WEST VIRGINIA DEPARTMENT OF EDUCATION

Science Standard-Specific Supports

Physics

Revised October 2022

Contents

Standards-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.

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[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.

Physics Introduction

Physics is an advanced elective course designed for students pursuing Science Technology Engineering Mathematics (STEM) education and careers. The course emphasizes a mathematical approach to the topics of Forces and Interactions, Energy, and Waves and Electromagnetic Radiation and prepares students for college physics. The physics course prepares 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. These 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 will 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

Physics

Topic: Force and Interactions

S.P.4. 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.]

Practices of Scientists and Engineers	Core Science Content
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.	Forces and Motion Newton's second law accurately predicts changes in the motion of macroscopic objects.
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) 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.P.6. 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.P.8. 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.]

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 apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.	**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)
Science Connecting Concepts	
Cause and Effect Systems can be designed to cause a desired effect.	

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

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

   - b) Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits.

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

Topic: Energy

S.P.11. 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.]

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 create a computational model or simulation of a phenomenon, designed device, process, or system.	Definitions of Energy Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. PS3.B: Conservation of Energy and Energy Transfer Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.
Science Connecting Concepts	
Systems and System Models Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scientific Knowledge Assumes an Order and Consistency in Natural Systems Science assumes the universe is a vast single system in which basic laws are consistent.	

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

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

        iii) The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and
        iv) The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.

2) Computational Modeling
    a) Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.
    b) Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.
3) Analysis
    a) Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
    b) Students identify and describe* the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

S.P.14. 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.]

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, 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.	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
Science Connecting Concepts	
Energy and Matter Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. 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.	should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary)

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.P.15. 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	**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.

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.	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). **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.
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 and their inputs and outputs analyzed and described using models.	

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

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

Topic: Waves and Electromagnetic Radiation

S.P.20 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.P.27 Diagram magnetic fields for different types of magnets and evaluate the strength of magnetic fields based on field line density. [Clarification Statement: Standard was adapted from one which originally included the following: “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.” Information below is intended to support the original text but supports the adopted standard. 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.

S.P.28 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]

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.	Types of Interactions Newton’s law of universal gravitation and Coulomb’s law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. Definitions of Energy “Electrical energy” may mean energy stored in a battery or energy transmitted by electric currents. (secondary)
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) Identifying the phenomenon to be investigated
    a) Students describe* the phenomenon under investigation, which includes the following idea: that an electric current produces a magnetic field and that a changing magnetic field produces an electric current.
2) Identifying the evidence to answer this question
    a) Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data about 1) an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and 2) an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit. Students describe* why these effects seen must be causal and not correlational, citing specific cause-effect relationships.
3) Planning for the investigation
    a) In the investigation plan, students include:
        i) The use of an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, and the types and positions of detectors;
        ii) A means to indicate or measure when electric current is flowing through the circuit;
        iii) A means to indicate or measure the presence of a local magnetic field near the circuit; and
        iv) A design of a system to change the magnetic field in a nearby circuit and a means to indicate or measure when the magnetic field is changing.
    b) In the plan, students state whether the investigation will be conducted individually or collaboratively.

4) Collecting the data
    a) Students measure and record electric currents and magnetic fields.
5) Refining the design
    a) Students evaluate their investigation, including an evaluation of:
        i) The accuracy and precision of the data collected, as well as limitations of the investigation; and
        ii) The ability of the data to provide the evidence required.
    b) If necessary, students refine the investigation plan to produce more accurate, precise, and useful data such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.

Engineering, Technology, and Applications of Science

Topic: Engineering Design

S.P.33. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Practices of Scientists and Engineers	Core Science Content
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.	**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.
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) 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 CO2 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.P.34 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.P.35 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.P.36. 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.

Practices of Scientists and Engineers	Core Science Content
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.	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.
Science Connecting Concepts	
Systems and System Models Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter, and information flows — within and between systems at different scales.	

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

1) 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.

WEST VIRGINIA DEPARTMENT OF EDUCATION

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