, or other pictorial depictions of quantitative information.
   c) Students identify the claim to be supported: that atoms, and therefore mass, are conserved during a chemical reaction.
2) Mathematical modeling
   a) Students use the mole to convert between the atomic and macroscopic scale in the analysis.
   b) Given a chemical reaction, students use the mathematical representations to
      i) Predict the relative number of atoms in the reactants versus the products at the atomic molecular scale; and

        ii) Calculate the mass of any component of a reaction, given any other component.

3) Analysis
    a) Students describe* how the mathematical representations (e.g., stoichiometric calculations to show that the number of atoms or number of moles is unchanged after a chemical reaction where a specific mass of reactant is converted to product) support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
    b) Students describe* how the mass of a substance can be used to determine the number of atoms, molecules, or ions using moles and mole relationships (e.g., macroscopic to atomic molecular scale conversion using the number of moles and Avogadro's number).

S.PS.11. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]

<table>
<tr><td>Practices of Scientists and Engineers</td><td>Core Science Content</td></tr>
<tr><td>Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. Students will apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.</td><td rowspan="3">Chemical Reactions
Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>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.</td></tr>
</table>

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

1) Articulating the explanation of phenomena
    a) Students construct an explanation that includes the idea that as the kinetic energy of colliding particles increases and the number of collisions increases, the reaction rate increases.
2) Evidence
    a) Students identify and describe* evidence to construct the explanation, including:
        i) Evidence (e.g., from a table of data) of a pattern that increases in concentration (e.g., a change in one concentration while the other concentration is held constant) increase the reaction rate, and vice versa; and
        ii) Evidence of a pattern that increases in temperature usually increase the reaction rate, and vice versa.
3) Reasoning
    a) Students use and describe* the following chain of reasoning that integrates evidence, facts, and scientific principles to construct the explanation:
        i) Molecules that collide can break bonds and form new bonds, producing new molecules.
        ii) The probability of bonds breaking in the collision depends on the kinetic energy of the collision being sufficient to break the bond, since bond breaking requires energy.

iii) Since temperature is a measure of average kinetic energy, a higher temperature means that molecular collisions will, on average, be more likely to break bonds and form new bonds.
iv) At a fixed concentration, molecules that are moving faster also collide more frequently, so molecules with higher kinetic energy are likely to collide more often.
v) A high concentration means that there are more molecules in a given volume and thus more particle collisions per unit of time at the same temperature.

S.PS.12. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. * [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

Practices of Scientists and Engineers	Core Science Content
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K– 8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. Students will refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**Chemical Reactions** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. **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)
Science Connecting Concepts	
Stability and Change Much of science deals with constructing explanations of how things change and how they remain stable.	

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

1) Using scientific knowledge to generate the design solution
   a) Students identify and describe* potential changes in a component of the given chemical reaction system that will increase the amounts of particular species at equilibrium. Students use evidence to describe* the relative quantities of a product before and after changes to a given chemical reaction system (e.g., concentration increases, decreases, or stays the same), and will explicitly use Le Chatelier's principle, including:
      i) How, at a molecular level, a stress involving a change to one component of an equilibrium system affects other components;
      ii) That changing the concentration of one of the components of the equilibrium system will change the rate of the reaction (forward or backward) in which it is a reactant, until the forward and backward rates are again equal; and

        iii) A description* of a system at equilibrium that includes the idea that both the forward and backward reactions are occurring at the same rate, resulting in a system that appears stable at the macroscopic level.

2) Describing criteria and constraints, including quantification when appropriate
    a) Students describe* the prioritized criteria and constraints and quantify each when appropriate. Examples of constraints to be considered are cost, energy required to produce a product, hazardous nature and chemical properties of reactants and products, and availability of resources.
3) Evaluating potential solutions
    a) Students systematically evaluate the proposed refinements to the design of the given chemical system. The potential refinements are evaluated by comparing the redesign to the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources).
4) Refining and/or optimizing the design solution
    a) Students refine the given designed system by making tradeoffs that would optimize the designed system to increase the amount of product and describe* the reasoning behind design decisions.

Topic: Energy

S.PS.15 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>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. Students will create a computational model or simulation of a phenomenon, designed device, process, or system.</td><td rowspan="3">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.

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

Scientific Knowledge Assumes an Order and Consistency in Natural Systems
Science assumes the universe is a vast single system in which basic laws are consistent.</td></tr>
</table>

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

1) Representation
   a) Students identify and describe* the components to be computationally modeled, including:
      i) The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero);
      ii) The initial energies of the system’s components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in each component), including a quantification in an algebraic description to calculate the total initial energy of the system;
      iii) The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and
      iv) The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.

2) Computational Modeling
   a) Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.
   b) Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.

3) Analysis
   a) Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
   b) Students identify and describe* the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

S.PS.17. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. * [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. Students will design, evaluate, and/or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</td><td rowspan="3">Definitions of Energy
At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

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

Defining and Delimiting an Engineering Problem
Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary)</td></tr>
<tr><th>Science Connecting Concepts</th></tr>
<tr><td>Energy and Matter
Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Influence of Science, Engineering and Technology on Society and the Natural World
Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.</td></tr>
</table>

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

1) Using scientific knowledge to generate the design solution
   a) Students design a device that converts one form of energy into another form of energy.
   b) Students develop a plan for the device in which they:
      i) Identify what scientific principles provide the basis for the energy conversion design;
      ii) Identify the forms of energy that will be converted from one form to another in the designed system;
      iii) Identify losses of energy by the design system to the surrounding environment;
      iv) Describe* the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and
      v) Describe* that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk.
2) Describing criteria and constraints, including quantification when appropriate
   a) Students describe* and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost and efficiency of energy conversion.
3) Evaluating potential solutions
   a) Students build and test the device according to the plan.
   b) Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
4) Refining and/or optimizing the design solution
   a) Students use the results of the tests to improve the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in tradeoffs.

S.PS.18 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (Second Law of Thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]

Practices of Scientists and Engineers	Core Science Content
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. Students will plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	**Conservation of Energy and Energy Transfer** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

Science Connecting Concepts	Energy in Chemical Processes
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.	Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.

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

1) Identifying the phenomenon to be investigated
   a) Students describe* the purpose of the investigation, which includes the following idea, that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
2) Identifying the evidence to answer this question
   a) Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including:
      i) The measurement of the reduction of temperature of the hot object and the increase in temperature of the cold object to show that the thermal energy lost by the hot object is equal to the thermal energy gained by the cold object and that the distribution of thermal energy is more uniform after the interaction of the hot and cold components; and
      ii) The heat capacity of the components in the system (obtained from scientific literature).
3) Planning for the investigation
   a) In the investigation plan, students describe*:
      i) How a nearly closed system will be constructed, including the boundaries and initial June 2015 Page 1 of 2 conditions of the system;
      ii) The data that will be collected, including masses of components and initial and final temperatures; and
      iii) The experimental procedure, including how the data will be collected, the number of trials, the experimental set up, and equipment required.
4) Collecting the data
   a) Students collect and record data that can be used to calculate the change in thermal energy of each of the two components of the system.
5) Refining the design
   a) Students evaluate their investigation, including:
      i) The accuracy and precision of the data collected, as well as the limitations of the investigation; and
      ii) The ability of the data to provide the evidence required.
   b) If necessary, students refine the plan to produce more accurate, precise, and useful data that address the experimental question.
   c) Students identify potential causes of the apparent loss of energy from a closed system (which should be zero in an ideal system) and adjust the design of the experiment accordingly.

S.PS.19 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.

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

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

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

Topic: Forces and Interactions

S.PS.21 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>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. Students will analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena.</td><td rowspan="3">Forces and Motion
Newton's second law accurately predicts changes in the motion of macroscopic objects.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Cause and Effect
Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</td></tr>
</table>

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

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

S.PS.23 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when the system is closed. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]

Practices of Scientists and Engineers	Core Science Content
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. Students will use mathematical representations of phenomena to describe explanations	**Forces and Motion** Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.
Science Connecting Concepts	
Systems and System Models When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.	

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

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

S.PS.24 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. * [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. Students will apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.</td><td rowspan="3">Forces and Motion
If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

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

Optimizing the Design Solution
Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. (secondary)</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Cause and Effect
Systems can be designed to cause a desired effect.</td></tr>
</table>

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

1) Using scientific knowledge to generate the design solution
   a) Students design a device that minimizes the force on a macroscopic object during a collision. In the design, students:
      i) Incorporate the concept that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t = m\Delta v$); and
      ii) Explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision.
   b) In the design plan, students describe* the scientific rationale for their choice of materials and for the structure of the device.
2) Describing criteria and constraints, including quantification when appropriate
   a) Students describe* and quantify (when appropriate) the criteria and constraints, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets).
3) Evaluating potential solutions
   a) Students systematically evaluate the proposed device design or design solution, including describing* the rationales for the design and comparing the design to the list of criteria and constraints.
   b) Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits.

4) Refining and/or optimizing the design solution
    a) Students use the test results to improve the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis.

Topic: Waves and Electromagnetic Radiation

S.PS.26 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media while differentiating between longitudinal and transverse waves. [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]

Practices of Scientists and Engineers	Core Science Content
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. Students will use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations.	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.
Science Connecting Concepts	
Cause and Effect Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.	

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

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

S.PS.27 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [Assessment Boundary: Assessment is limited to qualitative descriptions.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>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. Students will evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible.</td><td rowspan="3">Electromagnetic Radiation
When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Cause and Effect
Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller-scale mechanisms within the system.</td></tr>
</table>

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

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

Engineering, Technology, and Applications of Science

Topic: Engineering Design

S.PS.30. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>Asking Questions and Defining Problems
Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. Students will analyze complex real-world problems by specifying criteria and constraints for successful solutions.</td><td rowspan="3">Defining and Delimiting Engineering Problems
Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Influence of Science, Engineering, and Technology on Society and the Natural World
New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.</td></tr>
</table>

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

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

S.PS.31 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

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

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

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

S.PS.32 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Practices of Scientists and Engineers	Core Science Content
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. Students will evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**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.
Science Connecting Concepts	
Influence of Science, Engineering, and Technology on Society and the Natural World New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.	

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

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

S.PS.33. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. Students will use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.</td><td rowspan="3">Developing Possible Solutions
Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Systems and System Models
Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter, and information flows — within and between systems at different scales.</td></tr>
</table>

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

1) Representation
   a) Students identify the following components from a given computer simulation:
      i) The complex real-world problem with numerous criteria and constraints;

ii) The system that is being modeled by the computational simulation, including the boundaries of the systems;
iii) What variables can be changed by the user to evaluate the proposed solutions, tradeoffs, or other decisions; and
iv) The scientific principle(s) and/or relationship(s) being used by the model.

2) Computational Modeling
   a) Students use the given computer simulation to model the proposed solutions by:
      i) Selecting logical and realistic inputs; and
      ii) Using the model to simulate the effects of different solutions, tradeoffs, or other decisions.
3) Analysis
   a) Students compare the simulated results to the expected results.
   b) Students interpret the results of the simulation and predict the effects of the proposed solutions within and between systems relevant to the problem based on the interpretation.
   c) Students identify the possible negative consequences of solutions that outweigh their benefits.
   d) Students identify the simulation's limitations.

David L. Roach
West Virginia Superintendent of Schools