ARKANSAS
K-12 SCIENCE STANDARDS
EDUCATION FOR A NEW GENERATION

Chemistry

2016

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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

Topic

An asterisk indicates an engineering connection to a practice or disciplinary core idea.

GRADE TWO

Interdependent Relationships in Ecosystems

Students who demonstrate understanding can:

2-LS2-1 Plan and conduct an investigation to determine if plants need sunlight and water to grow. [Assessment Boundary: Assessment is limited to testing one variab...]

2-LS2-2 Develop a simple model that mimics the function o... ...eeds or pollinating plants. *

2-LS4-1 Make observations of plants and animals to compa... ...fferent habitats. [Clarification Statement: Emphasis is on the diversity of living things in a variety of habitats.] [Assessment Boundary: Assessment does not include specific animal and plant names in specific habitats.]

Student Performance Expectations (PEs)

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

Developing and Using Models

Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.

- Develop a simple model based on evidence to represent a proposed object or tool. (2-LS2-2)

Planning and Carrying Out Investigations

Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.

- Plan and conduct an investig... collaboratively to produce da... as the basis for evidence to a... question. (2-LS2-1)
- Make observations (firsthand or from media) to collect data that can be used to make comparisons. (2-LS4-1)

Designates which PE uses this practice

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Scientists look for patterns and order when making observations about the world. (2-LS4-1)

Connections to the Nature of Science

Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems

- Plants depend on water and light to grow. (2-LS2-1)
- Plants depend on animals for pollination or to move their seeds around. (2-LS2-2)

LS4.D: Biodiversity and Humans

- There are many different kinds of living things in any area, and they exist in different places on land and in water. (2-LS4-1)

ETS1.B: Developing Possible Solutions

- Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem's solutions to other people. (2-LS2-2)

Designates which PE incorporates this disciplinary core idea (DCI)

Crosscutting Concepts

Cause and Effect

- Events have causes that generate observable patterns. (2-LS2-1)

Structure and Function

- The shape and stability of structures of natural and designed objects are related to their function(s). (2-LS2-2)

Designates which PE incorporates this crosscutting concept (CC)

DCI codes from *A Framework for K-12 Science Education* in boldface type.

Connections to other DCIs in second grade: N/A

Connections to other DCIs across grade levels: **K.LS1.C** (2-LS2-1); **K-ESS3.A** (2-LS2-1); **K-2.ETS1.A** (2-LS2-2); **3.LS4.C** (2-LS4-1); **3.LS4.D** (2-LS4-1); **5.LS1.C** (2-LS2-1); **5.LS2.A** (2-LS2-2, 2-LS4-1)

Connections to the Arkansas English Language Arts and Mathematics Standards are often found by scrolling to the next page

Chemistry Learning Progression Chart

Topic 1: Structure of Matter	Topic 2: Properties of Matter	Topic 3: Reactions	Topic 4: Kinetics and Kinetic Molecular Theory	Topic 5: Thermochemistry	Topic 6: Equilibrium	Topic 7: Organic Chemistry
C-1-PS1-1 C-PS1-1AR C-PS2-4AR C-PS4-1AR C-PS4-3 C-PS4-4AR C-1-ETS1-3	C-2-PS1-1 C-PS1-3 C-PS2-1AR C-PS2-2AR C-PS2-3AR C-PS3-5AR	C-PS1-2 C-PS1-2AR C-PS1-7 C-PS3-1AR C-PS3-2AR C-3-ETS1-3	C-PS1-5 C-PS4-1AR C-PS4-2AR C-4-ETS1-4	C-PS1-4 C-PS1-4AR C-PS3-1AR C-5-ETS1-4	C-PS1-6 C-PS1-6AR C-6-ETS1-2	C-7-1AR C-7-2AR C-7-ETS1-1

Arkansas Performance Expectations (**AR**)

Chemistry Course Overview

Chemistry is a science course that builds upon students' understanding of the core ideas, science and engineering practices, and crosscutting concepts in the principles of chemistry and physics course. Candidates for this course are students who have completed principles of chemistry and physics and are seeking a deeper understanding of chemistry concepts. Teachers with a chemistry, physical science, physical/Earth, or other license as approved by ADE are able to teach this course. Students will earn 1 unit of chemistry credit.

There are seven topics in chemistry: (1) Structure of Matter, (2) Properties of Matter, (3) Reactions, (4) Kinetics and Kinetic Molecular Theory, (5) Thermochemistry, (6) Equilibrium, and (7) Organic Chemistry.

It should be noted that the chemistry 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 chemistry also continue their ability 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.

Chemistry Topics Overview

The performance expectations in **Topic 1: Structure of Matter** help students formulate an answer to the questions:
• What is the relationship between the structure and properties of matter?
• How do nuclear reactions differ from chemical reactions?
• How do electromagnetic radiation and matter interact?

Students use models to predict the substructure of atoms and provide more mechanistic explanations of the properties of substances. Students use patterns within the periodic table as a tool to explain and predict the properties of elements. Students use models of electromagnetic radiation to explore quantum mechanics. Students develop and use models of nuclear processes.

The performance expectations in **Topic 2: Properties of Matter** help students formulate an answer to the questions:
• How does the structure of matter determine its properties?
• How is matter characterized and identified?
• How is the mole concept used to quantify matter?

Students model the formation of bonds in compounds. Students identify and characterize various substances using formulas and nomenclature. Students use Coulomb's Law to describe and predict electrostatic forces between particles. Students quantify matter through the application of the mole concept.

The performance expectations in **Topic 3: Reactions** help students formulate an answer to the questions:
• How do substances combine or change (react) to make new substances?
• How are patterns used to predict chemical reactions?
• How are the mole concept and stoichiometry used to quantify matter in chemical reactions?

Students predict products of chemical reactions based on the rearrangements of atoms. Stoichiometry is used to determine quantities of reactants and products. Students use graphical models to explain energy changes.

The performance expectations in **Topic 4: Kinetics and Kinetic Molecular Theory** help students formulate an answer to the questions:
• How does collision theory explain the reactivity of matter?
• How does the kinetic molecular theory explain gas laws?

Students explain changes in the rate of reactions as temperature or concentration is changed. Students model particle response to changing variables based on gas laws and make predictions from data. In addition, students apply knowledge of reactions and solution stoichiometry to gaseous reactions and gas stoichiometry.

The performance expectations in **Topic 5: Thermochemistry** help students formulate an answer to the questions:
• How can energy transferred in a system be described in terms of changes in total bond energy?
• How does catalysis affect a chemical reaction?

Energy is understood as a quantitative property of a system. The total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy stored in bonds is used to explain the change in energy of a reaction. Students explain changes in energy, the role of activation energy, and the effect of a catalyst.

The performance expectations in **Topic 6: Equilibrium** help students formulate an answer to the questions:
• How can the relationship between a reaction and the reverse reaction be described?
• How is Le Chatelier's principle used to predict changes in a reversible reaction?

Students describe chemical reactions as reversible processes. In addition, students describe the effects of changing concentration, pressure, or temperature on the equilibrium of the system.

The performance expectations in **Topic 7: Organic Chemistry** help students formulate an answer to the question:
• How can patterns in chemical structure be used to identify organic compounds?

Students examine and identify different organic compounds through nomenclature of simple structures. Students identify various organic functional groups. The importance and widespread use of organics in both industrial and biological systems are described.

Chemistry Topic 1: Structure of Matter

Students who demonstrate understanding can:

C-1-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [AR Clarification Statement: Examples of properties predicted from patterns could include atomic radius, ionization energy, and electronegativity.]

C-PS1-1AR Obtain, evaluate, and communicate information on the evolution of atomic models over time. [Clarification Statement: Examples of models could include solid particle, plum pudding, planetary, and quantum mechanical).]

C-PS1-8 Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. [AR Clarification Statement: Emphasis is on quantitative models of nuclear processes including balancing nuclear equations, determining the rate of radioactive decay, and practical applications of nuclear energy and nuclear medicine).]

C-PS2-4AR Obtain, evaluate, and communicate information using Coulomb's law to describe and predict patterns of electrostatic forces between particles. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of electrical fields based on periodic trends.]

C-PS4-1AR Use mathematical representations and computational thinking to support a claim regarding patterns among the frequency, wavelength, and speed of waves. [Clarification Statement: Emphasis is on quantitative calculations.]

C-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. [AR Clarification Statement: Emphasis is on the particle-wave nature of light and electrons to understand the quantum model of the atom, including quantum numbers and the photoelectric effect.]

C-PS4-4AR Analyze and interpret data as it applies to the absorption and emission of energy in the form of electromagnetic radiation and models of the atom. [Clarification Statement: Emphasis is on the idea that photons provide information about the energy and location of the electrons. Models include the Bohr model and Quantum Mechanical model. Examples of investigations could include flame tests and analysis of atomic line spectra.]

C-1-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 alternative energy such as nuclear, wind, and solar.]

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. ()	**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. () ▪ The periodic table orders elements horizontally by the number of protons in the atom's	**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

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. ()

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible. ()
- Communicate technical information or 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). ()

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. ()

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. ()

PS1.B: Chemical Reactions

- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. ()
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. ()

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 protons does not change in any nuclear process. ()

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 forces between material objects. *()*

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.C: Optimizing the Design Solution

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 and/or fields, or between systems. ()

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ()

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

	Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. *()* **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 (tradeoffs) may be needed. ()	aspect of decisions about technology. () **------------------------------------** ***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.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. *()*

Chemistry Topic 2: Properties of Matter

Students who demonstrate understanding can:

C-2-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the Patterns of electrons in the outermost energy level of atoms. [AR Clarification Statement: Emphasis is on types of bonds (ionic, covalent, metallic) formed and numbers of bonds.]

C-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [AR Clarification Statement: Emphasis is on understanding the strengths of forces between particles, including identifying and naming specific intermolecular forces. Students use Coulomb's law to justify findings.]

C-PS2-1AR Develop and use models to explain the differences between chemical compounds using patterns as a method for identification. [Clarification Statement: Emphasis is on nomenclature and formula writing based on the type of compound (ionic, binary molecular, acids). Ionic compounds could include polyatomic ions.]

C-PS2-2AR Use mathematics and computational thinking to apply Coulomb's law to determine scale, proportion, and quantity of forces between particles. [Clarification Statement: Emphasis is on intermolecular forces in binary compounds using hydrogen bonding, dipole-dipole, and London dispersion.]

C-PS2-3AR Use mathematical representations to quantify matter through the analysis of patterns in chemical compounds. [Clarification Statement: Emphasis is on the mole concept, empirical formula, molecular formula, percent composition, and law of constant composition.]

C-PS3-5AR Develop and use a model of two particles interacting through electric fields to illustrate the forces between particles and the changes in energy due to the interaction. [Clarification Statement: Examples of models could include drawings and diagrams (Lewis structures or other types of dot diagrams).]

C-2-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 a method to test properties of solutions (conductivity, pH, turbidity) or a method to separate mixtures.]

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. ()	**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	**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

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. ()

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). ()

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,

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 certain criteria over others (trade-offs) may be needed. ()

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. ()

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

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. (HS-ETS) **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. ()		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 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 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. ()		

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. *()*

Chemistry Topic 3: Reactions

Students who demonstrate understanding can:

C-PS1-2 **Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.** [AR Clarification Statement: An example could include recognizing patterns to predict reaction products including transition elements.]

C-PS1-2AR **Plan and carry out an investigation to predict the outcome of a chemical reaction based on the patterns of chemical properties.** [Clarification Statement: Examples of various reaction types could include acid base, precipitation, or redox. Examples of patterns could include the use of solubility rules, activity series, or titrations.]

C-PS1-7 **Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.** [AR Clarification Statement: Emphasis is on demonstrating conservation of mass through mole concept, stoichiometry, limiting and excess reagents.]

C-PS3-1AR **Use mathematical representations to understand the proportion and quantity of particles in solution.** [Clarification Statement: Emphasis is on concentration (molarity, molality) solutions and developing net ionic equations.]

C-PS3-2AR **Construct an explanation about the relationship of energy and the behavior of particles using qualitative evidence.** [Clarification Statement: Emphasis is on particle behavior in different states of matter. Examples of evidence could include phase diagrams or heating curves.]

C-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 the effects of concentration of solutions on the freezing/boiling point (melting of ice on roadways).]

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

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 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

Disciplinary Core Ideas

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

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. ()

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. ()

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.

- Create a computational model or simulation of a phenomenon, designed device, process, or system. ()

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. ()

Planning and Carrying Out Investigations

Planning and carrying out investigations in 9-12 builds on K-

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. ()

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. *()*

- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. ()

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 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

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many

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. () **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. ()		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. *()*

Chemistry Topic 4: Kinetics and Kinetic Molecular Theory

Students who demonstrate understanding can:

C-PS1-5 **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.** [AR Clarification Statement: Emphasis is on student reasoning that focuses on Collison theory.]

C-PS4-1AR **Plan and carry out investigations to examine stability and change exhibited by gas particles in a closed system.** [Clarification Statement: Emphasis is on the relationships between pressure, volume, temperature, and quantity of particles (Graham's law of effusion, Dalton's law of partial pressure, gas stoichiometry).]

C-PS4-2AR **Argue from evidence cause and effect relationships of factors influencing behavior of gas particles.** [Clarification Statement: Emphasis is on the kinetic molecular theory.]

C-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: An example could include the Haber process used to produce ammonia.]

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. ()

Disciplinary Core Ideas

PS3.B: Conservation of Energy and Energy Transfer

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

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

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. ()

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation 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. ()
- Systems can be designed to cause a desired effect. ()

Stability and Change

- Much of science deals with constructing explanations of how

Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed worlds. Arguments may also come from current scientific or historical episodes in science. ▪ Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. () **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. () **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,	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. ()	things change and how they remain stable. () **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*** **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. ()

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. () **---** ***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. ()		

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. *()*

Chemistry Topic 5: Thermochemistry

Students who demonstrate understanding can:

C-PS1-4 Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. [AR Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects energy change (Hess's Law, net bond energy, endothermic, exothermic).]

C-PS1-4AR Analyze and interpret data to explain the energy (enthalpy) changes of a reaction. [Clarification Statement: Emphasis is on describing energy changes of a reaction (activation energy, catalyst).]

C-PS3-1AR Plan and conduct an investigation to calculate changes in energy within the system and/or energy flows in and out of the system. [Clarification Statement: Emphasis is on the use of mathematical expressions to describe the change in energy within the system. Investigations could also include electrochemistry (electrolysis).]

C-5-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 the efficiency of the internal combustion engine.]

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
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. () **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. ▪ Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. () **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	**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 (tradeoffs) may be needed. ()	**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. () --------------------------------------- ***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

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. () --- ***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. ()		may involve scientists, engineers, and others with wide ranges of expertise. ()

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). *()*

Chemistry Topic 6: Equilibrium

Students who demonstrate understanding can:

C-PS1-6 **Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*** [AR Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants, removing products, changing pressure, and changing temperature.]

C-PS1-6AR

Analyze and interpret data showing the change in concentration of products and reactants, and the stable state achieved under reversible conditions. [Clarification Statement: Emphasis is on a qualitative equilibrium.]

C-6-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 Haber process and other industrial processes.]

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

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.

- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS)

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

Disciplinary Core Ideas

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. ()

Crosscutting Concepts

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. ()

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

scientific claims or determine an optimal design solution. ()		**Influence of Engineering, Technology, and Science on Society and the Natural World** ▪ Modern civilization depends on major technological systems. () ▪ New technologies can have deep impacts on society and the environment, including some that were not anticipated. () ▪ 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 to Nature of Science*** **Science is a Human Endeavor** ▪ Science is a result of human endeavors, imagination, and creativity. ()

Connections:
ELA/Literacy –

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. ()

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. *(*

Mathematics –

MP.2 Reason abstractly and quantitatively. *()*

MP.4 Model with mathematics. ()

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. ()

Chemistry Topic 7: Organic Chemistry

Students who demonstrate understanding can:

C-7-1AR Obtain and combine information to describe the differences between alkanes, alkenes, and alkynes using patterns as a method for identification. [Clarification Statement: Emphasis is on nomenclature and formula writing for hydrocarbons one through ten.]

C-7-2AR Obtain and combine information to describe the differences between various functional groups using patterns as a method for identification. [Clarification Statement: Emphasis is on differences among alcohol, aldehyde, ketone, ether, carboxylic acid, ester, amine, and amide groups.]

C-7-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: Emphasis could be on crude oil refining process, supply, and demand.]

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

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. ()

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

Disciplinary Core Ideas

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. ()

Crosscutting Concepts

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. ()

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 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. ()

▪ Theories and laws provide explanations in science. () ▪ Laws are statements or descriptions of the relationships among observable phenomena. ()		

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

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