2018 Virginia Science Standards of Learning

Curriculum Framework

Board of Education

Commonwealth of Virginia

Superintendent of Public Instruction
James F. Lane, Ed.D.

Assistant Superintendent of Learning
Gena Keller

Office of Science, Technology, Engineering, and Mathematics
Tina Manglicmot, Ed.D., Director
Anne Petersen, Ph.D., Science Coordinator
Joshua Bearman, Science Specialist
Myra Thayer, Science Specialist

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The *2018 Virginia Science Standards of Learning Curriculum Framework* can be found on the Virginia Department of Education's website at http://www.doe.virginia.gov/testing/sol/standards_docs/science/index.shtml.

Introduction

The *2018 Virginia Science Standards of Learning Curriculum Framework* amplifies the *Science Standards of Learning for Virginia Public Schools* (SOL) and defines the content knowledge, skills, and understandings that provide a foundation in science concepts and practices. The framework provides additional guidance to school divisions and their teachers as they develop an instructional program appropriate for their students. It assists teachers as they plan their lessons by identifying enduring understandings and defining the essential science and engineering practices students need to master. This framework delineates in greater specificity the minimum content requirements that all teachers should teach and all students should learn.

School divisions should use the framework as a resource for developing sound curricular and instructional programs. This framework should not limit the scope of instructional programs. Additional knowledge and skills that can enrich instruction and enhance students' understanding of the content identified in the SOL should be included in quality learning experiences.

The framework serves as a guide for SOL assessment development. Assessment items may not and should not be a verbatim reflection of the information presented in the framework. Students are expected to continue to apply knowledge and skills from the SOL presented in previous grades as they build scientific expertise.

The Board of Education recognizes that school divisions will adopt a K–12 instructional sequence that best serves their students. The design of the SOL assessment program, however, requires that all Virginia school divisions prepare students to demonstrate achievement of the standards for elementary and middle school by the time they complete the grade levels tested. The high school end-of-course SOL tests, for which students may earn verified units of credit, are administered in a locally determined sequence.

Each topic in the framework is developed around the SOL. The format of the framework facilitates teacher planning by identifying the enduring understandings and the scientific and engineering practices that should be the focus of instruction for each standard. The categories of scientific and engineering practices appear across all grade levels and content areas. Those categories are: asking questions and defining problems; planning and carrying out investigations; interpreting, analyzing, and evaluating data; constructing and critiquing conclusions and explanations; developing and using models; and obtaining, evaluating, and communicating information. These science and engineering practices are embedded in instruction to support the development and application of science content.

Science and Engineering Practices

Science utilizes observation and experimentation along with existing scientific knowledge, mathematics, and engineering technologies to answer questions about the natural world. Engineering employs existing scientific knowledge, mathematics, and technology to create, design, and develop new devices, objects, or technology to meet the needs of society. By utilizing both scientific and engineering practices in the science classroom, students develop a deeper understanding and competence with techniques at the heart of each discipline.

Engineering Design Practices

Engineering design practices are similar to those used in an inquiry cycle; both use a system of problem solving and testing to come to a conclusion. However, unlike the inquiry cycle in which students ask a question and use the scientific method to answer it, in the engineering and design process, students use existing scientific knowledge to solve a problem. Both include research and experimentation; however, the engineering design process has a goal of a solving a societal problem and may have multiple solutions. More information on the engineering and design process can be found at https://www.eie.org/overview/engineering-design-process.

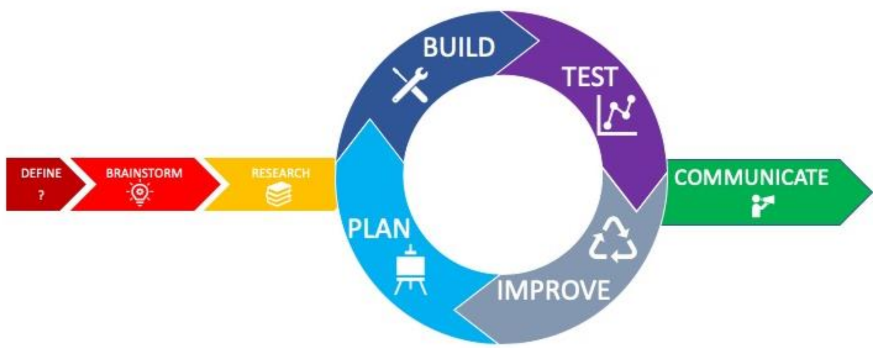

Figure 1: Engineering Design Process image based on the National Aeronautics and Space Administration (NASA) engineering design model.

The Engineering Design Process:

- Define: Define the problem, ask a question
- Imagine: Brainstorm possible solutions
- Research: Research the problem to determine the feasibility of possible solutions
- Plan: Plan a device/model to address the problem or answer the question
- Build: Build a device/model to address the problem or answer the question
- Test: Test the device/model in a series of trials
    - Does the design meet the criteria and constraints defined in the problem?
        - Yes? Go to Share (#8)
        - No? Go to Improve (#7)
- Improve: Using the results of the test, brainstorm improvements to the device/model; return to #3
- Share: Communicate your results to stakeholders and the public

Computational Thinking

The term *computational thinking* is used throughout this framework. Computational thinking is a way of solving problems that involves logically organizing and classifying data and using a series of steps (algorithms). Computational thinking is an integral part of Virginia's computer science standards and is explained as such in the *Computer Science Standards of Learning*:

> *Computational thinking is an approach to solving problems that can be implemented with a computer. It involves the use of concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts. Computational thinking practices such as abstraction, modeling, and decomposition connect with computer science concepts such as algorithms, automation, and data visualization. [Computer Science Teachers Association & Association for Computing Machinery]*

Students engage in computational thinking in the science classroom when using both inquiry and the engineering design process. Computational thinking is used in laboratory experiences as students develop and follow procedures to conduct an investigation.

Structure of the *2018 Virginia Science Standards of Learning Curriculum Framework*

The framework is divided into two columns: Enduring Understandings and Essential Knowledge and Practices. The purpose of each column is explained below.

Enduring Understandings
The Enduring Understandings highlight the key concepts and the big ideas of science that are applicable to the standard. These key concepts and big ideas build as students advance in their scientific and engineering understanding. The bullets provide the context of those big ideas at that grade or content level.

Essential Knowledge and Practices
Each standard is expanded in the Essential Knowledge and Practices column. What each student should know and be able to do as evidence of understanding of the standard is identified here. This is not meant to be an exhaustive list nor is a list that limits what is taught in the classroom. It is meant to be the key knowledge and practices that define the standard. Science and engineering practices are highlighted with a leaf bullet (see footer).

The *2018 Virginia Science Standards of Learning Curriculum Framework* is informed by the Next Generation Science Standards (https://www.nextgenscience.org/).

Physics

The Physics standards emphasize a more complex understanding of experimentation, the analysis of data, and the use of reasoning and logic to evaluate evidence. The use of mathematics, including algebra and trigonometry is important, but conceptual understanding of physical systems remains a primary concern. Students build on basic physical science principles by exploring in-depth the nature and characteristics of energy and its dynamic interaction with matter. Key areas covered by the standards include force and motion, energy transformations, wave phenomena and the electromagnetic spectrum, electricity, fields, and non-Newtonian physics. Technology, including graphing calculators, computers, and probeware are used when feasible. Students will use equipment safely. Mathematics, computational thinking, and experience in the engineering design process are essential as students advance in their scientific thinking.

Scientific and Engineering Practices

Engaging in the practices of science and engineering helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the many ways to investigate, model, and explain the world. These scientific and engineering practices include the use of scientific skills and processes to explore the content of science as outlined in the *Science Standards of Learning*. The engineering design practices are the application of science content to solve a problem or design an object, tool, process, or system. These scientific and engineering practices are critical to science instruction and are to be embedded throughout the year.

PH.1 The student will demonstrate an understanding of scientific and engineering practices by.

a) asking questions and defining problems
- **ask questions that arise from careful observation of phenomena, examination of a model or theory, or unexpected results, and/or to seek additional information**
- **determine which questions can be investigated within the scope of the school laboratory**
- **make hypotheses that specify what happens to a dependent variable when an independent variable is manipulated**
- **generate hypotheses based on research and scientific principles**
- **define design problems that involves the development of a process or system with interacting components and criteria and constraints**

b) planning and carrying out investigations
- **individually and collaboratively plan and conduct observational and experimental investigations**
- **plan and conduct investigations or test design solutions in a safe manner**

- **select and use appropriate tools and technology to collect, record, analyze, and evaluate data**

c) **interpreting, analyzing, and evaluating data**
- **record and present data in an organized format that communicates relationships and quantities in appropriate mathematical or algebraic forms**
- **use data in building and revising models, supporting explanation for phenomena, or testing solutions to problems**
- **analyze data using tools, technologies, and/or models (e.g., computational, mathematical, statistical) in order to make valid and reliable scientific claims or determine an optimal design solution**
- **analyze data graphically and use graphs to make predictions;**
- **consider limitations of data analysis when analyzing and interpreting data**
- **evaluate the impact of new data on a working explanation and/or model of a proposed process or system**
- **analyze data to optimize a design**

d) **constructing and critiquing conclusions and explanations**
- **make quantitative and/or qualitative claims based on data**
- **construct and revise explanations based on valid and reliable evidence obtained from a variety of sources**
- **apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena or design solutions**
- **compare and evaluate competing arguments in light of currently accepted explanations and new scientific evidence**
- **construct arguments or counterarguments based on data and evidence**
- **differentiate between scientific hypothesis, theory, and law**

e) **developing and using models**
- **evaluate the merits and limitations of models**
- **identify and communicate components of a system orally, graphically, textually, and mathematically**
- **develop and/or use models (including mathematical and computational) and simulations to visualize, explain, and predict phenomena and to interpret data sets**

f) **obtaining, evaluating, and communicating information**
- **compare, integrate, and evaluate sources of information presented in different media or formats to address a scientific question or solve a problem.**
- **gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and credibility of each source**
- **communicate scientific and/or technical information about phenomena and/or a design process in multiple formats**

Physics Content

PH.2 The student will investigate and understand, through mathematical and experimental processes, that there are relationships between position and time. Key topics include

a) displacement, velocity, and uniform acceleration;
b) linear motion;
c) uniform circular motion; and
d) projectile motion.

Central Idea: The movement of objects can be described using position, velocity, and acceleration. These quantities are related to each other with respect to time.

Vertical Alignment: Students begin their study of motion in early elementary and build on this understanding throughout their elementary years. In eighth grade, student instigate the relationships among work, force, and motion and are introduced to Newton's laws (PS.8).

Enduring Understandings	**Essential Knowledge and Practices**
Because all motion is relative, all positions of objects and the directions of forces and motions must be described in a chosen frame of reference. • Kinematics is the branch of mechanics concerned with the motion of objects without reference to forces (PH.2 b). • Position, displacement, velocity, and acceleration are vector quantities (PH.2 a). • Motion is described in terms of position, displacement, time, velocity, and acceleration (PH.2 b). • Velocity is the change in position (i.e., displacement) divided by the change in time. A straight-line, position-time graph indicates constant velocity. The slope of a position time graph is the velocity and the sign of the slope describes the direction of the velocity (PH.2 a).	In order to meet this standard, it is expected that students will • construct and analyze graphs showing position vs. time, velocity vs. time, and acceleration vs. time (PH.2 a) • design a model, illustration, and/or graph to explain how distance and velocity change for a free-falling object (PH.2 a) • solve problems involving displacement, velocity, acceleration, and time in one and two dimensions (only constant acceleration) (PH.2 a, b, d) • resolve vector diagrams involving displacement and velocity into their components along perpendicular axes (PH.2 b)

Enduring Understandings	Essential Knowledge and Practices
• Acceleration is the change in velocity divided by the change in time. A straight-line, velocity-time graph indicates constant acceleration. A horizontal-line, velocity-time graph indicates zero acceleration. The slope of a velocity-time graph is the acceleration and the sign of the slope describes the direction of the acceleration (PH.2 a). • Uniform circular motion is when an object travels in a circle with a constant speed. The constant change in direction of the object is caused by an acceleration that is directed toward the center of the circle and is always perpendicular to the velocity of the object (PH.2 c). • In a uniform vertical gravitational field with negligible air resistance, horizontal and vertical components of the motion of a projectile are independent of one another with constant horizontal velocity and constant vertical acceleration (PH.2 d).	• draw vector diagrams of a projectile's motion. Find range, trajectory, height of the projectile, and time of flight (uniform gravitational field, no air resistance) (PH.2 d) • solve problems related to free-falling objects, including 2-D motion (PH.2 b, d) • solve problems using uniform circular motion (PH.2 c) • plan, conduct, and communicate the results of experiments using kinematics (PH.2 b).

PH.3 The student will investigate and understand, through mathematical and experimental processes, that there are relationships among force, mass, and acceleration. Key laws include

a) Newton's laws of motion; and

b) Newton's law of universal gravitation.

Central Idea: Newton's laws of motion are three physical laws that, together, laid the foundation for classical mechanics. These laws describe the relationship between a body and the forces acting upon it, and its motion in response to those forces.

Vertical Alignment: Students begin their study of motion in early elementary and build on this understanding throughout their elementary years. In eighth grade, student instigate the relationships among work, force, and motion and are introduced to Newton's laws (PS.8)

Enduring Understandings	Essential Knowledge and Practices
The interactions of an object with other objects can be described by forces. These forces can transfer energy between objects which can cause a change in their motion. • Dynamics is the branch of mechanics concerned with the effect of forces on motion of a body or a system of bodies (PH.3 a). • Newton's three laws of motion are the basis of understanding the mechanical universe (PH.3 a). • Net force is the vector sum of all forces acting on an object (PH.3 a). • An object with no net force acting on it is stationary or moves with constant velocity (PH.3 a). • Forces are interactions that can cause objects to accelerate. When one object exerts a force on a second object, the second exerts a force on the first that is equal in magnitude but opposite in direction (PH.3 a). • The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass (PH.3 a). • Position, displacement, velocity, and acceleration are vector quantities (PH.3 a). • Motion is described in terms of position, displacement, time, velocity, and acceleration (PH.3 a). • Free body diagrams are used to show the relative magnitude and direction of all forces acting upon a system in a given situation (PH.3 a).	In order to meet this standard, it is expected that students will • qualitatively explain motion in terms of Newton's laws (PH.3 a) • solve problems involving force, mass, and acceleration (PH.3 a) • construct and analyze position vs. time, velocity vs. time, and acceleration vs. time, and force vs acceleration graphs (PH.3 a) • solve problems involving force(s), displacement, velocity, acceleration, and time in one and two dimensions (PH.3 a) • resolve vector diagrams involving force, displacement and velocity into their components along perpendicular axes (PH.3 a) • draw vector diagrams of a projectile's motion. Find range, trajectory, height of the projectile, and time of flight (uniform gravitational field, no air resistance) (PH.3 a) • solve problems involving multiple forces, using free-body diagrams (PH.3 a) • describe the forces involved in circular motion (PH.3 a) • plan and conduct experiments involving dynamics, including one dealing with Newton's second law (PH.3 a) • communicate results of experiments involving dynamics (PH.3 a) • design a model, illustration, and/or graph to explain how distance and velocity change for a free-falling object (PH.3 a)

Enduring Understandings	Essential Knowledge and Practices
• An object moving along a circular path with a constant speed experiences an acceleration directed toward the center of the circle (PH.3 a). • Friction is the force resisting the relative motion between surfaces in contact with each other (PH.3 a). • Weight is the gravitational force acting on a body (PH.3 b). • Newton's law of universal gravitation states that any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them (PH.3 b).	• use Newton's laws of motion to predict the effect of motion on objects (PH.3 a) • explain with words, charts, diagrams, and models the effects of distance and the amount of mass on the gravitational force between objects (PH.3 a) • solve problems using Newton's law of universal gravitation (PH.3 b).

PH.4 The student will investigate and understand, through mathematical and experimental processes, that conservation laws govern all interactions. Key ideas include
a) momentum is conserved unless an impulse acts on the system; and
b) mechanical energy is conserved unless work is done on, by, or within the system.

Central Idea: Conservation and momentum are two of the most fundamental concepts in physics and apply to all interactions.

Vertical Alignment: In Physical Science, students are introduced to the concepts of energy, energy conservation, and energy transfer and transformations (PS.5).

Enduring Understandings	Essential Knowledge and Practices
Changes that occur as a result of interactions are constrained by conservation laws. • Kinetic energy is the energy of motion. Potential energy is the energy due to an object's position or state (PH.4 b).	In order to meet this standard, it is expected that students will • illustrate that energy can be transformed from one form to another, using examples from everyday life (PH.4 b)

Enduring Understandings	**Essential Knowledge and Practices**
• Forces within a system transform energy from one form to another with no change in the system's total energy (PH.4 b). • Work is the mechanical transfer of energy to or from a system and is the product of a force at the point of application and the parallel component of the object's displacement (PH.4 b). • Power is the rate of change of the energy of the system (PH.4 b). • For a constant force acting on an object, the impulse by that force is the product of the force and the time the object experiences the force. The impulse also equals the change in the momentum of the object (PH.4 b). • Total energy and momentum are conserved PH.4 a, b). • For elastic collisions, total momentum and total kinetic energy are conserved. For inelastic collisions, total momentum is conserved and some kinetic energy is transformed to other forms of energy (PH.4 a). • In all systems, the principal of mass/energy applies, but only in a small number of systems is it significant enough to be considered (PH.4 b).	• qualitatively identify the various energy transformations in a simple scenario (PH.4 b) • investigate conservation of energy in a mechanical system in which energy is transformed from one form into another (b) • solve problems with conservation of energy and work and power (b) • investigate conservation of momentum in a mechanical system in which momentum is transferred between objects (PH.4 a) • use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system (PH.4 a) • solve problems with conservation of momentum (PH.4 a) • apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision (PH.4 a) • plan and conduct an experiment to investigate the conservation of electric charge (PH.4 b).

PH.5 The student will investigate and understand, through mathematical and experimental processes, that waves transmit energy and move in predictable patterns. Key ideas include

a) waves have specific characteristics;

b) wave interactions are part of everyday experiences; and

c) light and sound transmit energy as waves.

Central Idea: Waves can transfer energy and momentum from one location to another time with little or no permanent displacement of the particles of the medium.

Vertical Alignment: In Physical Science, students focus on waves as the movement of energy. Students explore characteristics of waves and their interactions by studying sound waves and electromagnetic radiation (PS.6, PS.7).

Enduring Understandings	Essential Knowledge and Practices
Waves can transfer energy and momentum from one location to another without the permanent transfer of mass. • Mechanical waves transport energy as a traveling disturbance in a medium (PH.5 a). • In a transverse wave, particles of the medium oscillate in a direction perpendicular to the direction the wave travels (PH.5 a). • In a longitudinal wave, particles of the medium oscillate in a direction parallel to the direction the wave travels (PH.5 a). • Wave velocity equals the product of the frequency and the wavelength (PH.5 a). • Frequency and period are reciprocals of each other (PH.5 a). • Waves are reflected and transmitted when they encounter a change in medium or a boundary (PH.5 a). • The overlapping of two or more waves results in constructive or destructive interference (PH.5 a). • When source and observer are in relative motion, a shift in frequency occurs (Doppler effect) (PH.5 a).	In order to meet this standard, it is expected that students will • use simulations and models to differentiate between examples of transverse and longitudinal waves (PH.5 a) • use a model representation of a wave to identify the period, wavelength, and amplitude (PH.5 a) • solve problems involving frequency, period, wavelength, and velocity (PH.5 a) • model or simulate reflection, refraction and diffraction of a wave when it encounters a change in medium or a boundary (PH.5 c) • explain the phenomena of constructive and destructive interference (PH.5 b) • plan and conduct an experiment investigating standing waves (PH.5 a) • describe the change in observed frequency of waves due to the motion of a source or a receiver (Doppler effect) (PH.5 c) • identify technological applications throughout the electromagnetic spectrum (PH.5 b) • identify common uses for radio waves, microwaves, X-rays and gamma rays (PH.5 b)

Enduring Understandings	**Essential Knowledge and Practices**
• Sound is a longitudinal mechanical wave that travels through matter (PH.5 c). • Light is a transverse electromagnetic wave that can travel through matter as well as a vacuum (PH.5 c). • Reflection is the change of direction of the wave in the original medium (PH.5 c). • Refraction is the change of direction of the wave at the boundary between two media (PH.5 c). • Diffraction is the spreading of a wave around a barrier or an aperture (PH.5 c). • The pitch of a note is determined by the frequency of the sound wave (PH.5 c). Electromagnetic radiation travels in waves and occurs over a wide range of frequencies. The dual nature of light is addressed in PH.9. • The color of light is determined by the frequency of the light wave (PH.5 c). • As the amplitude of a sound wave increases, the loudness of the sound increases (PH.5 c). • As the amplitude of a light wave increases, the intensity of the light increases (PH.5 c). • Frequency, wavelength, and energy vary across the entire electromagnetic spectrum (PH.5 b).	• use mathematical representations to support a claim regarding the relationships among the frequency, wavelength, and speed of waves traveling through various media (PH.5 a) • compare electromagnetic waves to mechanical waves (PH.5 b).

Enduring Understandings	Essential Knowledge and Practices
• The long wavelength, low frequency portion of the electromagnetic spectrum is used for communication (e.g., radio, TV, cellular phone) (PH.5 b). • Medium wavelengths (infrared) are used for heating and remote-control devices (PH.5 b). • Visible light comprises a relatively narrow portion of the electromagnetic spectrum (PH.5 b). • Ultraviolet (UV) wavelengths (shorter than the visible spectrum) are ionizing radiation and can cause damage to humans. UV is responsible for sunburn and can be used for sterilization and fluorescence (PH.5 b). • X-rays and gamma rays are the highest frequency (shortest wavelength) and are used primarily for medical purposes. These wavelengths are also ionizing radiation and can cause damage to humans (PH.5 b).	

PH.6 The student will investigate and understand, through mathematical and experimental processes, that optical systems form a variety of images. Key ideas include
a) the laws of reflection and refraction describe light behavior; and
b) ray diagrams model light as it travels through different media.

Central Idea: Light is an electromagnetic wave that does not need a medium to travel through space. Since light bends it is possible to alter what is seen using optical devices called lenses and mirrors. The path that light travels will bend in such a way that various images are formed that are used in projectors, cameras, and eyeglasses.

Vertical Alignment: In Physical Science, students are introduced to characteristics of electromagnetic radiation through an exploration of the electromagnetic spectrum and through observing the results of interactions of light (PS.7).

Enduring Understandings	Essential Knowledge and Practices
Electromagnetic radiation travels in waves and occurs over a wide range of frequencies. Cause-and-effect relationships may be used to predict the path of light caused by interactions with other materials. • The ray model of light can be used to understand the behavior of optical systems (PH.6 b). • Light incident on a smooth plane surface is reflected such that the angle of incidence equals the angle of reflection (PH.6 a). • The index of refraction is the ratio of the speed of light in a vacuum to the speed of light in the medium (PH.6 a). • This relationship between the angles of incidence and refraction and the indices of refraction of the two media is known as Snell's law. Snell's law applies to the refraction of light in any situation, regardless of what the two media are (PH.6 a). • For a converging lens, the focal point is the point at which a beam of light parallel to the principal axis converges (PH.6 b). • For a diverging lens, the focal point is the point from which a beam of light parallel to the principal axis appears to originate (PH.6 b). • A virtual image can be seen by an observer but cannot be projected on a screen because the light does not actually emanate from the image (PH.6 b). • The focal point is the point at which rays converge or from which they appear to diverge in a lens or mirror (PH.6 b).	In order to meet this standard, it is expected that students will • conduct an experiment utilizing Snell’s law to determine the index of refraction for a given material (PH.6 a) • investigate propagation, refraction, and reflection, using the ray model of light (PH.6 a) • construct ray diagrams to determine the location and type of image of an object using the laws of reflection and refraction (PH.6 b) • conduct an experiment to find the location of an image using an optical system (PH.6 b).

PH.7 The student will investigate and understand, through mathematical and experimental processes, that fields provide a unifying description of force at a distance. Key ideas include

a) gravitational, electric, and magnetic forces can be described using the field concept; and

b) field strength diminishes with increased distance from the source.

Central Idea: Field theories describe how forces interact with matter. A gravitational field is one that is created due to the mass of the object. Electric fields are created by the electric charge, positive or negative, that an object possesses. Finally, magnetic fields are created by the movement of an electric charge. All fields are considered vectors and are often represented by field lines to give a visual picture of the field location and strength.

Vertical Alignment: Students are exposed to the basic principles of electricity and magnetism in eighth grade to include electrical circuits, and the relationship between electric and magnetic fields (PS.9).

Enduring Understandings	**Essential Knowledge and Practices**
Fields existing in space can be used to explain interactions. • A field is a region in which each point is affected by a force. Objects fall to the ground because they are affected by the force of the Earth's gravitational field. A paper clip, placed in a magnetic field, is pulled toward the magnet, and the two like magnetic poles repel each other when one is placed in the other's magnetic field (PH.7 a). • An electric field surrounds an electric charge; when another charged particle is placed in that region, it experiences an electric force that either attracts or repels it (PH.7 a). • The strength of a field, or the forces in a particular region, could be represented by field lines; the closer the lines, the stronger the forces in that part of the field (PH.7 a). • The force found from Newton's law of gravitation and in Coulomb's law is dependent on the inverse square of the distance between two objects (PH.7 b).	In order to meet this standard, it is expected that students will • describe the-vector nature of the forces on an object in the presence of a field (PH.7 a) • compare Newton's law of universal gravitation and Coulomb's law of electrostatics (PH.7 a) • describe the effect of a uniform magnetic field on a moving electrical charge (PH.7 a) • plan and conduct an experiment utilizing sensors to explore and explain the nature of fields (PH.7 a, b) • develop and use of 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 (PH.7 a) • plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a

Enduring Understandings	Essential Knowledge and Practices
• The interaction of two particles at a distance can be described as a two-step process that occurs simultaneously: the creation of a field by one of the particles and the interaction of the field with the second particle (PH.7 a, b). • The force a magnetic field exerts on a moving electrical charge has a direction perpendicular to both the velocity and field directions. Its magnitude is dependent on the velocity of the charge, the magnitude of the charge, and the strength of the magnetic field (PH.7 a).	changing magnetic field can produce an electric current (PH.7 a) • describe the relationship between electric charges and magnetic fields (PH.7 a).

PH.8 The student will investigate and understand, through mathematical and experimental processes, that electrical circuits are a system used to transfer energy. Key ideas include

a) circuit components have different functions within the system;
b) Ohm's law relates voltage, current, and resistance;
c) different types of circuits have different characteristics and are used for different purposes;
d) electrical power is related to the elements in a circuit; and
e) electrical circuits have everyday applications.

Central Idea: An electrical circuit is a closed loop that begins and ends at a power source. Within that circuit voltages and currents are determined by the choice of power source and resistance of electrical components. The electrical power of a circuit or component in a circuit is the product of the current and the voltage.

Vertical Alignment: Students are exposed to the basic principles of electricity and magnetism in eighth grade to include electrical circuits, and the relationship between electric and magnetic fields (PS.9).

Enduring Understandings	Essential Knowledge and Practices
Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.	In order to meet this standard, it is expected that students will • describe the function of components in an electrical system (PH.8 a)

Enduring Understandings	**Essential Knowledge and Practices**
• Current is the rate at which charge moves through a circuit element (PH.8 b). • Electric potential difference (voltage) in a circuit provides the energy that drives the current (PH.8 b). • Elements in a circuit are positioned relative to other elements either in series or parallel (PH.8 a, c). • According to Ohm's law, the resistance of an element equals the voltage across the element divided by the current through the element (PH.8 b). • Potential difference (voltage) is the change in electrical potential energy per unit charge across that element (PH.8 b). • The dissipated power of a circuit element equals the product of the voltage across that element and the current through that element (PH.8 d). • In a DC (direct current) circuit, the current flows in one direction, whereas in an AC (alternating current) circuit, the current switches direction several times per second (PH.8 e).	• recognize a series and a parallel circuit (PH.8 b) • apply Ohm's law to a series and a parallel circuit (PH.8 b) assemble and analyze simple circuits composed of-voltage sources and loads in series and in parallel (PH.8 c) solve simple circuits using Ohm's law (PH.8 b, c) calculate the dissipated power of a circuit element (PH.8 d) • recognize that DC power is supplied by batteries and that AC power is supplied by electrical wall sockets (PH.8 e).

PH.9 The student will investigate and understand that extremely large and extremely small quantities are not necessarily described by the same laws as those studied in Newtonian physics. Topics, such as these listed, may be included.

a) wave/particle duality;
b) quantum mechanics and uncertainty;
c) relativity;
d) nuclear physics;
e) solid state physics;
f) nanotechnology;

g) **superconductivity;**
h) **the standard model; and**
i) **dark matter and dark energy.**

Central Idea: Newtonian physics doesn't adequately describe phenomena at the extremes of small size or high speed. As modern physics has explored areas of extreme speeds and subatomic particles, new paradigms have been created.

Vertical Alignment: Prior to this standard, students may have little or no classroom experience with these topics.

Enduring Understandings	**Essential Knowledge and Practices**
The study of modern and non-Newtonian physics can be applied in varied technological applications. The intent of this standard is not that each area be taught; instead, the teacher should select areas based on student interest and their own understandings of physics concepts. • For processes that are important on the atomic scale, objects exhibit both wave characteristics (e.g., interference) as well as particle characteristics (e.g., discrete amounts and a fixed definite number of electrons per atom) (PH.9 a, b). • Quantum mechanics requires an inverse relationship between the measurable location and the measurable momentum of a particle. The more accurately one determines the position of a particle, the less accurately the momentum can be known, and vice versa. This is known as the Heisenberg uncertainty principle (PH.9 a, b). • The special theory of relativity states that the laws of physics are the same for all inertial reference frames and the speed of light in a vacuum is constant and independent of the motion of all observers (PH.9 c).	In order to meet this standard, it is expected that students will • evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described by either a wave model or a particle model, and that for some situations one model is more useful than another (PH.9 a, b) • communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy (PH.9 a, b) • provide examples of technologies used to explore topics in modern physics (PH.9, b, c, d, e, f, g, h, i) • compare classical physics and modern physics at the extremes of speed and size (PH.9 a, b, c, d, e, f, g, h, i) • explore the connections between and the benefits of the pursuit of pure science and subsequent applications (PH.9 a, b, c, d, e, f, g, h, i).

Enduring Understandings	Essential Knowledge and Practices
• The general theory of relativity is a theory of space and time. The central idea is that space and time are two aspects of spacetime. Spacetime is curved in the presence of mass (PH.9 c). • The strong nuclear force binds protons and neutrons in the nucleus. Fission is the breakup of heavier nuclei into lighter nuclei. Fusion is the combination of lighter nuclei into heavier nuclei. The study of these topics is called *nuclear physics* (PH.9 d). • Natural radioactivity is the spontaneous disintegration of unstable nuclei. Alpha, beta, and gamma rays are different emissions associated with radioactive decay (PH.9 d). • Solid state physics is the study of rigid matter or solids through methods such as quantum mechanics, crystallography, electromagnetism, and metallurgy. It is the largest branch of condensed matter physics (PH.9 e). • Matter behaves differently at nanometer scale (size and distance) than at macroscopic scale (PH.9 f). • Certain materials at very low temperatures exhibit the property of zero resistance called *superconductivity* (PH.9 g). • Nuclear physics is the study of the nature of atomic nuclei, including the interactions among protons, neutrons, and the quarks that comprise them (PH.9 d). • The Standard Model of particle physics is a theory concerning the electromagnetic, weak, and strong nuclear	

Enduring Understandings	Essential Knowledge and Practices
interactions, as well as classifying all the known subatomic particles (PH.9 h). • The fundamental particles (quarks, protons, and neutrons) that emerged in the early universe soon after the big bang are the same types of particles that are studied today in particle physics experiments at laboratories such as the Large Hadron Collider (LHC) in Switzerland and the Thomas Jefferson National Accelerator Facility (JLab) in Newport News, Virginia (PH.9 h).	