Physical Science Instructional Supports

To meet the goals of *EachChildOurFuture*, Ohio's strategic plan for education, schools and districts will find it essential to have appropriate local curricula supported by high-quality instructional materials. Science is part of providing well-rounded content for students, as *well-rounded content* is one of the four learning domains listed in the strategic plan.

Science is an essential subject for students in grades K-12. It is important to build a strong foundation in science in early elementary years so students are prepared for understanding more complex material in intermediate and middle grades. It is equally important to continue students' science instruction by offering more advanced courses at the high school level. This allows students to better compete for admission to college or other postsecondary programs, as well as jobs. Advanced science courses in high schools also help produce a more scientifically literate public.

The instructional supports are intended to provide resources that can be used by educators to:

- Increase their own content/pedagogical knowledge;
- Choose high-quality materials for use with students;
- Incorporate disciplinary literacy into instruction;
- Make connections within and across disciplines;
- Identify and address common misconceptions/naïve thinking;
- Attend to equity issues in order to address the needs of diverse learners;
- Locate databanks and other primary sources.

The resources listed in this document are provided to enhance planning, instruction and assessment and are not mandatory. Local districts are responsible for crafting their local curricula and identifying appropriate instructional resources and materials. These supports are curated by Ohio educators. This document is intended to be fluid in nature and feedback on the usefulness of any of the materials it contains is greatly appreciated. The Ohio Department of Education encourages educators statewide to submit best practice instructional strategies to be added to the instructional supports. The Department will review these submissions and update the instructional supports on a regular basis. Send suggestions and comments via email to the Department's Science Team.

NATURE OF SCIENCE RESOURCES

The information and resources in this section are intended to enhance understanding of the nature of science and effective science instruction. They are not linked to a specific standard but can be useful to educators as they plan instruction to guide students' developing understanding of science as a discipline and way of knowing.

NATURE OF SCIENCE

- In this Nature of Science video, Paul Andersen of Bozeman Science provides a clear picture of what is and is not science and how scientific knowledge advances. The video provides good background information for educators and also is appropriate for use with older students.

SCIENTIFIC AND ENGINEERING PRACTICES

- Paul Andersen of Bozeman Science has a series of videos that explain each of the eight scientific and engineering practices.
  - Asking questions and defining problems
  - Developing and using models
  - Planning and carrying out investigations
  - Analyzing and interpreting data
  - Using mathematics and computational thinking
  - Constructing explanations and designing solutions
  - Engaging in argument from evidence
  - Obtaining, evaluating and communicating information

INTRODUCTION AND SYLLABUS

COURSE DESCRIPTION

Physical science is a high school level course, which satisfies the Ohio Core science graduation requirements of Ohio Revised Code Section 3313.603. This section of Ohio law requires three units of science. Each course should include inquiry-based laboratory experience that engages students in asking valid scientific questions and gathering and analyzing information.

Physical science introduces students to key concepts and theories that provide a foundation for further study in other sciences and advanced science disciplines. Physical science comprises the systematic study of the physical world as it relates to fundamental concepts about matter, energy and motion. A unified understanding of phenomena in physical, living, Earth and space systems is the culmination of all previously learned concepts related to chemistry, physics, and Earth and space science, along with historical perspective and mathematical reasoning.

COURSE CONTENT

The following information may be taught in any order; there is no ODE recommended sequence.

PS.M: STUDY OF MATTER

PS.M.1: Classification of matter
- Heterogeneous vs. homogeneous
- Properties of matter
- States of matter and its changes

PS.M.2: Atoms
- Models of the atom (components)
- Ions (cations and anions)
- Isotopes

PS.M.3: Periodic trends of the elements
- Periodic law
- Representative groups

PS.M.4: Bonding and compounds
- Bonding (ionic and covalent)
- Nomenclature

PS.M.5: Reactions of matter
- Chemical reactions
- Nuclear reactions

PS.EW: ENERGY AND WAVES

PS.EW.1: Conservation of energy
- Quantifying kinetic energy
- Quantifying gravitational potential energy

PS.EW.2: Transfer and transformation of energy (including work)

PW.EW.3: Waves
- Refraction, reflection, diffraction, absorption, superposition
- Radiant energy and the electromagnetic spectrum
- Doppler shift

PS.EW.4: Thermal energy

PS.EW.5: Electricity
- Movement of electrons
- Current
- Electric potential (voltage)
- Resistors and transfer of energy

PS.FM: FORCES AND MOTION

PS.FM.1: Motion
- Introduction to one-dimensional vectors
- Displacement, velocity (constant, average and instantaneous) and acceleration
- Interpreting position vs. time and velocity vs. time graphs

PS.FM.2: Forces
- Force diagrams
- Types of forces (gravity, friction, normal, tension)
- Field model for forces at a distance

PS.FM.3: Dynamics (how forces affect motion)
- Objects at rest
- Objects moving with constant velocity
- Accelerating objects

PS.U: THE UNIVERSE

PS.U.1: History of the universe

PS.U.2: Galaxies

PS.U.3: Stars
- Formation: stages of evolution
- Fusion in stars

NATURE OF SCIENCE (HIGH SCHOOL)

Nature of Science
One goal of science education is to help students become scientifically literate citizens able to use science as a way of knowing about the natural and material world. All students should have sufficient understanding of scientific knowledge and scientific processes to enable them to distinguish what is science from what is not science and to make informed decisions about career choices, health maintenance, quality of life, community and other decisions that impact both themselves and others.

Categories	High School
Scientific Inquiry, Practice and Applications All students must use these scientific processes with appropriate laboratory safety techniques to construct their knowledge and understanding in all science content areas.	• Identify questions and concepts that guide scientific investigations. • Design and conduct scientific investigations using a variety of methods and tools to collect empirical evidence, observing appropriate safety techniques. • Use technology and mathematics to improve investigations and communications. • Formulate and revise explanations and models using logic and scientific evidence (critical thinking). • Recognize and analyze explanations and models. • Communicate and support scientific arguments.

Science is a Way of Knowing
Science assumes the universe is a vast single system in which basic laws are consistent. Natural laws operate today as they did in the past and they will continue to do so in the future. Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise and extend this knowledge.
	• Various science disciplines use diverse methods to obtain evidence and do not always use the same set of procedures to obtain and analyze data (i.e., there is no one scientific method).
	  o Make observations and look for patterns.
	  o Determine relevant independent variables affecting observed patterns.
	  o Manipulate an independent variable to affect a dependent variable.
	  o Conduct an experiment with controlled variables based on a question or hypothesis.
	  o Analyze data graphically and mathematically.
	• Science disciplines share common rules of evidence used to evaluate explanations about natural phenomenon by using empirical standards, logical arguments and peer reviews.
	  o Empirical standards include objectivity, reproducibility, and honest and ethical reporting of findings.
	  o Logical arguments should be evaluated with open-mindedness, objectivity and skepticism.
	• Science arguments are strengthened by multiple lines of evidence supporting a single explanation.
	• The various scientific disciplines have practices, methods and modes of thinking that are used in the process of developing new science knowledge and critiquing existing knowledge.

Science is a Human Endeavor Science has been, and continues to be, advanced by individuals of various races, genders, ethnicities, languages, abilities, family backgrounds and incomes.	• Science depends on curiosity, imagination, creativity and persistence. • Individuals from different social, cultural, and ethnic backgrounds work as scientists and engineers. • Science and engineering are influenced by technological advances and society; technological advances and society are influenced by science and engineering. • Science and technology might raise ethical, social and cultural issues for which science, by itself, does not provide answers and solutions.
Scientific Knowledge is Open to Revision in Light of New Evidence Science is not static. Science is constantly changing as we acquire more knowledge.	• Science can advance through critical thinking about existing evidence. • Science includes the process of comparing patterns of evidence with current theory. • Some science knowledge pertains to probabilities or tendencies. • Science should carefully consider and evaluate anomalies (persistent outliers) in data and evidence. • Improvements in technology allow us to gather new scientific evidence.

*Adapted from Appendix H – Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards

PS.M: STUDY OF MATTER

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PS.M.2: Atoms

- Models of the atom (components)
- Ions (cations and anions)
- Isotopes

PS.M.3: Periodic trends of the elements

- Periodic law
- Representative groups

PS.M.4: Bonding and compounds

- Bonding (ionic and covalent)
- Nomenclature

PS.M.5: Reactions of matter

- Chemical reactions
- Nuclear reactions

CONTENT ELABORATION: STUDY OF MATTER

PS.M.1: Classification of matter

Matter was introduced in the elementary grades and the learning progression continued through middle school to include differences in the physical properties of solids, liquids and gases. Elements, compounds, mixtures, molecules, kinetic and potential energy and the particulate nature of matter were introduced. Content in Chemistry (e.g., electron configuration, molecular shapes, bond angles) will build on concepts in this course.

Matter can be classified in broad categories, such as homogeneous and heterogeneous, according to its composition or by its chemical properties (e.g., reactivity, flammability, pH) and physical properties (e.g., color, solubility, odor, hardness, density, conductivity, melting point and boiling point, viscosity, malleability). Solutions are homogeneous mixtures of a solute dissolved in a solvent. The amount of a solid solute that can dissolve in a solvent generally increases as the temperature increases since the particles have more kinetic energy to overcome the attractive forces between them. Water is often used as a solvent since so many substances will dissolve in water. Aqueous solutions can be classified as acidic (below 7 on the pH scale), neutral (7 on the pH scale), or basic (above 7 on the pH scale), but the discussion of hydroxide and hydrogen ions as they relate to the pH scale is reserved for Chemistry. Physical properties can be used to separate the substances in mixtures, including solutions.

Phase changes can be represented by graphing the temperature of a sample vs. the time it has been heated. Investigations include collecting data during heating, cooling and solid-liquid-gas phase changes. At times, the temperature will change steadily, indicating a change in the motion of the particles and the kinetic energy of the substance. However, during a phase change, the temperature of a substance does not change, indicating there is no change in kinetic energy. Since the substance continues to gain or lose energy during phase changes, these changes in energy are potential and indicate a change in the position of the particles.

When heating a substance, a phase change will occur when the kinetic energy of the particles is great enough to overcome the attractive forces between the particles; the substance then melts or boils. Conversely, when cooling a substance, a phase change will occur when the kinetic energy of the particles is no longer great enough to overcome the attractive forces between the particles; the substance then condenses or freezes. Phase changes are examples of changes that can occur when energy is absorbed from the surroundings (endothermic) or released into the surroundings (exothermic). When thermal energy is added to a solid, liquid or gas, most substances increase in volume because the increased kinetic energy of the particles causes an increased distance between the particles. This results in a change in density of the material. Generally, solids have greater density than liquids, which have greater density than gases due to the spacing between the particles. The density of a substance can be calculated from the slope of a mass vs. volume graph. Differences in densities can be determined by interpreting mass vs. volume graphs of the substances. Students should be able to calculate mass, volume or density, given two of the three values.

PS.M.2: Atoms
Content introduced in middle school, where the atom was introduced as a small, indestructible sphere, is further developed in this course. Over time, technology was introduced that allowed the atom to be studied in more detail. The atom is composed of protons, neutrons and electrons that have measurable properties, including mass and, in the case of protons and electrons, a characteristic charge. An atom is empty space with a very small positively charged nucleus. The nucleus is composed of protons and neutrons. The electrons move about in the empty space that surrounds the nucleus. Although current understanding goes beyond the Bohr Model, it still be used to represent the atom and develop the idea of valence electrons. Experimental evidence that led to the development of historic atomic models is reserved for Chemistry.

All atoms of a particular element have the same atomic number; an element may have different isotopes with different mass numbers. Atoms may gain or lose valence electrons to become anions or cations. Atomic number, mass number, charge and identity of the element can be determined from the numbers of protons, neutrons and electrons. Atomic mass calculations and explanations about configuration of electrons and how atomic spectra are produced are reserved for Chemistry.

PS.M.3: Periodic trends of the elements
Content from the middle school level, specifically the properties of metals, nonmetals and metalloids and their positions on the periodic table, is further expanded in this course. The periodic table was arranged so that elements with similar chemical and physical properties are in the same group or family. When elements are listed in order of increasing atomic number, the same sequence of properties appears over and over again; this is the periodic law. Trends in simple observable properties, like density or melting point, can be examined within families or groups on the periodic table. These trends allow scientists to make predictions about new elements. Metalloids are elements that have some properties of metals and some properties of nonmetals. Metals, nonmetals, metalloids, periods and groups or families, including the alkali metals, alkaline earth metals, halogens and noble gases, can be identified by their positions on the periodic table. Elements in Groups 1, 2 and 17 have characteristic ionic charges that will be used in this course to predict the formulas of compounds. Other trends in the periodic table (e.g., atomic radius, electronegativity, ionization energies) are reserved for Chemistry.

PS.M.4: Bonding and compounds
Middle school content introduced the concept that compounds are composed of atoms of two or more different elements joined together chemically. In this course, the chemical joining of atoms is studied in more detail. Atoms may be bonded together by losing, gaining or sharing valence electrons to form molecules or three-dimensional lattices. An ionic bond involves the attraction of two oppositely charged ions, typically a metal cation and a nonmetal anion formed by transferring electrons between the atoms. An ion attracts oppositely charged ions from every direction, resulting in the formation of a three-dimensional lattice. Covalent bonds result from the sharing of electrons between two atoms, usually nonmetals. Covalent bonding can result in the formation of structures ranging from small individual molecules to three-dimensional lattices (e.g., diamond). The bonds in most compounds fall on a continuum between the two extreme models of bonding: ionic and covalent.

Using the periodic table to determine ionic charge, formulas of ionic compounds containing elements from groups 1, 2, 17, hydrogen and oxygen can be predicted. Given a chemical formula, a compound can be named using conventional systems that include Greek prefixes where appropriate. Prefixes will be limited to represent values from one to 10. Given the name of an ionic or covalent substance, formulas can be written. Naming organic molecules is beyond this grade level and is reserved for an advanced chemistry course. Prediction of bond types from electronegativity values, polar covalent bonds, and writing formulas/naming compounds that contain polyatomic ions or transition metals are reserved for Chemistry.

PS.M.5: Reactions of matter

In middle school, the law of conservation of matter was expanded to chemical reactions, noting that the number and type of atoms and the total mass are the same before and after the reaction. In this course, conservation of matter is expressed by writing balanced chemical equations. At this level, reactants and products can be identified from an equation and simple equations can be written and balanced given either the formulas of the reactants and products or a word description of the reaction. Stoichiometric relationships beyond the coefficients in a balanced equation and classification of types of chemical reactions are reserved for Chemistry.

During chemical reactions, thermal energy is either transferred from the system to the surroundings (exothermic) or transferred from the surroundings to the system (endothermic). Since the environment surrounding the system can be large, temperature changes in the surroundings may not be detectable.

Nuclear reactions involve changes to the nucleus and typically produce much larger energies than chemical reactions. The strong nuclear force is an attractive force that binds protons and neutrons together in the nucleus. While the nuclear force is extremely weak at most distances, over the very short distances present in the nucleus the force is greater than the repulsive electrical forces among protons. When the attractive nuclear forces and repulsive electrical forces in the nucleus are not balanced, the nucleus is unstable. Through radioactive decay, the unstable nucleus emits radiation in the form of very fast-moving particles and energy to produce a new nucleus. Nuclei that undergo this process are said to be radioactive. Radioactive decay can result in the release of different types of radiation (alpha, beta, gamma), each with a characteristic mass, charge, and potential to alter and penetrate the material it strikes. Alpha decay changes the identity of the element. Beta decay results from the decay of a neutron. When a radioisotope undergoes alpha or beta decay, the resulting nucleus can be predicted and the balanced nuclear equation can be written.

For any radioisotope, the half-life is unique and predictable. Graphs can be constructed that show the amount of a radioisotope that remains as a function of time and can be interpreted to determine the value of the half-life. Half-life values are used in radioactive dating. Only whole number integers of half-lives will be addressed in this course.

Other examples of nuclear processes include nuclear fission and nuclear fusion. Nuclear fission involves splitting a large nucleus into smaller nuclei, releasing large quantities of energy. Nuclear fusion is the joining of smaller nuclei into a larger nucleus accompanied by the release of large quantities of energy. Nuclear fusion is the process responsible for formation of elements in the universe beyond hydrogen and is the source of energy in the sun and other stars. Using nuclear reactions as an energy resource can be addressed. Further details about nuclear processes, including mass-energy equivalence and nuclear power applications, are addressed in Physics.

EXPECTATIONS FOR LEARNING

The content in the standards needs to be taught in ways that incorporate the nature of science and engage students in scientific thought processes. Where possible, real-world data and problem- and project-based experiences should be utilized. *Ohio's Cognitive Demands* relate to current understanding and research about the ways people learn and are important aspects to the overall understanding of science concepts. Care should be taken to provide students opportunities to engage in all four types of thinking. Additionally, lessons need to be designed so that they incorporate the concepts described in the *Nature of Science*.

VISIONS INTO PRACTICE: CLASSROOM EXAMPLES

This section provides guidance for developing classroom tasks that go beyond traditional approaches to instruction. It is a springboard for generating innovative ideas to address the cognitive demands. A variety of activities are presented so that teachers can select those that best meet the needs of their students. This is not an all-inclusive checklist and is not intended to cover every aspect of the standards. **These activities are suggestions and are not mandatory.**

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.M.1: Classification of matter			
Heterogeneous vs. homogeneous			
Devise a method to purify water in developing countries.	Design a procedure to separate a homogeneous or heterogeneous mixture.	Using data from various physical separation techniques, construct a particle diagram for a mixture based on the particulate nature of matter.	Identify samples of matter as homogeneous or heterogeneous (e.g., salt water, chicken noodle soup).
Properties of matter			
	Investigate the effect of various factors (e.g., temperature, surface area of solute, stirring) on the rate materials (such as sugar cubes, salt crystals) dissolve.	Explain the process of burning a candle in terms of physical and chemical changes. Compare acids and bases found in the home (e.g., household cleaning products, soaps, coffee, soda, vinegar, fruit juices, antacids) using experimentally determined pH data from meters or from universal indicators.	Explain the location of acids, bases and neutral substances on the pH scale.
States of matter and its changes			
		Using a phase change diagram, determine the phase of water and other substances at different temperatures.	Identify the various phase changes and classify them as endothermic or exothermic.
PS.M.2: Atoms			
	Design and implement a procedure to test for the presence of common dissolved ions.	Research cations and anions and how they function in everyday products (e.g., as hair products, car washes, dryer sheets). Describe the difference between hard and soft water. Model the formation of ions with particle diagrams or manipulatives. Interpret the presence of dissolved ions in water with respect to human health.	Describe the location, charge, and relative size of a proton, neutron, and electron. Use information from the periodic table to calculate numbers of protons, neutrons and electrons for an element. Use this information to draw a Bohr model of the element. Define isotope and provide an example. Explain the importance of valence electrons. Use the periodic table and/or electron dot diagrams to identify the ionic charge of elements in groups 1, 2, 17, and 18.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.M.3: Periodic trends of the elements			
Design an alternate arrangement of elements in the periodic table.		Develop a flow chart or dichotomous key to identify a substance as a metal, nonmetal or metalloid. Explain the differences between the properties/ionic charge of 2 elements chosen from groups 1, 2, 17 and 18.	Using the periodic table and/or electron dot diagrams, identify the ionic charge of elements in groups 1, 2, 17 and 18. Explain why elements are grouped into families. Identify metals, nonmetals, metalloids, alkali metals, alkaline earth metals, halogens and noble gases based on their positions on the periodic table.
PS.M.4: Bonding and compounds			
Bonding (ionic and covalent)			
		Using modeling, compare ionic and covalent compounds in terms of molecular and three-dimensional lattice formation.	Describe how ionic and covalent bonds are formed in terms of valence electrons. Given elements and their locations on the periodic table, predict if they will form ionic or covalent compounds.
Nomenclature			
		Use naming conventions to find an example of a covalent compound and an ionic compound in an ingredient list. Explain why having a standard set of naming and formula writing rules is important.	Name the Greek prefixes 1-10. Given two elements, predict the chemical formula and name of an ionic compound (for example, calcium and chlorine = $CaCl_2$ = calcium chloride). Name binary covalent molecules and binary ionic compounds when given formulas. Determine the formulas for covalent molecules and binary ionic compounds when given their names.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.M.5: Reactions of matter			
Chemical reactions			
		Explain why $Na + Br_2$ yields $NaBr$ and not $NaBr_2$. Investigate safe chemical reactions (e.g., vinegar and baking soda in a Ziploc bag) to determine if they are exothermic or endothermic.	Give an example where temperature change is observable without measurement, where temperature change is observable with a thermometer, and where temperature change is impossible to measure. Balance a chemical equation when provided the formulas of reactants and products.
Nuclear reactions			
		Use the half-life of C-14 to explain appropriate uses of carbon dating. Describe how the radioactive isotopes of several elements are used in medical testing. Describe the short- and long-term effects of nuclear wastes on the environment. Research and interpret the consequences, information and technology involved in the discovery or synthesis of new elements. Include historical references (e.g., Madame Curie).	Describe alpha, beta and gamma radiation. Compare nuclear fission and nuclear fusion. Identify applications of radioisotopes.

RESOURCES FOR TEACHERS

Diverse Learners

- Investigate the density of differing concentrations of salt water. All students participate in designing the investigative methods and collecting data. Assign different data display and analysis methods to meet the math preparation of various students. Calculation of the density (D=M/V) for individual samples can be done by students with emerging math skills. Other students can find the density of a solution by plotting a mass vs. volume graph for a set of samples and finding the slope of the line of best fit. Mass vs. volume graphs with multiple lines can compare the densities of several different concentrations of salt water. More advanced students could be asked to design data displays that elicit more nuanced patterns, such as whether the change in density with concentration is linear. Have them share in heterogeneous groups and discuss how the various data sets/displays support each other. Determine a consensus model for how density changes with concentration for salt water. One extension would be to investigate whether the model extends to other solutions.
- This chromatography lesson provides a simple but engaging way to investigate mixtures and separation techniques. It is written toward beginners, but there are some suggested extensions or opportunities to adapt lessons for students working at or above grade level. It also could be used to introduce applications of mixture separation, such as forensics or pharmaceutical research.
- The Ohio Department of Education provides strategies for meeting the needs of all learners, including gifted students, English learners and students with disabilities.
- Resources based on the Universal Design for Learning principles are available at CAST.org.

Connections within and across disciplines

- This poem describes the changing states of matter. Use it to approach the content from a different perspective or collaborate with language arts teachers to include it in a poetry unit. Challenge students to create poetry that explains science concepts as an option for assessing student understanding.
- Investigate how technological advances led to increased understanding of atomic structure. Include research into current technologies being used to refine human understanding of the interactions of subatomic particles. Make and support a claim whether computer science or mechanical technologies were more instrumental in advancing understanding of atomic structure and the behavior of subatomic particles.
- Examine salt and sugar crystals under a microscope. Discuss how these crystal structures relate to ionic or covalent bonding. Compare the two crystal structures from an engineering perspective. Relate the relative structural strength to the strength of the two types of bonds.

Common Misconceptions

Misconception	Accurate science	Links/resources/suggestions
Breaking bonds releases energy.	Energy is required to break bonds and energy is released in the formation of bonds.	Question: Can you break a large piece of wood? Would it require energy to do this?
Models are simply physical copies of the real thing and used solely to communicate known information.	Models are conceptual representations that are important scientific tools. Models are used to formulate and refine scientific ideas. Models take many forms and can be used to construct knowledge. Their use in the classroom allows students to actively process new information about complex ideas concerning mechanisms and functions.	This video explains using modeling instruction in the classroom. This research study on the use of models by teachers and students shows that teachers' classroom use of models differs from scientific use of modeling. It also examines how students refine models over time.
Models can duplicate reality.	Models can do many things but, by definition, do not duplicate reality. Models can be simplifications of reality, conceptual reference frames, analogies, frameworks for inquiry, structures for analyzing systems or methods for showing other aspects of phenomena.	This Tools of Science: Modeling video could be used with students.
When multiple models are presented, there is one "right" model.	All models have limitations. Various models highlight different aspects of a system or concept. Different models may be "best" at different things.	It is important to engage students in the modeling process and allow them to develop and refine models over time. STEM Teaching Tools has a practice brief that overviews the use of modeling in the classroom and provides links to various resources.

Vocabulary

Science vocabulary is most effectively mastered when it is introduced in the natural course of instruction. Rather than being taught in isolation at the beginning of a lesson or unit, vocabulary should be taught as the need for a term is encountered. Starting instruction by defining vocabulary lists is discouraged. Careful modeling of the correct use of scientific terminology by the instructor, along with the encouragement of rich student discourse, is a better way to integrate the correct usage of scientific vocabulary into students' existing understandings. Teachers should encourage students to use proper terms as they ask questions, design experiments and support claims with evidence. Traditional word walls can be replaced with student-created illustrations of terms or scientific models annotated with proper vocabulary. Refer to STEM Teaching Tools Practice Brief 66 for more information.

RESOURCES FOR USE WITH STUDENTS

Lessons and Classroom Materials

- The University of Colorado publishes a series of free PhET simulations that can be used to support this content. Simulations of particular application to the study of matter include *Build An Atom*, *Build a Molecule*, *States of Matter*, *Balancing Chemical Equations* and *pH Scale*. PhET simulations also are available through a low-priced app.
- Investigate alternate methods to measure pH (for example, cabbage juice, pH meters, liquid or paper indicators). Make comparisons of precision, accuracy, cost, safety, availability and appropriate uses.
- Have each student group determine a method to collect data to create a phase change graph. Share and critique other group plans through a gallery walk or shared document folder. Carry out the investigations and compare resulting graphs to identify common patterns. Discuss what could account for differences between graphs. Determine a consensus model for what is happening during a phase change.
- The American Association for the Advancement of Science (AAAS) *Science NetLinks* project has a series of lessons on isotopes and radioactive decay. The first, Isotopes of Pennies, uses pre- and post-1982 pennies to investigate how mass numbers reflect the relative abundance of various isotopes. The second lesson, Radioactive Decay: A Sweet Simulation of a Half-Life, guides students to understand half-life with a simulation of radioactive decay using candies. Since using edible items in a science laboratory is discouraged, you may wish to substitute an alternative item. The final activity, Frosty the Snowman Meets His Demise: An Analogy to Carbon Dating, allows students to discover how observations in the present can be used to calculate the timing of events in the past.
- Research the chemical formulas for ingredients in common household products (such as food, cleaning supplies, medications, swimming pool products) to determine whether they contain ionic or covalent bonds.
- Use real-world examples to investigate the differences between an element in its elemental state versus in a compound (elemental sodium vs. sodium in table salt, chlorine vs. chlorine in a pool, fluorine vs. fluoride compounds in toothpaste).
- The Rutherford experiment is a simulation that shows high-speed particles bombarding a thin foil. While the simulation is not to scale, it does provide a dynamic visual to help students understand what is happening at the atomic level to explain Rutherford's experimental evidence.

Media

It is important to incorporate a variety of primary and secondary sources of information so students learn to reflect on, and engage in, quality discourse around pertinent topics, as well as evaluate the validity of information sources. Using media is a natural way to support disciplinary literacy or integrate science with English language arts. The following materials are relevant to this standard and can be incorporated into lessons. Students and classes have a variety of characteristics and needs. Always preview materials before use to determine appropriateness.

Articles

- This *New Yorker* article, The Histories Hidden in the Periodic Table, connects to the *Science is a Human Endeavor* section of the *Nature of Science* as it discusses lesser-known sides of the discovery of elements and development of the Periodic Table.

PS.EW: ENERGY AND WAVES

PS.EW.1: Conservation of energy

- Quantifying kinetic energy
- Quantifying gravitational potential energy

PS.EW.2: Transfer and transformation of energy (including work)

PS.EW.3: Waves

- Refraction, reflection, diffraction, absorption, superposition
- Radiant energy and the electromagnetic spectrum
- Doppler shift

PS.EW.4: Thermal energy

PS.EW.5: Electricity

- Movement of electrons
- Current
- Electric potential (voltage)
- Resistors and transfer of energy

CONTENT ELABORATION: ENERGY AND WAVES

Building upon knowledge gained in elementary and middle school, major concepts about energy and waves are further developed. Conceptual knowledge will move from qualitative understandings of energy and waves to ones that are more quantitative using mathematical formulas, manipulations and graphical representations.

PS.EW.1: Conservation of energy

Energy content learned in middle school, specifically conservation of energy and the basic differences between kinetic and potential energy, is elaborated on and quantified in this course. Energy has no direction and has units of joules (J). Kinetic energy, E_k, can be mathematically represented by $E_k = \frac{1}{2}mv^2$. Gravitational potential energy, E_g, can be mathematically represented by $E_g = mgh$. The amount of gravitational potential energy of an object is measured relative to a reference that is considered to be at a point of zero energy. The reference may be changed to help understand different situations. Only the change in the amount of energy can be measured absolutely. The conservation of energy and equations for kinetic and gravitational potential energy can be used to calculate values associated with energy (for example, height, mass, speed) for situations involving energy transfer and transformation. Opportunities to quantify energy from data collected in experimental situations (for example, a swinging pendulum, a car traveling down an incline) should be provided.

PS.EW.2: Transfer and transformation of energy (including work)

In middle school, concepts of energy transfer and transformation were addressed. Topics included conservation of energy, conduction, convection and radiation, the transformation of electrical energy and the dissipation of energy into thermal energy. Work was introduced as a method of energy transfer into or out of the system when an outside force moves an object over a distance. In this course, these concepts are further developed. As long as the force, F, and displacement, Δx, are in the same or opposite directions, work, W, can be calculated from the equation $W = F\Delta x$. Work can also be quantified as $W = \Delta E$. Energy transformations for a phenomenon can be represented through a series of pie graphs or bar graphs. Equations for work, kinetic energy and potential energy can be combined with the law of conservation of energy to solve problems; conceptual understanding of kinetic energy, potential energy and work should be emphasized. When energy is transferred from one system to another, some of the energy is transformed to thermal energy. Since thermal energy involves the random movement of many trillions of subatomic particles, it is less able to be organized to bring about further change. Therefore, even though the total amount of energy remains constant, less energy is available for doing useful work.

PS.EW.3: Waves
As addressed in middle school, waves transmit energy from one place to another, can transfer energy between objects and can be described by their speed, wavelength, frequency and amplitude. These concepts were applied to seismic waves traveling through different materials. In elementary and middle school, reflection and refraction of light were introduced, as was absorption of radiant energy by transformation into thermal energy. In this course, these processes are conceptually addressed (not mathematically) from the perspective of waves and expanded to include other types of energy that travel in waves. When a wave encounters a new material, the new material may absorb the energy of the wave by transforming it to another form of energy, usually thermal energy. Waves can be reflected off solid barriers or refracted when a wave travels from one medium into another medium. Waves may undergo diffraction around small obstacles or openings. When two waves traveling through the same medium meet, they pass through each other and continue traveling through the medium as before. When the waves meet, they undergo superposition, demonstrating constructive and destructive interference. Sound travels in waves and undergoes reflection, refraction, interference and diffraction. In Physics, many of these wave phenomena will be studied further and quantified. Radiant energy travels in waves and does not require a medium. Sources of light energy (e.g., the sun, a light bulb) radiate energy continuously in all directions. Radiant energy has a wide range of frequencies, wavelengths and energies arranged into the electromagnetic spectrum. The electromagnetic spectrum is divided into bands that have different applications in everyday life: radio (lowest energy), microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays (highest energy).

Radiant energy of the entire electromagnetic spectrum travels at the same speed in a vacuum. Specific frequency, energy, or wavelength ranges of the electromagnetic spectrum are not required. However, the relative positions of the different bands, including the colors of visible light, are important (e.g., ultraviolet has more energy than microwaves). Total radiant energy depends on more than just the frequency. Radiant energy exhibits wave behaviors including reflection, refraction, absorption, superposition and diffraction. For opaque objects (e.g., paper, a chair, an apple), little if any radiant energy is transmitted into the new material. However, the radiant energy can be absorbed, usually increasing the thermal energy of the object and/or the radiant energy can be reflected. For rough objects, the reflection in all directions forms a diffuse reflection, and for smooth shiny objects, reflections can result in clear images. Transparent materials transmit most of the energy through the material but smaller amounts of energy may be absorbed or reflected.

Changes in the observed frequency and wavelength of a wave can occur if the wave source and the observer are moving relative to each other. When the source and the observer are moving toward each other, the wavelength is shorter and the observed frequency is higher; when the source and the observer are moving away from each other, the wavelength is longer and the observed frequency is lower. This phenomenon is called the Doppler shift and can be illustrated by listening to an ambulance siren as it travels past. As discussed in the Universe section of this course, this phenomenon is important to current understanding of how the universe is expanding. As a result, the light we receive from distant galaxies has a noticeable shift toward redder wavelengths (the so-called "redshift"). Calculations to measure the apparent change in frequency or wavelength are not appropriate for this course.

PS.EW.4: Thermal energy
In middle school, thermal energy is introduced as the energy of movement of the particles that make up matter. Processes of heat transfer, including conduction, convection and radiation, were studied. In other sections of this course, the role of thermal energy during heating, cooling and phase changes is explored conceptually and graphically. In this course, rates of thermal energy transfer and thermal equilibrium are introduced. Thermal conductivity depends on the rate at which thermal energy is transferred from one end of a material to another. Thermal conductors have a high rate of thermal energy transfer and thermal insulators have a slow rate of thermal energy transfer. The rate at which thermal radiation is absorbed or emitted by a system depends on its temperature, color, texture and exposed surface area. All other things being equal, in a given amount of time, black, rough surfaces absorb more thermal energy than smooth, white surfaces. An object or system is continuously absorbing and emitting thermal radiation. If the object or system absorbs more thermal energy than it emits and there is no change in phase, the temperature increases. If the object or system emits more thermal energy than is absorbed and there is no change in phase, the temperature decreases. For an object or system in thermal equilibrium, the amount of thermal energy absorbed is equal to the amount of thermal energy emitted; therefore, the temperature remains constant. In Chemistry, changes in thermal energy will be quantified for substances that change their temperature.

PS.EW.5: Electricity

In earlier grades, concepts of electrical conductors and insulators were introduced. A complete loop is needed for an electrical circuit that may be in parallel or in series. In this course, current, voltage and resistance are introduced conceptually to explain what was observed in middle school. The differences between electrical conductors and insulators can be explained by how freely the electrons flow throughout the material due to how firmly electrons are held by the nucleus. By convention, electric current is the rate at which positive charge flows in a circuit. In reality, it is the negatively charged electrons that are actually moving. Current is measured in amperes (A). An ampere is equal to one coulomb of charge per second (C/s). In an electric circuit, the power source supplies the electrons already in the circuit with electric potential energy by doing work to separate opposite charges. For a battery, the energy is provided by a chemical reaction that separates charges on the positive and negative sides of the battery. This separation of charge is what causes the electrons to flow in the circuit. These electrons then transfer energy to other objects and transform electrical energy into other forms (e.g., light, sound, heat) in the resistors. Current continues to flow even after the electrons transfer their energy. Resistors oppose the rate of charge flow in the circuit. The potential difference or voltage across an energy source is a measure of potential energy in joules supplied to each coulomb of charge. The volt (V) is the unit of potential difference and is equal to one joule of energy per coulomb of charge (J/C). Potential difference across the circuit is a property of the energy source and does not depend upon the devices in the circuit. These concepts can be used to explain why current will increase as the potential difference increases and as the resistance decreases. Experiments, investigations and testing (3-D or virtual) are used to construct a variety of circuits and to measure and compare the potential difference (voltage) and current. Circuits are dealt with conceptually in this course. Calculations are reserved for Physics.

EXPECTATIONS FOR LEARNING

The content in the standards needs to be taught in ways that incorporate the nature of science and engage students in scientific thought processes. Where possible, real-world data and problem- and project-based experiences should be utilized. *Ohio's Cognitive Demands* relate to current understanding and research about the ways people learn and are important aspects to the overall understanding of science concepts. Care should be taken to provide students opportunities to engage in all four types of thinking. Additionally, lessons need to be designed so that they incorporate the concepts described in the *Nature of Science*.

VISIONS INTO PRACTICE: CLASSROOM EXAMPLES

This section provides guidance for developing classroom tasks that go beyond traditional approaches to instruction. It is a springboard for generating innovative ideas to address the cognitive demands. A variety of activities are presented so that teachers can select those that best meet the needs of their students. This is not an all-inclusive checklist and is not intended to cover every aspect of the standards. **These activities are suggestions and are not mandatory.**

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.EW.1: Conservation of energy			
	Devise a procedure to calculate the speed of an object at constant velocity using a meter stick and a stopwatch or a frame-by-frame motion video. Use measured speed and mass to calculate kinetic energy.		Calculate potential energy given an object's mass and its height above a reference point. Calculate the kinetic energy of a moving object given the mass and velocity. Calculate the drop heights of objects based on their velocity at impact. Explain how the gravitational potential energy of an object varies based on the position of the reference point. Use the principle of conservation of energy to solve for an unknown quantity in a problem (e.g., beginning gravitational potential energy equals final kinetic energy for a falling object).
PS.EW.2: Transfer and transformation of energy (including work)			
	Design and conduct an investigation to estimate the energy lost (dissipated) in each bounce of a bouncing ball.	Use data to explain energy transformations occurring in a closed system.	Calculate the amount of work done by a force applied to an object. Calculate the amount of work transferred into or out of a system using changes in energy.
Awesome roller coaster design			
Design and build a roller coaster with at least two loops and one hill. Use the roller coaster to calculate kinetic and potential energy and identify the quantity of energy transferred out of the system during the ride. Then engineer a new design that would decrease the energy loss from the system.	Design a method to estimate the energy transferred to the surrounding environment as thermal energy through work done by frictional forces.	Label the rollercoaster to identify places where energy is converted from one type to another (e.g., where kinetic energy is being converted into gravitational potential energy). Explain how the gravitational potential energy of an object varies based on the position of the reference point.	Calculate the velocity at the bottom and top of each hill based on conservation of energy. Measure the velocity of the object at the bottom of each hill. Compare the measured velocity to the calculated velocity.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.EW.3: Waves			
Design an experiment to investigate radiant energy transmission, absorption, and reflection with a variety of materials (e.g., opaque, transparent, rough, smooth). Investigate the relationship between speed, frequency and wavelength for a transverse wave traveling through a Slinky®. Make claims about what happens to the speed and the wavelength of the wave as the frequency is increased and give evidence to support any claims. For example, use information from the investigation to explore the implications of cell phone usage. Include beneficial and harmful aspects of the use of this technology.	Construct a model to compare mechanical waves and electromagnetic waves. Research an observable wave phenomenon and design a demonstration to present to the class.	Give examples and illustrate wave behaviors, including reflection, refraction, absorption, diffraction, and superposition. Identify the placement of each type of wave (e.g., gamma, x-ray, ultraviolet, visible, infrared, micro, radio) along the electromagnetic spectrum. Compare the relative wave energy, frequency and wavelength of different regions of the electromagnetic spectrum. Describe how the Doppler shift effect can produce a change in frequency for sound waves. Explain how sound or radiant waves are used in medicine or everyday life applications (e.g., ultrasound, lasers, x-rays).	Design an experiment to investigate radiant energy transmission, absorption, and reflection with a variety of materials (e.g., opaque, transparent, rough, smooth).
PS.EW.4: Thermal Energy			
Design a "cooler" cooler			
Use thermal conductivity concepts to improve a cooler design to keep beverages cold. Improve the design of the cooler to further reduce the transfer of thermal energy.	Design a method to investigate the thermal conductivity of potential materials to be used in the design.	Graphically compare potential materials based on the results of the investigations.	Differentiate between a thermal insulator and a thermal conductor. Provide examples of each.

Designing technological/engineering solutions using science concepts	**Demonstrating science knowledge**	**Interpreting and communicating science concepts**	**Recalling accurate science**
PS.EW.5 - Electricity			
Given several circuit boards where current does not flow, determine why the current is not flowing and implement a solution to resolve the problem. Design a circuit that produces the maximum amount of light from a given set of materials (e.g., light bulbs, LEDs, various lengths of wires, batteries).	Design an investigation to determine the relationship between potential difference and current through a resistor.	Illustrate electric flow in parallel and series circuits. Explain situations where each type of circuit is more advantageous. Explain how resistance is an important concept in an engineering design context (e.g., determining how many light fixtures a circuit can handle, understanding how lack of insulation can cause short circuits).	Differentiate how electrons move in an insulator vs. a conductor. Compare the flow of electrons in a circuit to the flow of electrical energy. Analyze a circuit or schematic, to determine if it is a series or parallel circuit. Define and measure current, voltage and resistance. Explain that cells are joined together to form a battery. Explain conceptually how batteries generate electric current.
Design an electrically powered alarm system.			
Design an alarm system that uses a change in a circuit to indicate that the alarm has been triggered, (e.g., a short circuit changing current flow through a branch, a branch of a circuit opening to cease current flow).		Explain how the system sets off the alarm in terms of changes in current or potential difference in the circuit.	

RESOURCES FOR TEACHERS

Equity/Diverse Learners

- The Ohio Department of Education provides strategies for meeting the needs of all learners, including gifted students, English learners and students with disabilities.
- Resources based on the Universal Design for Learning principles are available at CAST.org.

Connections within and across disciplines

- The Climate Literacy and Energy Awareness Network (CLEAN) has a variety of resources to teach about energy. Resources to build energy literacy include background information, videos and teaching strategies for each of seven energy principles. These principles explore energy as it relates to physical and biological systems and human societies.
- The STEMCoding Project at The Ohio State University has a video and sample code for generating wave interference to explore constructive and destructive interference in sound waves. Wave interference patterns can be seen in the resulting video. The second and third videos in the series apply mathematics.

Common Misconceptions

Misconception	Accurate science	Links/resources/suggestions
Potential energy is a thing that objects hold inside them (like cereal stored in a closet). Stored energy is something that causes energy later: it is not energy until it is released.	Potential energy is energy that objects have because of their location in a system along with properties such as mass, elasticity or charge.	
The only type of potential energy is gravitational.	Potential energy can be gravitational, elastic, chemical, magnetic or electrical.	Have students classify potential energy not simply as potential but by the type of potential energy when speaking about or labeling potential energy on models or depictions.
Gravitational potential energy depends only upon the height of an object.	Gravitational potential energy depends on the masses of the objects involved, as well as the distance separating them.	Observe the indentations left in a sand pile after dropping various masses from the same height.
Objects do not have any energy if they are not moving.	Objects that are not moving still can have gravitational potential, elastic potential, electric potential and chemical potential energy.	Using the Energy Skate Park PhET simulation, students can measure the gravitational potential energy of objects that are not in motion. Class conversations can include discussions of objects or materials that have chemical potential energy, such as the gasoline in the cars or buses that brought them to school that day. Examine stretched rubber bands or springs that are compressed.

Misconception	Accurate science	Links/resources/suggestions
Doubling the velocity of a moving object will double its kinetic energy.	Based on the equation $E_k= ½*m*v^2$, doubling the velocity will increase kinetic energy by a factor of 4, tripling the velocity will increase the kinetic energy by a factor of 9, etc.	Have students plug numbers into the formula to determine by what factor the kinetic energy increases.
Energy can be created and destroyed.	Energy is conserved during most changes in the Earth environment. Some processes can change matter to energy, such as nuclear fusion.	
Energy is literally lost in many energy transformations.	Energy may exit the system being observed but has simply been dissipated to the environment as heat.	Investigate and discuss situations where the generation of heat in energy transformations is observable, such as incandescent light bulbs, rubbing hands together, temperature of tires after driving.
Energy can be changed completely from one form to another with no loss of useful energy.	Very few energy transformations occur without some energy being transferred out of the system as thermal energy.	Be cautious when using problems and situations where friction and resistance are ignored. Be sure students understand these are not accurate representations of reality.
"Charging" a battery adds electrons, which are then lost over time as the battery is used.	For every electron that leaves the negative terminal of the battery to travel through the circuit, there is another electron from the circuit that moves into the positive end of the battery. The battery never "charges up" even though charges flow through it.	
Current in an electrical circuit is the movement of electrons through the circuit.	Current is the flow of energy through the system. This energy travels near the speed of light. Electron drift speed is only a few centimeters or meters per hour depending on the circuit.	

Vocabulary

Science vocabulary is most effectively mastered when it is introduced in the natural course of instruction. Rather than being taught in isolation at the beginning of a lesson or unit, vocabulary should be taught as the need for a term is encountered. Starting instruction by defining vocabulary lists is discouraged. Careful modeling of the correct use of scientific terminology by the instructor, along with the encouragement of rich student discourse, is a better way to integrate the correct usage of scientific vocabulary into students' existing understandings. Teachers should encourage students to use proper terms as they ask questions, design experiments and support claims with evidence. Traditional word walls can be replaced with student-created illustrations of terms or scientific models annotated with proper vocabulary. Refer to STEM Teaching Tools Practice Brief 66 for more information.

RESOURCES FOR USE WITH STUDENTS

Lessons and Classroom Materials

- Have students use this doppler shift simulation to determine the relationship between frequency, wavelength, velocity, pitch and/or intensity. The oPhysics website has a variety of other simulations useful for instructing various physics concepts.
- A plasma ball can be an engaging demonstration to spark an investigation into the movement of electrons through a gas. In a plasma ball, photons are emitted as electrons move through neon, xenon and other noble gases. Touching the ball provides a path of lowered resistance, increasing the flow of electrons.
- Have students build or use an electric bicycle to run common household items. Energy analysis of the system can be used to address various topics from this standard.
- Explore refraction of light between two media with different indices of refraction using lasers and a variety of materials, such as water, air, glass, plastic and so forth. Investigate where a person would have to sit in relation to the location of underwater life to see it through a plastic or glass barrier.
- The University of Colorado publishes a series of free PhET simulations that can be used to support this content. Simulations of particular application to the study of energy and waves include *Energy Skate Park*, *Wave Interference and* several other sound and wave simulations. PhET simulations also are available through a low-priced app. This lesson on the Doppler effect utilizes the PhET simulation on sound.

Media

It is important to incorporate a variety of primary and secondary sources of information so students learn to reflect on, and engage in, quality discourse around pertinent topics, as well as evaluate the validity of information sources. Using media is a natural way to support disciplinary literacy or integrate science with English language arts. The following materials are relevant to this standard and can be incorporated into lessons. Students and classes have a variety of characteristics and needs. Always preview materials before use to determine appropriateness.

PS.FM: FORCES AND MOTION

PS.FM.1: Motion

- Introduction to one-dimensional vectors
- Displacement, velocity (constant, average and instantaneous) and acceleration
- Interpreting position vs. time and velocity vs. time graphs

PS.FM.2: Forces

- Force diagrams
- Types of forces (gravity, friction, normal, tension)
- Field model for forces at a distance

PS.FM.3: Dynamics (how forces affect motion)

- Objects at rest
- Objects moving with constant velocity
- Accelerating objects

CONTENT ELABORATION: FORCES AND MOTION

Building upon content in elementary and middle school, major concepts of motion and forces are further developed. In middle school, speed was addressed conceptually, mathematically and graphically. The concepts that forces have both magnitude and direction and can be represented with force diagrams, that forces can be added to find a net force and that forces may affect motion have been addressed in middle school. At the high school level, mathematics (including graphing) is used when describing these phenomena, moving from qualitative understanding to one that is more quantitative. For this course, motion is limited to segments of uniform motion (e.g., at rest, constant velocity, constant acceleration) in a straight line either horizontally, vertically, up an incline or down an incline. Motions of two objects may be compared or addressed simultaneously (e.g., when or where would they meet).

PS.FM.1: Motion

The motion of an object depends on the observer's frame of reference and is described in terms of distance, position, displacement, speed, velocity, acceleration and time. Position, displacement, velocity and acceleration are all vector properties (magnitude and direction). All motion is relative to whatever frame of reference is chosen for there is no motionless frame from which to judge all motion. The relative nature of motion will be addressed conceptually, not mathematically. Non-inertial reference frames are excluded. Motion diagrams can be drawn and interpreted to represent the position and velocity of an object. Showing acceleration on motion diagrams is reserved for Physics.

The displacement or change in position of an object is a vector quantity that can be calculated by subtracting the initial position from the final position ($\Delta x = x_f - x_i$). Displacement can be positive or negative depending upon the direction of motion. Displacement is not always equal to the distance travelled. Examples should be given where the distance is not the same as the displacement.

Velocity is a vector quantity that represents the rate at which position changes. Average velocity can be calculated by dividing displacement (change in position) by the elapsed time ($v_{avg} = (x_f - x_i)/(t_f - t_i)$). Velocity may be positive or negative depending upon the direction of motion. Velocity should be distinguished from speed, which is always positive. Provide examples of when the average speed is not the same as the average velocity. Objects that move with constant velocity have the same displacement for each successive time interval. While speeding up or slowing down and/or changing direction, the velocity of an object changes continuously, from instant to instant. The speed of an object at any instant (clock reading) is called instantaneous speed.

Acceleration is a vector quantity that represents the rate at which velocity changes. Average acceleration can be calculated by dividing the change in velocity by elapsed time ($a_{avg} = (v_f - v_i)/(t_f - t_i)$). At this grade level, it should be noted that acceleration can be positive or negative, but specifics about what kind of motions produce positive or negative accelerations will be addressed in Physics. Deceleration is an ambiguous term that should only be used when an object is slowing down. Care should be given to ensure students do not associate negative acceleration with only deceleration. Objects with negative acceleration could be increasing their speed. Objects that have no acceleration can either be standing still or be moving with constant velocity (speed and direction). Constant acceleration occurs when the change in an object's instantaneous velocity is the same for equal successive time intervals. Motion can be represented by position vs. time and velocity vs. time graphs. Specifics about the speed, direction and change in motion can be determined by interpreting such graphs. For this course, graphs will be limited to positive x-values and show only uniform motion involving segments of constant velocity or constant acceleration. Motion can be investigated by collecting and analyzing data in the laboratory and should include constant velocity as well as constant acceleration. Technology can enhance motion exploration and investigation through video analysis, the use of motion detectors and graphing data for analysis.

Objects that move with constant velocity and have no acceleration form a straight line (not necessarily horizontal) on a position vs. time graph. Objects that are at rest will form a horizontal line on a position vs. time graph. Objects that are accelerating will show a curved line on a position vs. time graph. Velocity can be calculated by determining the slope of a position vs. time graph. Positive slopes on position vs. time graphs indicate motion in a positive direction. Negative slopes on position vs. time graphs indicate motion in a negative direction. While it is important that students can construct graphs by hand, computer graphing programs or graphing calculators can also be used so more time can be spent on graph interpretation and analysis. Constant acceleration is represented by a straight line (not necessarily horizontal) on a velocity vs. time graph. Objects that have no acceleration (at rest or moving at a constant velocity) will have a horizontal line for a velocity vs. time graph. Average acceleration can be determined from the slope of a velocity vs. time graph. The details about motion graphs should not be taught as rules to memorize, but rather as generalizations that can be developed from interpreting the graphs.

PS.FM.2: Forces
Force is a vector quantity, having both magnitude and direction. Force diagrams are useful tools for visualizing and analyzing the forces acting on objects. The (SI) unit of force is a newton. One newton of net force will cause a 1 kg object to experience an acceleration of 1 m/s^2. A newton can also be represented as $kg \cdot m/s^2$. The opportunity to measure force in the lab is provided (e.g., with a spring scale or a force probe). Normal forces and tension forces are introduced conceptually at this level. These forces and other forces introduced in prior grades (friction, drag, gravitational, electric and magnetic) can be used as examples of forces that affect motion.

In this course, only forces in one dimension (positive and negative) will be addressed. The net force can be determined by one-dimensional vector addition. Gravitational force (weight) can be calculated from mass, but all other forces will only be quantified from force diagrams. Friction is a force that opposes motion. Kinetic friction (e.g., sliding or, rolling), drag and static friction can be addressed conceptually. More quantitative study of friction forces, universal gravitational forces, elastic forces and electrical forces is reserved for Physics.

A normal force exists between two solid objects when their surfaces are pressed together due to other forces acting on one or both objects (e.g., a solid sitting on or sliding across a table, a ladder leaning against a wall, a ball hitting a bat). A normal force is always a push directed at right angles from the surfaces of the interacting objects. A tension force occurs when a non-slack rope, wire, cord or similar device pulls on another object.

In middle school, the concept of a field as a region of space that surrounds objects with the appropriate property (mass for gravitational fields, charge for electric fields, a magnetic object for magnetic fields) was introduced to explain gravitational, magnetic and electrical forces that occur over a distance. In high school, the field concept is further developed. The stronger the field, the greater the force exerted on objects placed in the field. The field of an object is always there even if the object is not interacting with anything else. The gravitational force (weight) of an object is proportional to its mass. Weight, F_g, can be calculated from the equation $F_g = mg$, where g is the gravitational field strength of an object which is equal to 9.8 N/kg or 9.8 m/s^2 on the surface of Earth.

PS.FM.3: Dynamics (how forces affect motion)
The focus of the content is to develop a conceptual understanding of the laws of motion to explain and predict changes in motion, not to name or recite a memorized definition. When the vector sum of the forces (net force, F_{net}) acting on an object is zero, the object does not accelerate. For an object that is moving, this means the object will remain moving without changing its speed or direction. For an object that is not moving, the object will continue to remain stationary.

An object will accelerate (increase or decrease its speed or change its direction of motion) when an unbalanced net force acts on it. The rate at which an object changes its speed or direction (acceleration) is proportional to the vector sum of the forces (net force, F_{net}) and inversely proportional to the mass ($a = F_{net}/m$). These laws will be applied to systems consisting of a single object upon which multiple forces act. Vector addition will be limited to one dimension (positive and negative). While both horizontal and vertical forces can be acting on an object simultaneously, for this level, one of the dimensions must have a net force of zero.

A force is an interaction between two objects. Both objects in the interaction experience an equal amount of force, but in opposite directions. Interacting force pairs are often confused with balanced forces. Interacting force pairs can never cancel each other out because they always act on different objects. Naming the force (e.g., gravity, friction) does not identify the two objects involved in the interacting force pair. Objects involved in an interacting force pair can be easily identified easily by using the format "A acts on B so B acts on A." For example, the truck hits the sign therefore the sign hits the truck with an equal force in the opposite direction. Earth pulls the book down so the book pulls Earth up with an equal force. In Physics, all laws will be applied to systems of many objects.

EXPECTATIONS FOR LEARNING

The content in the standards needs to be taught in ways that incorporate the nature of science and engage students in scientific thought processes. Where possible, real-world data and problem- and project-based experiences should be utilized. *Ohio's Cognitive Demands* relate to current understanding and research about the ways people learn and are important aspects to the overall understanding of science concepts. Care should be taken to provide students opportunities to engage in all four types of thinking. Additionally, lessons need to be designed so that they incorporate the concepts described in the *Nature of Science*.

VISIONS INTO PRACTICE: CLASSROOM EXAMPLES

This section provides guidance for developing classroom tasks that go beyond traditional approaches to instruction. It is a springboard for generating innovative ideas to address the cognitive demands. A variety of activities are presented so that teachers can select those that best meet the needs of their students. This is not an all-inclusive checklist and is not intended to cover every aspect of the standards. **These activities are suggestions and are not mandatory.**

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.FM.1: Motion			
	Conduct an investigation to determine the acceleration of a freely falling object.	Given real-world examples, explain how the frame of reference of an observer affects the appearance of motion. Create a velocity vs. time graph for an object using data from its position vs. time graph. Write a story describing an object's motion that corresponds to a velocity vs. time graph.	Identify examples of data that are vector quantities and examples of data that are scalar quantities. Determine the displacement of an object in one dimension, as measured from a frame of reference. Describe how an object can have a distance that is not the same as the displacement. Distinguish average velocity from instantaneous velocity. Calculate the velocity of an object by measuring the time to travel different distances and determine if the object moves with constant or changing velocity. Calculate the acceleration of an object from its change in speed during a given time interval. On a velocity vs. time graph, identify when an object is showing no motion, constant velocity and constant acceleration. Given a position vs. time graph, velocity vs. time graph, or acceleration vs. time graph, identify the other corresponding graphs.
Speed detection device			
Build a model of a device that could be used to determine the speed of a car travelling down the street.	Design a system or method to collect the data needed to calculate the speed of a car travelling down the street.	Present to the class how data will be measured and how it will be used to determine the speed of the car.	Decide what data must be collected to determine the speed of a car.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
	Accelerating objects		
	Design a procedure to accurately measure the acceleration of a cart rolling down a ramp from rest. Collect data necessary to investigate the relationship between position and time for the cart. Analyze the data to determine the acceleration of the cart. Use this value to determine the speed of the cart at the end of the ramp. Measure the velocity of the cart at the end of the ramp (motion sensor) and compare it to the value calculated from the experimental data.	Make a claim about the relationship between position and time for an accelerating object and use evidence to support the claim. Present the findings to the class.	Calculate the final velocity of an object from the measured acceleration. Use motion sensors to determine speed and acceleration of objects.
	Motion of two objects		
Investigate how knowledge of the intersection point for two moving objects is used for controlling traffic patterns (for example, air traffic control, trains).	Design a procedure to investigate the motion of two objects with different constant speeds (for example, battery operated cars). Predict where two objects will cross paths when released at different times.	Produce position vs. time graphs and motion diagrams for two moving objects.	Determine the speed of two moving objects using their position vs. time graphs.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.FM.2: Forces			
	Determine the relationship between weight of an object in newtons (measured with a spring scale) and mass of an object in kilograms. Graph data for a variety of objects and interpret the graph to determine the gravitational field strength at the location where the measurements were taken.	Investigate the relationship between the frictional force on an object and the normal force between the object and the surface.	Solve problems determining the acceleration of an object from a force diagram. Identify the forces acting on various objects (e.g., a skydiver, a hanging mass, a chair resting on the floor) and draw force diagrams for the objects. Use a force diagram to predict the motion of an object. Calculate the weight of an object from its mass. Identify the relationship between gravitational field strength and the magnitude of the force on an object placed in the field. Compare the weight of objects on Earth to the predicted weights on other planets in our Solar System using the planets' gravitational field strength.
Rube Goldberg machine			
Design a Rube Goldberg machine that completes a task (for example, makes a fidget spinner spin, pops a balloon). Explain energy transfers in the machine caused by the force of gravity, friction, tension and normal forces.		Draw force diagrams for an object in the Rube Goldberg machine that is in equilibrium and for an object that is accelerating.	Identify the forces present throughout the Rube Goldberg machine. Calculate the forces involved in one energy transfer in the machine.
PS.FM.3: Dynamics (how forces affect motion)			
	Design an investigation to show the importance of seatbelt use. Create a persuasive public message (poster, television commercial, PSA, jingle or rap) including artifacts from the investigation to support the message. Focus on the forces and accelerations that a person would experience when wearing or not wearing a seat belt.	Provide an example of an object in equilibrium and determine the forces that are acting on the object. Create a force diagram of that object labeling the identified forces.	

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
Protective packaging			
Design and test methods that decrease the force on an object (such as an egg or cell phone) so that it will survive being dropped from a given height. The focus should be on reducing the magnitude of the forces that the object will experience. Redesign and retest the methods based on initial testing.	Determine and carry out a procedure to measure the amount of force necessary to break an object (such as an egg or cell phone screen). **Note:** *Use inoperative cell phones and observe proper safety protocols.*	Describe the amount of force needed to break an object (e.g., an egg cell phone screen). Use data collected to support the claim. Include any assumptions made.	

RESOURCES FOR TEACHERS

Equity/Diverse Learners

- The PhET Force and Motion Basics Simulation provides good visual representations of forces, motion, speed and acceleration. Students can manipulate forces and see how motion is affected. It allows students to explore how forces affect motion both visually and quantitatively. This tool could be useful to review basic concepts from grade 8, to provide a tool for students still mastering basic motion concepts or to begin the exploration of acceleration.
- The Ohio Department of Education provides strategies for meeting the needs of all learners, including gifted students, English learners and students with disabilities.
- Resources based on the Universal Design for Learning principles are available at CAST.org.

Connections within and across disciplines

- The STEMcoding project has a variety of activities that pair coding with physics concepts. Two Fun with Fluids simulations can be used to examine the motion of particles as they flow through constrictions in pipes and fall on different shaped surfaces. This content integrates the study of matter, PS.M, with this standard. Chris Orban, physics professor at The Ohio State University, explains the simulations in this YouTube video.
- STEMcoding also has an hour of code project with videos and coding activities on incorporating accurate physics into video games. These use a topic of high interest to many students to provide an opportunity to integrate physics and coding while studying motion and acceleration.

Common Misconceptions

Misconception	Accurate Science	Links/Resources/Suggestions
Students often confuse the concepts of velocity and acceleration.	Velocity is a change in distance, while acceleration is a change in velocity, both over a change in time.	
If the speed of an object is constant, there is no acceleration.	An object can have a constant speed but be changing direction and therefore have an acceleration other than zero.	
High velocities coincide with large accelerations and low velocities coincide with small accelerations.	An object can be traveling at a high velocity, but the acceleration is a measure of the change in that velocity so the change in velocity may be small, medium or large.	
Acceleration is positive when an object speeds up and negative when the object is slowing down.	Acceleration takes into account direction toward or away from a reference point.	
Everything that moves will eventually come to a stop. Rest is the "natural" state of all objects.	A net force is required to change the motion of an object. Most things slow down because there is an unbalanced frictional force.	

Misconception	Accurate Science	Links/Resources/Suggestions
A continuous force is needed for continuous motion.	A net force changes motion but that motion then continues due to inertia. Inertia is the tendency to continue doing whatever the object is doing, whether in motion or at rest. A moving object will continue to move at a constant velocity if there is no force acting on the object.	
There is no gravity in outer space.	Gravitational forces decrease as the distance between the objects increases but still exists.	Discuss motion within galaxies or solar systems. Investigating the distances from the sun to comets at their outer reaches or from the center of the Milky Way to our solar system may help students realize the extent to which gravitational forces exist. This relates to standard PS.U as well.

Vocabulary

Science vocabulary is most effectively mastered when it is introduced in the natural course of instruction. Rather than being taught in isolation at the beginning of a lesson or unit, vocabulary should be taught as the need for a term is encountered. Starting instruction by defining vocabulary lists is discouraged. Careful modeling of the correct use of scientific terminology by the instructor, along with the encouragement of rich student discourse, is a better way to integrate the correct usage of scientific vocabulary into students' existing understandings. Teachers should encourage students to use proper terms as they ask questions, design experiments and support claims with evidence. Traditional word walls can be replaced with student-created illustrations of terms or scientific models annotated with proper vocabulary. Refer to STEM Teaching Tools Practice Brief 66 for more information.

RESOURCES FOR USE WITH STUDENTS

Lessons and Classroom Materials

- Interactive Video Vignettes (IVVs) are designed as ungraded web-based assignments for introductory physics students. They combine the convenience of online video coupled with video analysis as well as the interactivity of an individual tutorial. Most of them take a student about 10 minutes or less to complete. Vignettes that match the content of this standard include Newton's First Law, Newton's Second Law, and Newton's Third Law.
- Forces in 1 Dimension is an interactive PhET simulation that allows students to explore the forces at work when trying to push various objects. An applied force is selected and the resulting friction force and total force acting on the cabinet shown. Forces vs. time, position vs. time, velocity vs. time, and acceleration vs. time graphs can be created in real time. Force diagrams are also displayed.
- The Name that Motion Concept Builder has students match verbal descriptions of motion to the visual and dot diagrams. The Physics Classroom has a variety of other resources for instructing physics concepts.
- This video tutorial from The Physics Classroom explains acceleration. It could be used during virtual instruction, in flipped classrooms or as a review. A written tutorial and an animation are available as well.

Media

It is important to incorporate a variety of primary and secondary sources of information so students learn to reflect on, and engage in, quality discourse around pertinent topics, as well as evaluate the validity of information sources. Using media is a natural way to support disciplinary literacy or integrate science with English language arts. The following materials are relevant to this standard and can be incorporated into lessons. Students and classes have a variety of characteristics and needs. Always preview materials before use to determine appropriateness.

CLASSROOM PORTALS

- This physical science teacher uses student modeling as the class investigates the phenomenon of pie plates flying off a van de Graaff generator.

PS.U: THE UNIVERSE
PS.U.1: History of the universe
PS.U.2: Galaxies
PS.U.3: Stars

- Formation; stages of evolution
- Fusion in stars

CONTENT ELABORATION: THE UNIVERSE

In early elementary school, observations of the sky and space are the foundation for developing a deeper knowledge of the solar system. In late elementary school, the parts of the solar system are introduced, including characteristics of the sun and planets, orbits and celestial bodies. At the middle school level, energy, waves, gravity and density are emphasized in the physical sciences, and characteristics and patterns within the solar system are explored. In this course, the universe and galaxies are introduced, building upon the knowledge about space and the solar system from earlier grades.

PS.U.1: History of the Universe
The big bang model is a broadly accepted theory for the origin and evolution of our universe. It postulates that 12 to 14 billion years ago, the portion of the universe seen today was only a few millimeters across (NASA). According to the big bang" theory, the contents of the known universe expanded explosively into existence from a hot, dense state 13.7 billion years ago (NAEP, 2009). After the big bang, the universe expanded quickly (and continues to expand) and then cooled down enough for atoms to form. Gravity pulled the atoms together into gas clouds that eventually became stars, which comprise young galaxies. Foundations for the big bang model can be included to introduce the supporting evidence for the expansion of the known universe (e.g., Hubble's law and red shift or cosmic microwave background radiation). A discussion of Hubble's law and red shift is found in the Galaxies section, below. Technology provides the basis for many new discoveries related to space and the universe. Visual, radio and x-ray telescopes collect information from across the entire electromagnetic spectrum; computers are used to manage data and complicated computations; space probes send back data and materials from remote parts of the solar system; and accelerators provide subatomic particle energies that simulate conditions in the stars and in the early history of the universe before stars formed.

PS.U.2: Galaxies
A galaxy is a group of billions of individual stars, star systems, star clusters, dust and gas bound together by gravity. There are billions of galaxies in the universe (NAEP 2009, page 52), and they are classified by size and shape. Most observed galaxies are classified as elliptical, spiral and irregular. The Milky Way is a spiral galaxy. It has more than 100 billion stars and a diameter of more than 100,000 light years. At the center of the Milky Way is a massive black hole around which is a collection of stars bulging outward from the disk, from which extend spiral arms of gas, dust and most of the young stars. The solar system is part of the Milky Way galaxy. Hubble's law states that galaxies that are farther away have a greater red shift, so the speed at which a galaxy is moving away is proportional to its distance from Earth. Red shift is a phenomenon due to Doppler shifting, so the shift of light from a galaxy to the red end of the spectrum indicates that the galaxy and the observer are moving farther away from one another. Doppler shifting is also found in the Energy and Waves section of this course.

PS.U.3: Stars
Early in the formation of the universe, stars coalesced out of clouds of hydrogen and helium and clumped together by gravitational attraction into galaxies. When heated to a sufficiently high temperature by gravitational attraction, stars begin nuclear reactions, which convert matter to energy and fuse the lighter elements into heavier ones. All elements, except for hydrogen and some helium and lithium, originated from nuclear fusion reactions of stars.

Stars are classified by their color, size, luminosity and mass. A Hertzprung-Russell diagram can be used to estimate the sizes of stars and predict how stars will evolve. Most stars fall on the main sequence of the H-R diagram, a diagonal band running from the bright hot stars on the upper left to the dim cool stars on the lower right. Stars like the sun will eventually collapse to become a white dwarf, while more massive stars will collapse to form neutron stars or black holes. For stars like the sun, this process of collapse will produce a nebula. More massive stars will collapse with a supernova explosion. The gas ejected from the system during the end stages of the star's life may eventually coalesce under gravity to form new stars, and the stellar life cycle with begin again.

Note: *Names of stars and naming the evolutionary stage of a star from memory is not the focus. The emphasis is on the interpretation of data (using diagrams and charts) and the criteria and processes needed to make those determinations.*

EXPECTATIONS FOR LEARNING

The content in the standards needs to be taught in ways that incorporate the nature of science and engage students in scientific thought processes. Where possible, real-world data and problem- and project-based experiences should be utilized. *Ohio's Cognitive Demands* relate to current understanding and research about the ways people learn and are important aspects to the overall understanding of science concepts. Care should be taken to provide students opportunities to engage in all four types of thinking. Additionally, lessons need to be designed so that they incorporate the concepts described in the *Nature of Science*.

VISIONS INTO PRACTICE: CLASSROOM EXAMPLES

This section provides guidance for developing classroom tasks that go beyond traditional approaches to instruction. It is a springboard for generating innovative ideas to address the cognitive demands. A variety of activities are presented so that teachers can select those that best meet the needs of their students. This is not an all-inclusive checklist and is not intended to cover every aspect of the standards. These activities are suggestions and are not mandatory.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.U.1: History of the universe			
Create or improve a device to collect data from a portion of the universe, understanding that there are situations where we cannot directly observe or measure something in a straightforward way.	Analyze a plot of distance vs. redshift of galaxies to recognize the trend that more distant galaxies are moving away from our location faster. Design a model to show this phenomenon (e.g., drawing dots on a balloon and blowing it up, paperclips on a stretching rubber band).	Use a 12-month calendar to construct a "Cosmic Calendar" to depict the 14-billion-year history of the universe. Explain the "raisin cake" analogy for the expansion of the universe and how it makes sense of the observed relationship between distance and redshift of nearby galaxies. Investigate features of a solid planetary body using the *WorldWide Telescope*. Identify features that are oldest vs. those that are youngest and draw conclusions about the reasons for the differences using current theory to support the conclusions.	Explain that the universe had a beginning in the distant past; the universe is not infinitely old. Provide evidence that the universe is expanding.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.U.2: Galaxies			
Research the Hubble space telescope from an engineering perspective. What were the problems encountered by this mission and how they were solved? How was the telescope upgraded over time? What scientific knowledge was gained from these technological improvements and fixes? What future improvements to the Hubble telescope would you make?[1] Evaluate data analyzing the penetration ability of gamma radiation, X-rays, UV, visible light, infrared and radio wavelengths in Earth's atmosphere. Based on the analysis and pertinent considerations (e.g., certain wavelengths of light are blocked from reaching Earth's surface by the atmosphere, how efficiently telescopes work at different wavelengths, telescopes in space are much more expensive to construct than Earth-based telescopes) recommend to a federal funding agency which telescope project should receive funds for construction. The two projects to consider are: • Project 1 – A UV wavelength telescope, placed high atop Mauna Kea in Hawaii at 14,000 ft. above sea level, which will be used to look at distant galaxies. • Project 2 – A visible wavelength telescope, placed on a satellite in orbit around Earth, which will be used to observe a pair of binary stars located in the constellation Ursa Major (Big Dipper). (Prather, Slater, Adams, & Brissenden, 2008).		Use real-time data from the NASA Hubble Mission to research and document the history of the mission, marking the time, discoveries and impact to humans. Present a final product (e.g., an e-portfolio, presentation formal poster session).	Identify three galaxy types: elliptical, spiral and irregular. Identify the Milky Way as a spiral galaxy. Recognize that our solar system is part of the Milky Way Galaxy. Explain that galaxies formed in the early universe when gravity caused gas clouds to collapse to form stars. Explain how we are able to see galaxies.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
PS.U.3: Stars			
Design a pinhole camera and refine it to project an image of the sun that has a good balance between brightness and resolution. Relate the size of the hole to brightness and resolution.		Explain how gravity wave detection confirmed the existence of black holes. A gravity wave signal was detected in 2015 from two black holes that collided and merged together without creating a huge explosion because the light produced by this event got sucked into the resulting black hole. This could not have happened if the two objects had been stars. Use a Hertzsprung-Russell diagram to predict the evolution of stars (e.g., how long the star will last, what it will become after it runs out of fuel). Choose a star or star system and draw a sunset from the perspective of a planet that is in the "habitable zone" for that star(s). Research how computer simulations are used to model the formation of stars. Observe star formation and end states. Document observations. A nearby gas cloud where stars are forming is the Orion nebula which is easy to see with a telescope or binoculars. The bright stars at the center of the nebula are recently formed and illuminate the surrounding gas and dust. The Crab nebula is an example of the end state of a star that is easy to see with a telescope or binoculars.	Explain how stars form. Describe the stages of our sun and compare them to those of more and less massive stars. Explain how stars can end up as white dwarfs, neutron stars and black holes. Compare the sizes of these end products. Explain fusion reactions in stars and how they are different from chemical reactions. Describe how the plasma phase differs from the other phases of matter.

[1]Hubble servicing information

RESOURCES FOR TEACHERS

Equity/Diverse Learners

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- Resources based on the Universal Design for Learning principles are available at CAST.org.

Connections within and across disciplines

- The Stellar Fusion game could be incorporated into a lesson linking this content with PS.M.5 nuclear reactions. It introduces students to possible fusion reactions but does not include any supporting assignment. Students use the arrow keys on the keyboard to get elements to fuse, with the goal of creating Iron. A list of possible fusion reactions in stars is listed below the game.

Common Misconceptions

Misconception	Accurate Science	Links/Resources/Suggestions
Star clusters are galaxies.	Star clusters are smaller than galaxies. A star cluster is a group of stars formed at the same time period. They generally contain from tens to possibly a few million stars. Although some dwarf galaxies contain only thousands or millions of stars, most contain billions or hundreds of billions.	This blog explains the terms solar system, star cluster and galaxy in language that is easy to understand.
Everything in the universe is expanding away from our location because we are at the center of the universe's expansion.	Everything is expanding away from everything else and there is no center. There is no direction or constellation that you can look toward to see the center of the universe. This is because there is no center to the universe.	NASA provides information pertaining to the universe and the big-bang theory.

Vocabulary

Science vocabulary is most effectively mastered when it is introduced in the natural course of instruction. Rather than being taught in isolation at the beginning of a lesson or unit, vocabulary should be taught as the need for a term is encountered. Starting instruction by defining vocabulary lists is discouraged. Careful modeling of the correct use of scientific terminology by the instructor, along with the encouragement of rich student discourse, is a better way to integrate the correct usage of scientific vocabulary into students' existing understandings. Teachers should encourage students to use proper terms as they ask questions, design experiments and support claims with evidence. Traditional word walls can be replaced with student-created illustrations of terms or scientific models annotated with proper vocabulary. Refer to STEM Teaching Tools Practice Brief 66 for more information.

RESOURCES FOR USE WITH STUDENTS

Lessons and Classroom Materials

- Investigating a mystery tube can help students understand the challenges faced in developing an understanding of our universe where direct observations are seldom possible. A variety of Nature of Science skills are incorporated into this lesson.
- NASA has a collection of images from the Hubble Space Telescope that show many of the objects in the Messier catalog. These could be used in a variety of ways. For example, the images could be printed out and students could sort them by galaxy type. Note that not all images in this collection are galaxies, so be sure to read the descriptions. The online images and accompanying descriptions provide discussion material for other topics, such as supernovas (for example, crab nebula).
- Hubble's Law is explained in this Khan Academy video. It is one in a series of related lectures.
- Stars and planetary systems form from the collapse of gas and dust into a spinning protoplanetary disc. The release of gravitational energy as gas falls inwards through the disk causes the disk to heat up. Because they are hot, these disks can be seen with infrared telescopes. Something similar happens in a blender. Use molasses or a mixture of water and cornstarch in a blender to investigate how temperature increases. Measure the temperature with a thermometer or infrared camera and compare to a blender running for the same duration with only water in it. The water-only case is like the solar system is now. No gas extends through the solar system, thus there is no significant heating. Have students explain how this activity relates to star formation.
- NASA has a variety of resources and images related to the Hubble Space Telescope, including information about the various servicing missions that have occurred.
- The James Webb Space Telescope is introduced in this video. The largest space telescope to date, this instrument will allow data collection that was previously not possible. Images and videos from NASA document the construction process.

Media

It is important to incorporate a variety of primary and secondary sources of information so students learn to reflect on, and engage in, quality discourse around pertinent topics, as well as evaluate the validity of information sources. Using media is a natural way to support disciplinary literacy or integrate science with English language arts. The following materials are relevant to this standard and can be incorporated into lessons. Students and classes have a variety of characteristics and needs. Always preview materials before use to determine appropriateness.

Articles

- Astronomy is a natural topic for addressing *Scientific Knowledge is Open to Revision in the Light of New Evidence.* This article from SciTechDaily discusses how our sun may have had a twin at one point and provides an example of how our science understanding is always evolving.
- This article from Space.com on the Chinese Five-hundred-meter Aperture Spherical Telescope (FAST), the world's largest radio telescope, highlights the importance of international cooperation among scientists.

Videos

- A series of two-minute animations from the Atacama Large Millimeter/submillimeter Array (ALMA) explain many concepts related to this standard with analogies to everyday experiences that are easy to understand. Some of the topics support other standards in this course.
- This animated video helps students visualize the Doppler effect and understand how redshift informs astronomers about the motion of stars relative to Earth.
- Having students watch a Powers of Ten video helps develop a sense of the scale of the universe.