ARKANSAS

K-12 SCIENCE STANDARDS

EDUCATION FOR A NEW GENERATION

Physics

2016

Table of Contents

Notes:

1. Student Performance Expectations (PEs) may be taught in any sequence or grouping within a grade level. Several PEs are described as being "partially addressed in this course" because the same PE is revisited in a subsequent course during which that PE is fully addressed.
2. An asterisk (*) indicates an engineering connection to a practice, core idea, or crosscutting concept.
3. The Performance Expectation codes ending in **AR** indicate Arkansas-specific standards.
4. The Clarification Statements are examples and additional guidance for the instructor. **AR** indicates Arkansas-specific Clarification Statements.
5. The Assessment Boundaries delineate content that may be taught but not assessed in large-scale assessments. **AR** indicates Arkansas-specific Assessment Boundaries.
6. The section entitled "foundation boxes" is reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Integrated and reprinted with permission from the National Academy of Sciences.
7. The examples given (e.g.,) are suggestions for the instructor.
8. Throughout this document, connections are provided to the nature of science as defined by *A Framework for K-12 Science Education* (NRC 2012).
9. Throughout this document, connections are provided to Engineering, Technology, and Applications of Science as defined by *A Framework for K-12 Science Education* (NRC 2012).
10. Each set of PEs lists connections to other disciplinary core ideas (DCIs) within the Arkansas K-12 Science Standards and to the Arkansas English Language Arts Standards, Arkansas Disciplinary Literacy Standards, and the Arkansas Mathematics Standards.

Arkansas K-12 Science Standards Overview

The Arkansas K-12 Science Standards are based on *A Framework for K-12 Science Education* (NRC 2012) and are meant to reflect a new vision for science education. The following conceptual shifts reflect what is new about these science standards. The Arkansas K-12 Science Standards

- reflect science as it is practiced and experienced in the real world,
- build logically from Kindergarten through Grade 12,
- focus on deeper understanding as well as application of content,
- integrate practices, crosscutting concepts, and core ideas, and
- make explicit connections to literacy and math.

As part of teaching the *Arkansas K-12 Science Standards*, it will be important to instruct and guide students in adopting appropriate safety precautions for their student-directed science investigations. Reducing risk and preventing accidents in science classrooms begin with planning. There are four recommended steps in carrying out a hazard and risk assessment for any planned lab investigation.

1) Identify all hazards. Hazards may be physical, chemical, health, or environmental.
2) Evaluate the type of risk associated with each hazard.
3) Write the procedure and all necessary safety precautions in such a way as to eliminate or reduce the risk associated with each hazard.
4) Prepare for any emergency that might arise in spite of all of the required safety precautions.

According to Arkansas Code Annotated § 6-10-113 (2012) for eye protection, every student and teacher in public schools participating in any chemical or combined chemical-physical laboratories involving caustic or explosive chemicals or hot liquids or solids is required to wear industrial-quality eye protective devices (eye goggles) at all times while participating in science investigations.

The Arkansas K-12 Science Standards outline the knowledge and science and engineering practices that all students should learn by the end of high school. The standards are three-dimensional because each student performance expectation engages students at the nexus of the following three dimensions.

- Dimension 1 describes scientific and engineering practices.
- Dimension 2 describes crosscutting concepts, overarching science concepts that apply across science disciplines.
- Dimension 3 describe core ideas in the science disciplines.

The Science and Engineering Practices

The eight practices describe the major practices that scientists use to investigate, build models and theories of the world around them or engineers use as they build and design systems. The practices are essential for all students to learn and are as follows:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Crosscutting Concepts

The seven crosscutting concepts bridge disciplinary boundaries and unit core ideas throughout the fields of science and engineering. Their purpose is to help students deepen their understanding of the disciplinary core ideas, and develop a coherent, and scientifically based view of the world. The seven crosscutting concepts are as follows:
1. *Patterns.* Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. *Cause and effect: Mechanism and explanation*. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
3. *Scale, proportion, and quantity.* In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
4. *Systems and system models.* Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. *Energy and matter: Flows, cycles, and conservation.* Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. *Structure and function.* The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
7. *Stability and change.* For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Disciplinary Core Ideas

The Disciplinary Core Ideas describe the content that occurs at each grade or course. The Arkansas K-12 Science Standards focus on a limited number of core ideas in science and engineering both within and across the disciplines and is built on the notion of learning as a developmental progression. The Disciplinary Core Ideas are grouped into the following domains:

- Physical Science (PS)
- Life Science (LS)
- Earth and Space Science (ESS)
- Engineering, Technology and Applications of Science (ETS)

Connections to the Arkansas English Language Arts Standards

Evidence-based reasoning is the foundation of good scientific practice. The Arkansas K-12 Science Standards incorporate reasoning skills used in language arts to help students improve mastery and understanding in all three disciplines. The Arkansas K-8 Science Committee made every effort to align grade-by-grade with the English language arts (ELA) standards so concepts support what students are learning in their entire curriculum. Connections to specific ELA standards are listed for each student performance expectation, giving teachers a blueprint for building comprehensive cross-disciplinary lessons.
The intersections between Arkansas K-12 Science Standards and Arkansas ELA Standards teach students to analyze data, model concepts, and strategically use tools through productive talk and shared activity. Reading in science requires an appreciation of the norms and conventions of the discipline of

science, including understanding the nature of evidence used, an attention to precision and detail, and the capacity to make and assess intricate arguments, synthesize complex information, and follow detailed procedures and accounts of events and concepts. These practice-based standards help teachers foster a classroom culture where students think and reason together, connecting around the subject matter and core ideas.

Connections to the Arkansas Disciplinary Literacy Standards

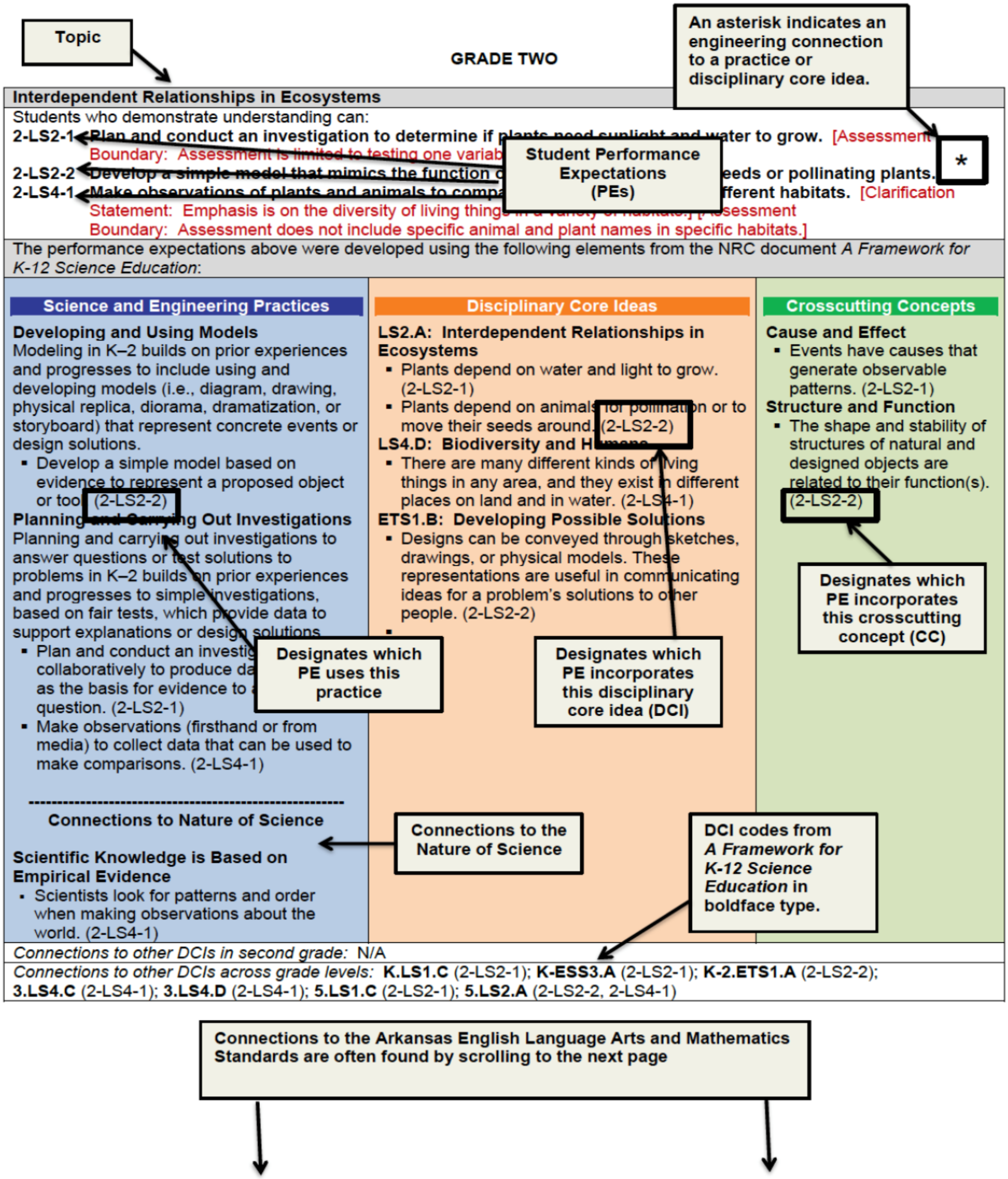
Reading is critical to building knowledge in science. College and career ready reading in science requires an appreciation of the norms and conventions of each discipline, such as the kinds of evidence used in science; an understanding of domain-specific words and phrases; an attention to precise details; and the capacity to evaluate intricate arguments, synthesize complex information, and follow detailed descriptions of events and concepts. When reading scientific and technical texts, students need to be able to gain knowledge from challenging texts that often make extensive use of elaborate diagrams and data to convey information and illustrate concepts. Students must be able to read complex informational texts in science with independence and confidence because the vast majority of reading in college and workforce training programs will be sophisticated nonfiction.

For students, writing is a key means of asserting and defending claims, showing what they know about a science, and conveying what they have experienced, imagined, thought, and felt. To be college and career ready writers, students must take task, purpose, and audience into careful consideration, choosing words, information, structures, and formats deliberately. They need to be able to use technology strategically when creating, refining, and collaborating on writing. They have to become adept at gathering information, evaluating sources, and citing material accurately, reporting finds from their research and analysis of sources in a clear and cogent manner. They must have the flexibility, concentration, and fluency to produce high-quality first-draft text under a tight deadline and the capacity to revisit and make improvements to a piece of writing over multiple drafts when circumstances encourage or require it.

Connections to the Arkansas Mathematics Standards

Science is a quantitative discipline, so it is important for educators to ensure that students' science learning coheres well with their understanding of mathematics. To achieve this alignment, the Arkansas K-12 Science Committee made every effort to ensure that the mathematics standards do not outpace or misalign to the grade-by-grade science standards. Connections to specific math standards are listed for each student performance expectation, giving teachers a blueprint for building comprehensive cross-disciplinary lessons.

How to Read
Arkansas K-12 Science



Physics Learning Progression Chart

Topic 1: Mechanical Physics	Topic 2: Work and Energy	Topic 3: Heat and Thermodynamics	Topic 4: Waves, Sound, and Simple Harmonic Motion	Topic 5: Electricity
P-ESS1-2 P-ESS1-4 P-PS2-1 P-PS2-2 P-PS2-3AR P-PS2-4 P-1-ETS1-2	P-PS2-1AR P-PS2-1ARa. P-PS2-1ARb. P-PS2-1ARc. P-PS2-1ARd. P-PS2-1ARe. P-PS2-1ARf. P-2-ETS1-3	P-PS3-1 P-PS3-1ARa. P-PS3-1ARb. P-PS3-3AR P-PS3-4 P-3-ETS1-1 P-3-ETS1-2 P-3-ETS1-3 P-3-ETS1-4	P-PS4-1ARa. P-PS4-1ARb. P-PS4-1ARc. P-4-ETS1-4	P-PS2-4 P-PS2-5 P-PS3-2 P-PS5-1AR P-PS5-2AR P-PS5-3AR P-5-ETS1-1

Arkansas Performance Expectations (**AR**)

Physics Course Overview

Physics is a science course that continues to develop conceptual understanding of key concepts of physics. The concepts are building upon students' understanding of the core ideas, science and engineering practices, and crosscutting concepts in the principles of chemistry and physics course. The standards engage students in the investigation of physical laws and application of the principles of physics to address real world problems. Students should develop an understanding of physics as it applies to the world around them and be prepared to enter technical fields or continue their physics education at college level. Candidates for this course are students who have completed principles of chemistry and physics and are seeking a deeper understanding of physics concepts. Teachers with a physics, physical science, physical/earth, physics/math license or others as approved by ADE are able to teach this course. Students will earn 1 unit of physics credit.

There are seven topics in physics: 1) Mechanical Physics, (2) Work and Energy, (3) Heat and Thermodynamics, (4) Waves, Sound, and Simple Harmonic Motion, and 5) Electricity.

It should be noted that the physics standards are not intended to be used as curriculum. Instead, the standards are the minimum that students should know and be able to do. Therefore, teachers should continue to differentiate for the needs of their students by adding depth and additional rigor.

Students in physics continue to develop possible solutions for major global problems with engineering design challenges. At the high school level, students are expected to engage with major global issues at the interface of science, technology, society and the environment, and to bring to light the kinds of analytical and strategic thinking that prior training and increased maturity make possible. As in prior levels, these capabilities can be thought of in three stages:

- **Defining the problem** at the high school level requires both qualitative and quantitative analysis. For example, the need to provide food and fresh water for future generations comes into sharp focus when considering the speed at which world population is growing and conditions in countries that have experienced famine. While high school students are not expected to solve these challenges, they are expected to begin thinking about them as problems that can be addressed, at least in part, through engineering.
- **Developing possible solutions** for major global problems begins by breaking them down into smaller problems that can be tackled with engineering methods. To evaluate potential solutions, students are expected to not only consider a wide range of criteria but to also recognize that criteria needs to be prioritized. For example, public safety or environmental protection may be more important than cost or even functionality. Decisions on priorities can then guide tradeoff choices.
- **Improving designs** at the high school level may involve sophisticated methods, such as using computer simulations to model proposed solutions. Students are expected to use such methods to take into account a range of criteria and constraints, anticipate possible societal and environmental impacts, and test the validity of their simulations by comparison to the real world.

Physics Topics Overview

The performance expectations in **Topic 1: Mechanical Physics** help students investigate:

- Vectors
- 1-D Motion
- 2-D Motion
- Rotational Motion
- Projectile Motion
- Newton's Law of Gravity

Students investigate concepts of motion and create models, including algebraic expressions and conceptual models.
.
The performance expectations in **Topic 2: Work and Energy** help students investigate:

- Conservation of Energy
- Work
- Energy
- Power
- Impulse

Students conduct investigations and use mathematical models to evaluate kinetic and potential energy of systems.

The performance expectations in **Topic 3**: **Heat and Thermodynamics** help students investigate:

- Kinetic Molecular Theory
- Law of Thermodynamics
- Pressure
- Fluid Dynamics

Students use computational models to investigate the conservation of energy and the total change of energy in a system.

The performance expectations in **Topic 4: Waves, Sound and Simple Harmonic Motion** help students investigate:

- Longitudinal/Transverse
- Light
- Optics

Students use data to analyze wave properties and create visual and mathematical representations for the propagation of light and sound. Students use principles of simple harmonic motion to relate periodic properties of waves to vibrations. The differences and similarities of mechanical waves and electromagnetic waves are investigated through experiments involving light and sound.

The performance expectations in **Topic 5: Electricity** help students investigate:

- Potential Difference
- DC Circuits
- Power Laws
- Current and Voltage

- Transmission of Electricity
- Magnetism
- Static Charge
- Safety

Students analyze data related to the interaction of electric and magnetic fields. By creating circuits and measuring electrical quantities, students investigate fundamental laws governing electricity and magnetism. Students use Ohm's law and the power law to analyze aspects of electrical circuits.

Physics Topic 1: Mechanical Physics

Students who demonstrate understanding can:

P-ESS1-2 Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. [AR Clarification Statement: Emphasis is on gravity as the force that holds the solar system and Milky Way galaxy together and controls orbital motions within them. Examples of models could be physical (analogy of distance along a football field, computer simulations of elliptical orbits) or conceptual (mathematical proportions relative to size of familiar objects).]

P-ESS1-4 Use mathematical or computational representations to predict the motion of orbiting objects in the solar system. [AR Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions as they apply to human-made satellites, planets, and moons.]

P-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [AR Clarification Statement: Examples of data could include tables and graphs of position or velocity as functions of time for objects subject to a net unbalanced force (falling object, object rolling down a ramp, moving object being pulled by a constant force.]

P-PS2-2 Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. [AR Clarification Statement: Emphasis is on balanced and unbalanced forces (Newton's first law) in a system, qualitative and quantitative comparisons of forces, mass and changes in motion (Newton's second law), frame of reference, and specification of units. Assessment includes use of trigonometry.]

P-PS2-3AR Create a model of motion and forces, including vectors graphed on the coordinate plane, to describe and predict the behavior of a system. [Clarification Statement: Emphasis is on vector addition for 1-D (frame of reference), 2-D motion (projectile, rotational motion), vectors applied to force diagrams, and vector direction for gravitational forces.]

P-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electrical fields.]

P-1-ETS1-2

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. [AR Clarification Statement: Problems could include acceleration factors (one-dimensional motion), vectors (two-dimensional motion), and gravity (Newton's laws).]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. ▪ Use a model to predict the relationships between systems or between components of a system. ()	**ESS1.A: The Universe and Its Stars** • The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years. () • The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. ()	**Patterns** ▪ Empirical evidence is needed to identify patterns. () ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. () **Cause and Effect**

Planning and Carrying Out Investigations Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. () **Using Mathematics and Computational Thinking** Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical representations of phenomena to support claims. () **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Construct and revise an explanation based on valid and	• Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. () **ESS1.C: The History of Planet Earth** ▪ Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. () **PS1.A: Structure and Properties of Matter** ▪ Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1) ▪ The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. () ▪ The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. () **PS2.B: Types of Interactions** ▪ Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact	▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. () ▪ Systems can be designed to cause a desired effect. () **Systems and System Models** ▪ When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. () ▪ Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. () **Structure and Function** ▪ Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. () **-------------------------------------** ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ▪ Science assumes the universe is a vast single system in which basic laws are consistent. () ▪ Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they

reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. () Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. () ▪ Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. () **Asking Questions and Defining Problems** Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. ▪ Analyze complex real-world problems by specifying criteria and constraints for successful solutions. ()	forces between material objects. *()* **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *()* **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. ()	will continue to do so in the future. () --------------------------------------- ***Connections to Engineering, Technology, and Applications of Science*** **Interdependence of Science, Engineering, and Technology** ▪ Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. () **Influence of Engineering, Technology, and Science on Society and the Natural World** ▪ Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. ()

Connections:
ELA/Literacy –

RST.9-10.7 Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. *()*

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. ()

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. ()

WHST.9-12.5 Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. ()

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate;

	synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *()*
WHST.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. ()
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *()*
Mathematics –	
MP.2	Reason abstractly and quantitatively. ()
MP.4	Model with mathematics. ()
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. ()
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *()*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *()*

Physics Topic 2: Work and Energy

Students who demonstrate understanding can:

P-PS2-1ARa. Develop computational and graphical models to calculate and illustrate the work done and changes in energy in a system. [Clarification Statement: Emphasis is on force vs. displacement graph.]

P-PS2-1ARb. Plan and conduct an investigation to provide evidence that work done equals energy stored in a conservative system. [Clarification Statement: An example of an investigation could include Hooke's law where energy is stored in a spring.]

P-PS2-1ARc. Plan and conduct an investigation to rate the power used in performing work on a system. [Clarification Statement: Emphasis is on the quantitative determination of power in interactions. Examples could include use of pulleys and electric motors.]

P-PS2-1ARd. Analyze data to demonstrate the relationship between rotational and linear motion, energy, and momentum. [Clarification Statement: Emphasis is on linear motion and angular motion, force and torque, linear momentum and angular momentum, and linear kinetic energy and rotational kinetic energy.]

P-PS2-1ARe. Use mathematical representations to support the claim that the change in kinetic energy of a system is equal to the net work performed upon the system. [Clarification Statement: Emphasis is on quantitative kinetic energy in interactions.]

P-PS2-1ARf. Use mathematical representations to support the claim that the total impulse on a system of objects is equal to the change in momentum of the system. [Clarification Statement: Emphasis is on quantitative conservation of momentum in interactions.]

P-2-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. [AR Clarification Statement: Examples could include analysis of nuclear, coal, and hydro-electric power plants.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). ▪ Develop a model based on evidence to illustrate the relationships between systems or between components of a system. () **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and	**PS1.C: Nuclear Processes** ▪ Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. *()* **PS3.D: Energy in Chemical Processes and Everyday Life** • Nuclear Fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. *()* **PS1.C: Nuclear Processes** ▪ Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus	**Energy and Matter** ▪ The total amount of energy and matter in closed systems is conserved. () ▪ Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. () ▪ Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. () **Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and

independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. () ▪ Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. () ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. () **Using Mathematics and Computational Thinking** Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. () **Planning and Carrying Out Investigations** Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.	protons does not change in any nuclear process. () **ETS1.A: Defining and Delimiting Engineering Problems** ▪ Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. () ▪ Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. () **ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. () ▪ Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. () **ETS1.C: Optimizing the Design Solution** ▪ Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of	correlation and make claims about specific causes and effects. () ▪ Systems can be designed to cause a desired effect. () **Systems and System Models** ▪ When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. () ▪ Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. () **-------------------------------------** ***Connections to Engineering, Technology, and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World** ▪ Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. () ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. ()

▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. () **Analyzing and Interpreting Data** Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. ▪ Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. () **---** ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. () ▪ Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. ()	certain criteria over others (trade-offs) may be needed. ()	**-----------------------------------** ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ▪ Science assumes the universe is a vast single system in which basic laws are consistent. ()
Connections:		

ELA/Literacy –	
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *()*
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (*)*
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.)
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (*)*
WHST.9-12.1	Write arguments focused on *discipline-specific content.* ()
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *()*
SL.11-12.4	Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. *()*
Mathematics –	
MP.2	Reason abstractly and quantitatively. (*)*
MP.4	Model with mathematics. ()
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. ()
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (*)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (*)*
HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context. *()*
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *()*
HSA-CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *()*
HSF-IF.B.5	Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes. *()*
HSS-ID.B.6	Represent data on two quantitative variables on a scatter plot, and describe how those variables are related. *()*

Physics Topic 3: Heat and Thermodynamics

Students who demonstrate understanding can:

P-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [AR Clarification Statement: Emphasis is on systems of two or three components, thermal energy, kinetic energy, and energies in gravitational, magnetic, and electric fields.]

P-PS3-1ARa. Construct an explanation based on evidence of the relationships between heat, temperature, and the Kinetic Molecular Theory. [Clarification Statement: Emphasis on planning and conducting experiments to collect then analyze data. An example could include measuring temperature changes related to phase change and specific heat.]

P-PS3-1ARb. Plan and conduct an investigation of the relationships between pressure, volume, temperature, and amount of gas. [Clarification Statement: Emphasis is on use of gas law apparatuses.]

P-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [AR Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.]

P-PS3-3AR Use mathematical representations to model the conservation of energy in fluids. [Clarification Statement: Emphasis is on fluid dynamics as expressed in Bernoulli's equation and Pascal's principle.]

P-PS3-4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [AR Clarification Statement: Emphasis is on mathematical thinking to describe energy changes. Examples of investigations could include mixing liquids at different initial temperatures and adding objects at different temperatures to water.]

P-3-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. [AR Clarification Statement: Examples could include use of wind and solar energy and total energy loss from homes.]

P-3-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. [AR Clarification Statement: Examples could include designing and building a machine, using schematics to break down an engine into major functional blocks, and designing improvements to reduce total energy loss from a home.]

P-3-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts. [AR Clarification Statement: Examples could include evaluating the different parts of a machine, the entire machine, and reducing energy loss in homes.]

P-3-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. [AR Clarification Statement: Examples could include analyzing potential and kinetic energy efficiency (windmills, roller coasters) and modeling energy loss in homes with and without proposed improvements.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system. ()

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. ()
- Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. ()
- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. ()

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational

PS1.A: Structure and Properties of Matter

- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. ()

PS1.B: Chemical Reactions

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. ()

PS3.A: Definitions of Energy
Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. ()

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. ()
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. ()
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how

Energy and Matter

- The total amount of energy and matter in closed systems is conserved. ()
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ()
- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. ()

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ()
- Systems can be designed to cause a desired effect. ()

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent. ()
- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. ()

Connections to Engineering, Technology, and Applications of Science

simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. () **Planning and Carrying Out Investigations** Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. () **Asking Questions and Defining Problems** Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. ▪ Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (	kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. () ▪ The availability of energy limits what can occur in any system. () **PS4.B Electromagnetic Radiation** ▪ Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. *()* **ETS1.A: Defining and Delimiting Engineering Problems** ▪ Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (▪ Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. () **ETS1.B: Developing Possible Solutions** ▪ When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *()*	**Interdependence of Science, Engineering, and Technology** ▪ Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. () **Influence of Engineering, Technology, and Science on Society and the Natural World** ▪ Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. ()

Connections:
ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. ()
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. ()

RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. *()*
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. ()
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *()*
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *()*
Mathematics –	
MP.2	Reason abstractly and quantitatively. ()
MP.4	Model with mathematics. *()*
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(*
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *()*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *()*
HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context. *()*
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *()*
HSA-CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *()*

Physics Topic 4: Waves, Sound, and Simple Harmonic Motion

Students who demonstrate understanding can:

P-PS4-1ARa. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, speed and energy of waves traveling in various media. [Clarification Statement: Emphasis is on the dependence of wave speed upon media properties and the proportionality between the quantities (frequency and speed, wavelength and speed, frequency and wavelength, energy and wavelength).]

P-PS4-1ARb. Develop and use models to investigate longitudinal and transverse waves in various media. [Clarification Statement: Emphasis is on structure and function of waves.]

P-PS4-1ARc. Develop and use models to describe the interaction of light with matter. [Clarification Statement: Emphasis is on both geometric (ray diagrams) and algebraic models (mirror and thin lens equation, Snell's law).]

P-4-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. [AR Clarification Statement: Emphasis is on solutions with various constraints and criteria. An example could include effect of wind resistance on structural integrity of a skyscraper as a function of its height.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9-12 level builds on K-8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations. ()
- Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. ()

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between

Disciplinary Core Ideas

PS3.D: Energy in Chemical Processes

- Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. (

PS4.A: Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. ()
- Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. ()
- Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. ()

PS4.B: Electromagnetic Radiation

Crosscutting Concepts

Patterns

- Empirical evidence is needed to identify patterns. ()
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. ()

Energy and Matter

- The total amount of energy and matter in closed systems is conserved. ()
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ()
- Energy cannot be created or destroyed—it only moves between one place and another place, between objects

systems and their components in the natural and designed worlds. ▪ Use a model to predict the relationships between systems or between components of a system. () --- ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. ()	▪ Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. () ▪ When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. () ▪ Photoelectric materials emit electrons when they absorb light of a high-enough frequency. () **PS4.C: Information Technologies and Instrumentation** ▪ Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (**ETS1.B: Developing Possible Solutions** ▪ Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. ()	and/or fields, or between systems. () ---------------------------- ***Connections to Engineering, Technology, and Applications of Science*** **Interdependence of Science, Engineering, and Technology** ▪ Science and engineering complement each other in the cycle known as research and development (R&D). () **Influence of Engineering, Technology, and Science on Society and the Natural World** ▪ Modern civilization depends on major technological systems. ()
Connections: *ELA/Literacy –*		

RST.9-10.8	Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. ()
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *(*
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. *(*)
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. ()
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *()*
WHST.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. ()
Mathematics –	
MP.2	Reason abstractly and quantitatively. (*)*
MP.4	Model with mathematics. ()
HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context. (*)*
HSA-SSE.B.3	Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. *()*
HSA.CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *()*

Physics Topic 5: Electricity

Students who demonstrate understanding can:

P-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [AR Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of forces between static electric charges.]

P-PS2-5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [AR Clarification Statement: Examples of investigations could be to create electromagnets and manipulate bar magnets through a coil of wire connected to an ammeter.]

P-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). [AR Clarification Statement: Emphasis is on electric potential difference.]

P-PS5-1AR Use mathematical representations and conduct investigations to provide evidence of the relationships between power, current, voltage, and resistance. [Clarification Statement: Emphasis is on insulators and conductors accounting for Ohm's Law, total resistance for combinations of resistors, and *P*=*IV*.]

P-PS5-2AR Evaluate competing design solutions for construction and use of electrical consumer products.* [Clarification Statement: Examples could include efficiency of light bulbs (visible intensity vs. power) and thermal energy limits of wire.]

P-PS5-3AR Obtain and combine information on alternating and direct current circuits in various applications. [Clarification Statement: Examples could include why public utilities use AC while many devices use DC and energy loss in transmission of electricity.]

P-5-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. [AR Clarification Statement: Examples could include analysis of renewable energy systems for electricity generation and the effect of autonomous electric cars on the economy, society, and the environment.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). ▪ Develop a model based on evidence to illustrate the relationships between systems or between components of a system. () **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to	**PS2.A: Forces and Motion** ▪ Newton's second law accurately predicts changes in the motion of macroscopic objects. () ▪ Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. () ▪ If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. () **PS2.B: Types of Interactions** ▪ Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and	**Patterns** ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (▪ Empirical evidence is needed to identify patterns. () **Cause and Effect** ▪ Empirical evidence is required to differentiate between cause and correlation

explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. ▪ Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. () ▪ Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. () ▪ Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. () **Using Mathematics and Computational Thinking** Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ▪ Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. () **Planning and Carrying Out Investigations** Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on	predict the effects of gravitational and electrostatic forces between distant objects. () ▪ Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. () **PS3.C: Relationship Between Energy and Forces** ▪ When two objects interacting through a field change relative position, the energy stored in the field is changed. () **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. ()	and make claims about specific causes and effects. () ▪ Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. () **Scale, Proportion, and Quantity** • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). () ------------------------------- ***Connections to Engineering, Technology, and Applications of Science*** **Interdependence of Science, Engineering, and Technology** • Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. ()

types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. () **Obtaining, Evaluating, and Communicating Information** Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. ▪ Communicate scientific ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). () **---** ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ▪ Theories and laws provide explanations in science. () ▪ Laws are statements or descriptions of the relationships among observable phenomena. (d)		

Connections:
ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. *()*
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. ()
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. ()
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *()*
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.*()*
WHST.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. *()*

WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *()*
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *()*
Mathematics –	
MP.2	Reason abstractly and quantitatively. ()
MP.4	Model with mathematics. ()
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. ()
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *()*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. ()
HSA-SSE.A.1	Interpret expressions that represent a quantity in terms of its context. (
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. *()*
HSA-SSE.B.3	Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (
HSA-CED.A.1	Create equations and inequalities in one variable and use them to solve problems. ()
HSA-CED.A.2	Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.*)*
HSA-CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *()*
HSF-IF.C.7	Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases. *()*
HSS-ID.A.1	Represent data with plots on the real number line (dot plots, histograms, and box plots). *()*

Contributors

The following educators contributed to the development of this course:

Susan Allison – Benton School District	Rebecca Koelling – Highland School District
Katie Anderson – Little Rock School District	Karen Ladd – Nettleton School District
Dr. Katherine Aulds - Northwest Arkansas Community College	Steven Long – Rogers School District
Dr. Daniel Barth - University of Arkansas at Fayetteville	Chris Lynch – Black River Technical College
Angela Bassham – Salem School District	Jacki Marlin – Perryville School District
Allison Belcher – Little Rock School District	Monica Meadows – Pulaski County Special School District
Debbie Bilyeu – Arkansas AIMS	Patti Meeks – Hamburg School District
Tami Blair – Texarkana School District	Melissa Miller – Farmington School District
Stephen Brodie – University of Arkansas at Fort Smith STEM Center	Jim Musser – Arkansas Tech University
Stephanie Brown – Quitman School District	Nanette Nichols – Wilbur D. Mills AR Education Cooperative
Cindy Bunch – Manila School District	Dennis Pevey – eSTEM Public Charter School
Cindy Cardwell – Bentonville School District	Tami Philyaw – Smackover – Norphlet School District
Larry Cooper – Springdale School District	Kathy Prislovsky – Stuttgart School District
Sarah Croswell – Virtual Arkansas Academy	Kathy Prophet – Springdale School District
Tami Eggensperger – Cabot School District	Rhonda Riggin – Booneville School District
Shelley Forbess – El Dorado School District	Will Squires – Caddo Hills School District
Kyla Gentry – Searcy School District	Tim Trawick – Conway School District
Jenna Gill – Siloam Springs School District	David Wentz – Pea Ridge School District
Douglas Hammon – Little Rock School District	Andrew Williams – University of Arkansas at Monticello
Keith Harris – University of Arkansas at Little Rock Partnership for STEM Education	Wendi J.W. Williams – Northwest Arkansas Community College
Leonda Holthoff – Star City School District	Cathy Wissehr – University of Arkansas at Fayetteville
Amanda Jones – Poyen School District	Diedra Young – Ridgeway High School, Pine Bluff