Science

College Board Standards for College Success™

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Standards Outline

Science Practices

Standard SP.1

Scientific Questions and Predictions
Asking scientific questions that can be tested empirically and structuring these questions in the form of testable predictions

Objectives

SP.1.1 **Scientific Questions**
Students recognize, formulate, justify and revise scientific questions that can be addressed by science in order to construct explanations.

SP.1.2 **Predictions**
Students make and justify predictions concerning natural phenomena. Predictions and justifications are based on observations of the world, on knowledge of the discipline and on empirical evidence.

Standard SP.2

Generation of Evidence
Collecting data to address scientific questions and to support predictions

Objectives

SP.2.1 **Data Collection**
Students select and use appropriate measurement methods and techniques for gathering data, and systematically record and organize observations and measurements.

SP.2.2 **Evaluating Data for Evidence**
Students determine which data from a specific investigation can be used as evidence to address a scientific question or to support a prediction or an explanation, and distinguish credible data from noncredible data in terms of quality.

Standard SP.3

Data Analysis
Searching for regularities and patterns in observations and measurements (i.e., data analysis)

Objectives

SP.3.1 **Analyzing Data for Patterns**
Students analyze data to discover patterns.

Standard SP.4

Evidence-Based Explanations and Models
Using evidence and science knowledge to construct scientific explanations, models and representations

Objectives

SP.4.1 **Constructing Explanations**
Students construct explanations that are based on observations and measurements of the world, on empirical evidence and on reasoning grounded in the theories, principles and concepts of the discipline.

SP.4.2 **Models and Representations**
Students construct, use, re-express and revise models and representations of natural and designed objects, systems, phenomena and scientific ideas in the appropriate context and in formulating their explanation.

SP.4.3 **Evaluating Explanations**
Students evaluate, compare and contrast explanations that are based on observations of the world, on empirical evidence and on reasoning grounded in the theories, principles and concepts of the discipline.

Standard SP.5

Quantitative Applications
Using mathematical reasoning and quantitative applications to interpret and analyze data to solve problems

Objectives

SP.5.1 **Proportionality Between Variables**
Students reason about relationships between variables (e.g., data, representations, uncertainty, samples) through the lens of ratios, rates, percentages, probability or proportional relationships when approaching or solving problems or when interpreting results or situations.

SP.5.2 **Patterns of Bivariate Relationships**
Students apply, analyze and create algebraic representations, relationships and patterns of linear functions, systems of linear inequalities, and one- or two-dimensional changes to solve problems, interpret situations and address scientific questions.

Science, Technology and Society

Standard STS.1

Science, Technology and Society
A critical interdependence exists among science, technology and society.

Objectives

STS.1.1 **Interdependence of Science and Technology**
Students explain the interdependence of science and technology: how the ongoing development of technology relies on the advancements of science while scientific research relies on technological progress. Students understand how the evolution of various technologies (e.g., biotechnology, seismology, computational software, lasers) radically alters the practice of many science disciplines by affecting the quality and quantity of available data.

STS.1.2 **Advantages and Disadvantages to Society**
Students understand how science and technology together can be used for the benefit of society as well as their own lives (e.g., weather predictions, development of medications, creation of safety devices in cars), but that some technological capabilities (e.g., cloning, genetic recombination, nuclear energy studies, access to fossil fuels, chemical engineering) create ethical and economic dilemmas for society.

STS.1.3 **Evaluating Online Information**
Students recognize that the amount of information, as well as access to information, has exploded since the creation of the Internet. Online information should be judged using the same science practices and critical and skeptical views that reflect the way science is conducted and evaluated. Students also recognize the relationship between digital technology and the fact that social networking is a source of information generation and of the determination of "truths" in our current society. Students understand that this information presents a specific perspective that is not backed by research; therefore, the information and the perspective do not represent the empirical reality of science.

Earth Science

Standard ES.1

Dynamic Earth Processes
Dynamic processes shape and order Earth.

Objectives

ES.1.1 **Earth's Surface**
Students understand that physical and chemical changes in Earth's materials result from the interactions of Earth's surface with water, air, gravity, tectonic forces and biological activity. These changes create landscapes on Earth's surface.

ES.1.2 **Energy Transfer**
Students understand that the uneven distribution of thermal energy and materials in Earth's systems, combined with gravity, is the underlying cause of the movement of matter within the lithosphere (plate tectonics), hydrosphere (ocean currents) and atmosphere (winds).

ES.1.3 **Tectonism**
Students understand that tectonic plates interact along their boundaries, resulting in folding, faulting, earthquakes and volcanoes.

ES.1.4 **Weather Processes**
Students understand that weather is the result of short-term interactions (days) among the atmosphere, hydrosphere, lithosphere and biosphere.

ES.1.5 **Rock-Forming Environment**
Students understand that the physical and chemical properties of rocks and fossil fuels indicate the environment in which they were formed.

Standard ES.2

Independent and Interacting Systems
Earth is composed of interdependent and interacting systems.

Objectives

ES.2.1 **Atmosphere as a System**
Students understand that Earth's atmosphere acts as a system that absorbs and distributes matter and energy.

ES.2.2 **Oceans as a System**
Students understand that Earth's oceans act as a system that absorbs and distributes matter and energy.

ES.2.3 **Lithosphere as a System**
Students understand that the lithosphere is a system of large plates that move matter and energy in Earth's systems.

ES.2.4 **Climate**
Students understand that climate is the result of interactions among the atmosphere, hydrosphere, lithosphere and biosphere.

ES.2.5 **Planetary Evolution**
Students understand that Earth is part of a solar system and has unique characteristics that are based on its position and its stage of planetary evolution.

Standard ES.3

Earth's History

Earth's history can be inferred from evidence left from past events.

Objectives

ES.3.1 Relative and Absolute Dating

Students understand that various dating methods — relative and absolute — have been used to determine the age of Earth.

ES.3.2 Rock and Fossil Records

Students understand that the rock and fossil records provide evidence of the evolution of Earth's environment and the associated changes in life over time.

Standard ES.4

Cycles of Matter and Energy

Matter on Earth is finite and moves through various cycles that are driven by the transformation of energy.

Objectives

ES.4.1 Water Cycle

Students understand water cycles at various rates and at various scales within Earth's systems.

ES.4.2 Carbon Cycle

Students understand that the carbon cycle illustrates the transformation and pathways of carbon and carbon compounds through Earth's systems.

Standard ES.5

Humans and the Environment

Humans and the environment impact each other.

Objectives

ES.5.1 Humans and Natural Resources

Students understand that human societies require natural resources derived from Earth. The amounts and types of resources required are a function of the size, growth and affluence of the human population. The value of a natural resource is dependent on its amount and its ease of extractability from Earth.

ES.5.2 Humans and Natural Hazards

Students understand that natural hazards impact human society. Societies try to reduce the impacts of natural hazards through disaster reduction, which entails early warning and engineering projects that seek risk reduction.

ES.5.3 Humans' Impact on the Environment

Students understand that all human activities, including use of resources, have environmental consequences that occur over a range of spatial and temporal scales. Because of the complexity of Earth's systems and because of the occurrence of unintended consequences, a systems framework is commonly used to understand important environmental issues such as pollution, climate change or ecosystem disruption. A systems analysis guides scientific investigations, decision making and the identification of potential solutions to environmental issues.

Life Science

Standard LS.1

Evolution

The diversity and unity of life can be explained by the process of evolution.

Objectives

LS.1.1 **Evidence of Common Ancestry and Divergence**
Students understand that an analysis over time of both the anatomical structures and the DNA compositions of organisms can be used to infer lines of descent back to a common ancestor.

LS.1.2 **Natural Selection**
Students understand that when a trait is favorable to an organism, the number of organisms with that trait will increase over time; and that when a trait is unfavorable, the number of organisms with that trait will decrease over time. Students understand that as a result, there is an increase in the proportion of individuals with the advantageous trait in a population. Over time, the process of natural selection leads to both the extinction of existing species and the evolution of new species.

LS.1.3 **Genetic Variation Within Populations**
Students understand that genetic variation within a population is essential for natural selection. Mutations, as well as random assortment of existing genes, can produce genetic variation in a population.

Standard LS.2

Cells as a System
Cells are a fundamental structural and functional unit of life.

Objectives

LS.2.1 **Cell Function**
Students understand that cells perform the essential functions of life, such as energy transfer and transformation, exchange of gas, disposal of waste, growth, reproduction, and interaction with the environment.

LS.2.2 **Cell Structure**
Students understand that cells have internal structures that carry out specialized life functions, and that these internal structures vary depending on a cell's function.

LS.2.3 **Cell Growth and Repair**
Students understand that cells of multicellular organisms repeatedly divide to make more cells for growth and repair.

LS.2.4 **Cell Differentiation**
Students understand that in multicellular organisms, the single cell (zygote) ultimately divides and differentiates into specialized cells that form the various tissues and organs of the organism.

Standard LS.3

Interdependent Relationships
Interdependent relationships characterize biological ecosystems.

Objectives

LS.3.1 **Living Systems and the Physical Environment**
Students understand that in all ecosystems, living organisms interact with and depend on the physical (abiotic) conditions of their environment for survival.

LS.3.2 **Interactions of Living Systems**
Students understand that organisms in all ecosystems interact with and depend on each other, and that organisms with similar needs compete for limited resources.

LS.3.3 **Ecosystem Stability**
Students understand that a complex set of interactions within an ecosystem can maintain the number and types of organisms in an ecosystem that is relatively constant over long periods of time.

Standard LS.4

Matter and Energy
Biological systems utilize energy and molecular building blocks to carry out life's essential functions.

Objectives

LS.4.1 **Matter Cycling**
Students understand that matter is continuously recycled within the biological system and between the biological (biotic) and physical (abiotic) components of an ecosystem.

LS.4.2 **Energy Transfer**
Students understand that all of the processes that take place within organisms require energy. In most ecosystems, the energy is derived from the Sun and transferred into chemical energy in photosynthetic organisms of that ecosystem.

Standard LS.5

Information Transmission, Storage and Retrieval
Living systems have multiple mechanisms that are used to store, retrieve and transmit information.

Objectives

LS.5.1 **Changing Model of Inheritance**
Students describe the historic ideas that led to the identification of DNA as the molecule that contains and transmits genetic information.

LS.5.2 **Genetic Information Transmission**
Students understand that during reproduction, genetic information (DNA) is transmitted between parent and offspring. In asexual reproduction the lone parent contributes DNA to the offspring, and in sexual reproduction both parents contribute DNA to the offspring.

LS.5.3 **DNA to Trait**
Students understand that genetic information (DNA) is used to produce proteins that largely determine the traits of an organism. These traits often result from the interactions and expression of many genes.

LS.5.4 **Imperfect Transmission of Genetic Information**
Students understand that there are various ways in which the transmission of genetic information can be imperfect, and that these imperfections may have positive, negative or no consequences to the organism.

LS.5.5 **Nongenetic Information Transmission**
Students understand that nongenetic transmission of information within and among organisms involves specialized molecules, cell structures and cell systems.

Physical Science

Standard PS.1

Interactions, Forces and Motion
Changes in the natural and designed world are caused by interactions. Interactions of an object with other objects can be described by forces that can cause a change in motion of one or both interacting objects.

Objectives

PS.1.1 **Patterns of Straight-Line Motion**
Students understand that there are different patterns of straight-line motion that can be represented using different models.

PS.1.2 **Forces and Motion**
Students understand that when the sum of the forces is equal to zero, either the object is not moving and it will continue to not move, or the object is moving and it will always continue to move at a constant speed in a straight line (Newton's first law).

PS.1.3 **Interactions and Forces**
Students understand that interactions can be described in terms of forces. These interactions occur when two objects in contact push or pull on each other, which can cause a change in motion of one or both objects.

PS.1.4 **Gravitational Force**
Students understand that gravity is an attractive interaction between any two objects with mass, which can cause a change in motion of the objects.

PS.1.5 **Magnetic and Electric Charge Interactions**
Students understand that magnetic and electric charge interactions occur between mutually attracting or repelling objects, which can cause a change in motion of one or both objects. Materials can be classified as magnetic or nonmagnetic, depending on how they interact with a magnet.

Standard PS.2

Physical and Chemical Properties of Matter
Matter has mass and volume and can exist as a solid, liquid or gas. All pure substances have their own unique set of physical and chemical properties that can be used to identify them.

Objectives

PS.2.1 **Properties of Matter**
Students understand that pure substances are composed of matter that has definable properties. Through macroscopic observation and measurement of these properties, students can describe and identify these substances.

PS.2.2 **States of Matter**
Students understand through observation that matter can exist in three common states: solid, liquid or gas. Students understand that these macroscopic observations serve as evidence of the concept that matter can exist as elements, compounds or mixtures.

PS.2.3 **Particulate Nature of Matter**
Students understand that matter is composed of atoms that can interact in different ways to form molecules and crystals. The structure, behavior and properties of matter can be explained by using models that depict particles in constant motion as well as the strength of the interacting forces among the particles.

Standard PS.3

Conservation of Matter
Matter can be transformed by a change of state or by undergoing chemical reactions, but it can never be created or destroyed.

Objectives

PS.3.1 **Conservation of Matter**
Students understand that matter can neither be created nor destroyed during any interaction, including change of state or a change that takes place as a result of a chemical reaction.

PS.3.2 **Physical and Chemical Changes of Matter**
Students understand that chemical reactions produce new substances with new properties, whereas changes of state alter the appearance of a substance, not the identity of a substance.

Standard PS.4

Conservation of Energy
When any change occurs, energy is transferred and/or transformed, but it is never lost.

Objectives

PS.4.1 **Mechanical Energy Transfer (Work) and Energy Changes**
Students understand that interactions between objects can be described not only in terms of forces but also in terms of energy transfers between the objects. Energy can be transferred from one object to the other by means of pushes or pulls that result in changes in motion.

PS.4.2 **Electric Circuit Interactions**
Students understand that during electric circuit interactions, electrical energy is transferred from the source of electric current to the electrical device, or devices, in the circuit.

PS.4.3 **Mechanical Wave Interactions**
Students understand that during mechanical wave interactions, mechanical energy is transferred through a material without a transfer of matter.

PS.4.4 **Conservation of Energy**
Students understand that energy can be transferred from one object to another within a system or across a system boundary and/or transformed within a system from one form to another, but it never disappears.

PS.4.5 **Thermal Energy**
Students understand that thermal energy can be transferred and/or transformed by different mechanisms (i.e., conduction, convection and radiation).

Chemistry

Standard C.1

Structure of Matter
Matter is composed of small particles called atoms that are in constant motion and that combine in various predictable ways.

Objectives

C.1.1 **Atomic Theories**
Students understand the current model of atomic structure, how the model has changed over time, and how experimental evidence about atomic structure has led to changes in the atomic model.

C.1.2 **Electrons**
Students understand that the interactions of electrons between and within atoms are the primary factors that determine the properties of matter.

C.1.3 **Bonding**
Students understand that matter is composed of atoms of elements, most of which are bonded in different but predictable ways.

C.1.4 **Representations of Matter**
Students understand that atoms, molecules and ionic substances can be represented with a variety of models.

C.1.5 **States of Matter**
Students understand that matter exists in different states, and that these states are determined by atomic–molecular level structure, attractions between particles, and the relative motions of particles.

C.1.6 **Nuclear Chemistry**
Students understand that changes occurring in the nucleus of an atom may alter the identity of an atom and often result in large changes in energy.

Standard C.2

Matter and Change
The properties of matter and the changes that matter undergoes result from its atomic–molecular level structure. For any chemical or physical change, matter is conserved.

Objectives

C.2.1 **Periodic Table**
Students understand that the periodic table is an organizational tool that can be used for the prediction and classification of the trends and properties of elements.

C.2.2 **Structure–Property Relationships**
Students understand the relationship between molecular-level structure and chemical and physical properties.

C.2.3 **Conservation of Matter**
Students understand that matter is conserved whenever any change occurs.

C.2.4 **Chemical Equilibrium**
Students understand that many reactions do not proceed completely from reactants to products; instead, reactions reach a state of dynamic equilibrium where the amounts of reactants and products appear constant.

C.2.5 **Chemical Kinetics**
Students understand that for a chemical reaction to occur, reacting particles must collide in the appropriate orientation with enough energy to overcome the activation energy barrier.

Standard C.3

Energy and Change

When any change occurs, energy is transferred and/or transformed, but it is never lost.

Objectives

C.3.1 **Conservation of Energy**
Students understand that energy is conserved during any change — energy may be transformed into another type of energy, but it never disappears.

C.3.2 **Energy Transfers and Transformations**
Students understand that when any change occurs, energy is transferred or transformed; some energy (in the form of thermal energy) always spreads out, making it more difficult to effect further change.

C.3.3 **Chemical Energy**
Students understand that energy changes associated with chemical reactions are a result of the rearrangement of atoms in a chemical system.

Physics

Standard P.1

Interactions, Motion and Forces

Changes in the natural and designed world are caused by interactions. Interactions of an object with other objects can be described by forces that can cause a change in motion of one or both interacting objects.

Objectives

P.1.1 **Patterns of Constant and Changing Linear Motion**
Students understand that the constant and changing linear motion of an object is characterized by the vector quantities of displacement, velocity and acceleration.

P.1.2 **Forces and Changes of Motion**
Students understand that the acceleration of an object is proportional to the vector sum of all the forces (net force) on the object and inversely proportional to the object's mass ($\vec{a} = \vec{F}_{net}/m$). When two interacting objects push or pull on each other, the force on one object is equal in magnitude but opposite in direction to the force on the other object.

P.1.3 **Contact Interactions and Forces**
Students understand that some types of contact interactions have force laws that are empirical approximations. Some contact interactions have no force laws because the value of the force depends on other forces from different simultaneous interactions. These interactions can cause a change in motion of one or both interacting objects.

P.1.4 **Gravitational Interactions and Forces**
Students understand that the gravitational force on an object is proportional to the product of the two interacting masses and inversely proportional to the square of the distance between the centers of the masses (Newton's law of universal gravitation).

When an object's distance from Earth's surface is small compared to Earth's radius, then all objects fall with approximately the same acceleration (ignoring the effect of air resistance).

P.1.5 Electrical Interactions and Forces

Students understand that electrical interactions occur between mutually attracting or repelling charged objects, which can cause a change in motion of one or both objects. The attraction between a charged object and a neutral object is caused by the separation of charges in neutral objects.

Standard P.2

Interactions and Conservation Principles

The interaction of an object with other objects is governed by conservation principles such as the conservation of mass, energy, mass–energy (nuclear interactions), electric charge and linear momentum.

Objectives

P.2.1 Conservation of Charge, Mass and Energy

Students understand that charge is always conserved. Mass and energy are conserved separately for all types of interactions (except for interactions at the subatomic scale) and for all defined systems (open and closed). There is no measurable change in the mass of a system when energy is transferred across the boundary of the system.

P.2.2 Conservation of Linear Momentum

Students understand that the linear momentum of an object/system is the product of its mass multiplied by its velocity, and that interactions across the boundary of the system can transfer momentum into or out of the system. Linear momentum is always conserved for all defined systems (open and closed) and types of interactions.

P.2.3 Nuclear Interactions and the Conservation of Mass–Energy

Students understand that much larger amounts of energy can be transferred out of a system during nuclear interactions than during chemical interactions. Nuclear interactions can result in a change in the number of protons, thus changing the identity of the element.

Standard P.3

Interactions and Energy

Interactions of an object with other objects can be described and explained by using the concept of the transfer of energy from one object to another, both within a defined system and across the boundary of the system. Energy transfers across the boundary of a system can change the energy within the system.

Objectives

P.3.1 Contact Interactions and Energy

Students understand that a mechanical energy transfer (work) across the boundary of a system can change the kinetic energy, the stored elastic energy and other types of energy within the system.

P.3.2 Electric Current Interactions and Energy

Students understand that during electric circuit interactions, electrical energy is transferred from the source of electric current to the electric device, or devices, in the circuit. In most electric circuit interactions, energy is also transferred to the surroundings.

P.3.3 Mechanical Wave Interactions and Energy

Students understand that during mechanical wave interactions, mechanical energy is transferred through a material without a transfer of matter; different objects or materials can cause the path of the wave to change; and waves pass through each other, causing interference patterns.

P.3.4 Radiant Energy Interactions

Students understand that during radiant energy interactions, energy can be transferred over a distance without a material (medium) and that there are two models that illustrate how this happens. There is a continuous range of radiant energies that includes visible light. Some objects produce their own visible light, while others reflect light from their surroundings.

P.3.5 **Heating and Cooling Interactions and Energy**
Students understand that during heating and cooling interactions, there is a thermal energy transfer (heat) across the boundary of a system, affecting the temperature or the state of matter of the system. These interactions depend on the properties of the materials and on how far the system is from equilibrium.

Standard P.4

Interactions and Fields
Attractive and repulsive interactions at a distance (e.g., gravitational, magnetic, electrical and electromagnetic) can be described by using the concept of fields.

Objectives

P.4.1 **Forces and Fields**
Students understand that a field model is used to visualize at-a-distance interactions, and that these fields are the agents of the interaction.

P.4.2 **Energy and Fields**
Students understand that the energy stored in a system of two mutually attracting or repelling objects can be modeled as energy stored in the field of the two objects.

P.4.3 **Electromagnetic Interactions and Fields**
Students understand that an electromagnetic interaction occurs when a flow of charged particles creates a magnetic field around the moving particles, or when a changing magnetic field creates an electric field.

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Introduction to College Board Standards for College Success™

The College Board has developed college- and career-readiness standards for science in order to help states, school districts and schools provide all students with the rigorous education that will prepare them for success in college, opportunity in the workplace, and effective participation in civic life. The College Board's commitment to this project is founded on the belief that all students can meet high expectations for academic performance when they are taught rigorous standards by qualified teachers.

College Board programs and services have supported the transition from high school to college for more than 100 years. Advanced Placement® (AP®) courses enable students to transition into college-level study when they are ready, even while still in high school. The SAT®, the SAT Subject Tests™ and the PSAT/NMSQT® all measure content knowledge and critical thinking and reasoning skills that are the foundation for success in college. The College Board Standards for College Success™ make the necessary college-readiness knowledge, skills and abilities explicit so that states, school districts, schools and teachers can better align their educational programs with clear definitions of college readiness.

The College Board is dedicated to helping its members address the educational needs of their students. In an increasingly global economy, preparing more students to succeed in college is among the most critical priorities for the United States. According to the U.S. Department of Labor (2006), almost 85 percent of current jobs and approximately 90 percent of the fastest-growing and highest-paying jobs require some postsecondary education. Preparing students for college *before* they graduate from high school is critical to students' completing a college degree. Students who do not attain this level of education will likely be unprepared to successfully compete in the workplace.

Researchers who study students' transition to postsecondary education have cited a "disconnect" between the instruction provided to students in grades K–12 and what postsecondary educators believe students need to know and be able to do in order to be successful in college or in workforce training (Kirst & Venezia, 2001, 2004; Conley, 2007). Many of these same researchers suggest that more purposefully aligning K–12 educational standards — as well as the curricula and assessments that are based on these standards — with the expectations of higher education is a critical first step for bridging this gap.

The design of the College Board Standards for College Success reflects the need for vertically aligning the curricula, instruction, assessment and professional development across two grade bands — beginning in middle school (grades 6–8) and culminating in high school (grades 9–12) — with expectations for college and workforce success. The College Board Standards for College Success are, therefore, more purposefully targeted than many standards documents because they are deliberately aligned with expectations for entrance into college-level science courses, and because they include performance expectations (PEs) that specify how content knowledge is to be used and developed through reasoning and in problem solving. This level of specificity provides sufficient guidance for curriculum supervisors and teachers to design instruction and assessments that prepare students in middle school and high school for AP and college courses, but the College Board Standards for College Success are not designed uniquely as preparation for AP courses. Rather, the College Board uses these standards to align its own curriculum and assessment programs to achieve the overarching goal of college readiness. By developing academic standards that align with the expectations of postsecondary educators, the College Board is addressing many of the issues identified by the Alliance for Excellence in Education (2007) as impediments to college success for all.

Development of the *Science College Board Standards for College Success*

BACKGROUND AND CONTEXT

Since the enactment of the No Child Left Behind (NCLB) Act of 2001, every state, as well as the District of Columbia, has established its own set of academic standards for science. Because states and school districts across the nation vary widely in their goals and approaches to science education, these standards also vary widely in terms of their rigor, focus, breadth, depth and content. While many states have aligned their science standards with standards from national and professional organizations, such as the *National Science Education Standards* (National Research Council [NRC], 1996) or the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), that promote a broad definition of science literacy for all, few states and school districts have focused explicitly on aligning science standards to the goals of college or workforce readiness for all students.

To address the need for purposeful college- and career-readiness standards in science, the College Board convened the Science Standards Advisory Committee in 2006 to guide the development of standards that make explicit what *all* students should know, understand and be able to do in order to be prepared for introductory college-level science courses or their AP equivalents. The committee was composed of middle and high school teachers, higher education subject matter experts, assessment specialists, teacher-education faculty, individuals with expertise on science learning, and curriculum experts with experience in developing standards for states and for national professional organizations (committee members are listed on pages xx–xxi).

In contemporary educational discourse, the term "standard" is used to mean several different things. Content standards generally specify what students should know and be able to do as a result of instruction in a subject area. They describe the concepts and skills that students are expected to master at a particular point in their education. The purpose of content standards is to guide instruction by focusing educators on a specific set of topics that represents the goals of the authoring body — often state decision-makers or committees established by professional disciplinary societies. Performance standards, which under NCLB are also called achievement standards, describe what is expected of students regarding their level of proficiency or mastery on state or district assessments. When the policymakers and the public call for higher educational standards, they often use the term to refer to an entity that includes both of these types of standards.

The *Science College Board Standards for College Success* includes *learning standards* that meet the policymakers' demands for higher educational standards by specifying what students need in order to succeed in college-level science courses in earth science, life science, chemistry and physics. However, by including focused and specific *performance expectations* (PEs) that describe the ways students are expected to use and build their science knowledge to accomplish a goal or task, these standards can also serve as *performance standards*. Therefore, the science standards bridge the state-level description of what students should know and be able to do in science with the classroom performances that will enable students to meet these state or district expectations.

In order to illustrate the developmental growth in the complexity of knowledge, skills and abilities that might be expected of students at different levels and with appropriate instruction, the sophistication of the performance expectations increases as the standards move from the 6–8 grade band to the 9–12 grade band. The performance expectations included in this standards document should not be interpreted as an exhaustive list of expectations, but as representative of how students should engage in science practices and apply their knowledge to achieve the learning standards. These performance expectations are intended to help educators in designing instruction and assessments that address the goal of college readiness.

APPROACH

The committee members approached their task by agreeing on what it means to "know science" for the purposes of these standards. Drawing on their combined experience and more than 25 years of research in the learning sciences, they agreed that knowing science requires individuals to integrate a complex structure of many types of knowledge. These knowledge types include the ideas of science, the relationships between the ideas, the reasons for these relationships, and the ways to use these ideas to complete the following tasks: explain and predict other phenomena, interpret situations, solve problems and participate productively in science practice and discourse. Much of the supporting research is summarized in synthesis reports and research handbooks, such as *A History of Ideas in Science Education: Implications for Practice* (DeBoer, 1991); *How People Learn: Brain, Mind, Experience, and School* (National Research Council, 1999); *How Students Learn: Science in the Classroom* (National Research Council, 2005); *Scientific Thinking and Science Literacy* (Lehrer & Schauble, 2006); *The Cambridge Handbook of the Learning Sciences* (Sawyer, 2006); *Taking Science to School: Learning and Teaching Science in Grades K-8* (National Research Council, 2007); and *Handbook of Research on Science Education* (Abell & Lederman, 2007). In addition, the committee's thinking was influenced by *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993); *National Science Education Standards* (National Research Council [NRC], 1996); and by the work of professional disciplinary societies in earth science, life science, chemistry and physics.

The committee members then adopted the following goals and guiding criteria for the standards:

- The standards must be clear, concise and coherent — they should clearly reflect careful judgment and specificity about which aspects of science students need for college readiness and success.

- The standards must provide the specificity and detail that are necessary to provide sufficient guidance to teachers and curriculum developers who will use the standards to develop both curriculum and instructional materials.

- The standards must be reasonable in scope — they should focus only on the essential content and practices that create a pathway to college success for all students.

- The standards must be rigorous and scientifically correct. In defining rigor, the Science Standards Advisory Committee sought to shift the meaning from a focus on learning all of the facts and specific examples about a concept to an understanding and application of core principles of the discipline and an integration of that knowledge with the processes that are necessary for practicing science.

- The standards must provide a conceptual framework that clearly indicates how each of the science disciplines is organized and how smaller concepts support the principles, laws and theories that are foundational to the discipline. The standards should focus on relating core principles to phenomena that students will encounter in the natural world so that students can use their knowledge to explain and predict these natural phenomena.

- The standards must seamlessly provide a pathway of preparation for the AP courses in environmental science, biology, chemistry and physics.

The Science Standards Advisory Committee faced the key challenge of deciding what should be included as science standards and how these standards should align with existing state and national standards documents. Members of the committee addressed this challenge by focusing on college readiness rather than on the broader goal of science literacy for all. They focused on defining the knowledge, skills and abilities that students need for success in first-year college courses or their Advanced Placement counterparts. They used the Advanced Placement course and exam specifications as a target for the standards' pathway. Key national standards and international frameworks — such as *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993); *National Science Education Standards* (National Research Council [NRC], 1996); *ICT Literacy Map — Science* (Partnership for 21st Century Skills, 2004); *Assessing Scientific, Reading and Mathematical Literacy: A Framework for PISA 2006* (Organisation for Economic Co-Operation and Development [OECD], 2006); and *Science Framework for the 2009 National Assessment of Educational Progress (NAEP)* (National Assessment Governing Board [NAGB], 2008) — were carefully reviewed and referenced as the standards were developed, but the committee did not align the science College Board Standards with any one set of national or state standards or with any one assessment framework. Consequently, it is intended that the standards do not address every topic that is included in state science standards; this standards document seeks to increase the depth of the standards as opposed to their breadth. Teachers and curriculum supervisors will need to decide how to integrate or supplement their own standards with the science College Board Standards in order to narrow any gap between state expectations for science learning and the expectations and demands of postsecondary education.

The science College Board Standards focus primarily on the development of the knowledge, skills and abilities that are required to understand the overarching principles and core ideas that have explanatory power within and across science disciplines — the "big ideas" of science. While there is no universal agreement about what constitutes these "big ideas," the Science Standards Advisory Committee agreed that it was important to align the standards with the ideas and understandings that are foundational to the Advanced Placement science courses, as developed by National Science Foundation (NSF)-funded, discipline-specific, expert committees responsible for redesigning AP science. The AP science curricula are now developed by using a process of backwards design (Wiggins & McTighe, 1998). The NSF-funded AP committee members identify a small number of big ideas around which to organize the courses. They further specify, in statements known as enduring understandings, the content knowledge related to these ideas that is important to learn in an AP course or in a first-year college course in the discipline. As a result of this process, AP science courses are increasingly structured around a small number of organizing principles and around the specification of the enduring understandings that support students' comprehension of these larger principles.

Although the science College Board Standards are not designed as an exhaustive compendium of all levels of science knowledge, they are complete with regard to their intended purpose of providing a clear, concise and coherent pathway to college readiness. They not only include the content that students need to learn for college success, but they also make explicit the related concepts and principles that are necessary to develop students' understanding, the prerequisite knowledge that students need in order to progress to higher-level courses, and a framework that shows how subsequent knowledge will build over time and deepen students' conceptual understanding. As previously mentioned, the science College Board Standards also include student performance expectations that specify how students can demonstrate mastery of a concept and an understanding of how one concept connects to others. More importantly, the standards also set boundaries around these expectations by clearly delineating what is not included or intended so that teachers and students can focus on the most important concepts. These “BOUNDARY” statements immediately follow the corresponding performance expectation and, in some instances, appear immediately following an objective or an essential knowledge (EK) statement.

SUPPORTING DATA

College readiness continues to be an emerging concept, and it has been defined by a number of groups and researchers — each with a slightly different interpretation of what the term means. The definition of college readiness that undergirds the work of the Science Standards Advisory Committee states that students are college ready when they have the knowledge, skills and abilities to successfully complete a college course of study without remediation (College Board, 2007). The term “succeed” is defined as completing introductory courses at a level of understanding and proficiency that makes it possible for students to consider taking the next course in the sequence or the next-level course in the subject area (Conley, 2007).

To support the approach to the development of the science standards, the committee examined the work of other organizations that studied the same national and international frameworks that the committee had reviewed. These organizations include the Fordham Foundation (Gross, et al., 2005); the Council of Chief State School Officers (CCSSO, 2007); Achieve, Inc. (2007; 2008); and the American Federation of Teachers. The committee members also consulted the work of Editorial Projects in Education, which produces the *Quality Counts* reports released by *Education Week*. All of these materials provided the committee with a clearer understanding of students’ science classroom experiences and with insight on where critical gaps exist between K–12 expectations for science learning and what is needed for success in higher education.

To further support the committee’s selection of the knowledge, skills and abilities that are needed for success in introductory college science courses, the committee members reviewed a College Board–sponsored survey of 146 postsecondary institutions that defined the knowledge, skills and abilities that their faculty members believed were critical to success in first-year college courses (Conley, Aspengren, Gallagher, & Ray, 2005). Data were collected from 171 additional postsecondary institutions, and the knowledge, skills and abilities necessary for successful performance in introductory college courses were identified (Conley, Aspengren, Gallagher, Stout, & Veach, 2006). The definitions of college readiness gathered through these surveys, as well as through course analyses and case studies, represent a well-researched, empirically validated definition of college readiness.

Since there are limited data available to support complete learning progression standards, the committee used the research available for guidance when developing the pathways to college readiness. When the research was not available, the distribution of expertise among the committee’s middle school and high school teachers, college faculty and learning specialists identified relevant experiences to further support the pathway’s development.

Organization of the *Science College Board Standards for College Success*

The *Science College Board Standards for College Success* is organized into eight areas of science study: unifying concepts; science practices; science, technology and society; and the five disciplines (earth science, life science, physical science, chemistry and physics). The science practices standards describe the ways in which students are expected to both develop and apply their knowledge of the discipline by engaging in the types of “practices” that scientists use to accomplish a goal or to complete a task. The practices described here are not discrete skills, but rather a rich set of integrated processes and ways of thinking that support the development of a conceptual understanding of science concepts; develop the habits of mind that are necessary for scientific thinking; and allow students to engage in science in ways that are similar to those used by scientists. The science practices and all of the discipline-specific standards, specifically the performance expectations, focus on goals that are central to science: establishing lines of evidence, and using the evidence to develop and refine scientific explanations and to make predictions about natural phenomena.

In making the decision to focus on evidence-based explanations, the committee noted that several national and international assessments of science achievement have been redesigned and now more explicitly focus on evaluating students’ ability to explain phenomena in the context of observations (*Science Framework for the 2009 National Assessment of Educational Progress* [NAGB, 2008] and *Assessing Scientific, Reading and Mathematical Literacy: A Framework for PISA 2006* [OECD, 2006]). The inclusion of explanation as part of these assessments highlights a growing consensus about its importance in science learning and achievement.

All of the discipline-specific (earth science, life science, physical science, chemistry and physics) standards use *unifying concepts* and *science practices* to describe what students should know and be able to do in order to be college ready. Each group of standards — science practices; science, technology and society; and discipline-specific — begins with a detailed narrative of the goals for science learning in that particular area of study. This narrative is followed by the standards and objectives, as well as performance expectations (PEs) and/or essential knowledge (EK) statements. Performance expectations are housed only in the discipline-specific standards to illustrate the integration of the objectives within the science practices and the objectives within the content knowledge standards.

HIERARCHICAL STRUCTURE WITHIN EACH OF THE FIVE DISCIPLINES

Standard: The discipline-specific standards represent the core ideas of each discipline. Each idea is expressed in one overarching statement that is followed by a more in-depth discussion of the related content. A key word or phrase precedes each standard and helps articulate the idea of the standard when referenced by other disciplines or during curriculum or instructional planning.

Objective: The objectives provide detailed descriptions of more specific core principles and concepts within the discipline. They are the target understandings for college readiness and the key elements of the conceptual framework of the content knowledge. They also provide a specific explanation of the learning goals that directly relate to the corresponding standard.

Performance Expectation: For each objective, there are performance expectations that specify what students in grades 6–8 and 9–12 should know, understand and be able to do before leaving high school, so that they are prepared for college success. The performance expectations illustrate how students engage in science practices in order to develop a better understanding of the objective and the essential knowledge statements. These expectations support targeted instruction and assessment by providing tasks that are measurable and observable. The number of PEs for a given objective does not indicate any level of importance, and it is assumed that some PEs may require greater amounts of instructional time than others. The purpose of all of the PEs is to provide ways in which students can master the content described in the corresponding objective; however, each discipline approaches this pathway toward the objectives differently.

Essential Knowledge: The essential knowledge statements support the corresponding objective and delineate the conceptual targets for student learning. These statements provide a more detailed description of the broader knowledge outlined in the objective. Students can then concentrate on using or ascertaining this more focused knowledge, rather than on an exhaustive list of less essential knowledge. The conceptual targets also enhance their learning and provide more time for students to apply this knowledge as they develop their science practices. The EK statements should be approached from a holistic perspective, and they should not be viewed as a list of discrete, unrelated facts for students to memorize.

ADDITIONAL FEATURES

Linking knowledge in different contexts within one single discipline, as well as linking knowledge from one discipline to another, are key strategies for increasing depth of student understanding. To emphasize the importance of these factors, objective-to-objective connections are provided where appropriate. An objective is often followed by a list of other objectives — within the discipline as well as from other disciplines — that are connected in some way to that objective. These *suggested* connections are simply examples that emphasize the importance of linking knowledge within one discipline in order to build a more robust understanding of the concept, as well as linking knowledge from one discipline to another; this is not an exhaustive list of *required* connections. These connections are intended for either the 6–8 grade band or the 9–12 grade band; there are no connections spanning the 6–12 grade band. Certain connections have been identified because they represent a logical reinforcement of a concept, big idea and/or unifying concept. Others promote an enriched understanding of different aspects of a concept, big idea and/or unifying concept. Those connections that reference objectives in a different discipline offer a broader application of the knowledge, independent of context. All of the objectives within the same standard are inherently connected; therefore, no connections have been made from a given objective to another within the same standard.

Additionally, most objectives within the discipline-specific standards prepare students for the enduring understandings that will increasingly be the focus and the end goals of the AP science courses. Immediately following the suggested connections is a list of the AP enduring understandings that map to the given objective. A summary of these AP enduring understandings can be found in the appendixes that immediately follow the physics standards. It is important that the reader understands that the *Science College Board Standards for College Success* does not list AP standards; rather, it prepares students for success in an AP science course, or in an equivalent introductory college-level course. The AP Physics courses are designed to be students' first courses in physics. Consequently, the 9–12 physics standards are not an exclusive pathway toward AP Physics courses; rather, the 9–12 physics standards prepare students for an introductory college-level course.

The committee recognized at the outset of the project that the different science disciplines and the science learning community use different language to describe similar concepts. Therefore, a glossary of terms is provided to make clear how terminology is used for the purpose of this standards document; it is not a complete glossary of all science terms.

USING THE *SCIENCE COLLEGE BOARD STANDARDS FOR COLLEGE SUCCESS*

The *Science College Board Standards for College Success* specifies what students should know, understand and be able to do in order to be prepared for first-year college science courses or their AP equivalents, but it does not prescribe any specific course progressions. Rather, the science standards seek to build a pathway that allows for a variety of course progressions or integrated approaches to be implemented.

Because education in the United States is decentralized — and because states, school districts and schools all can create their own curriculum and approach to instruction — these standards do not dictate or embrace one approach to science education over another. For example, some students study physics when they first begin high school (Council of Chief State School Officers [CCSSO], 2007); for other students, physics is the capstone course of their high school science career. Some students attend schools where integrated science is the foundation of the science curriculum; others may attend schools that relegate certain courses, such as earth science, to a single course in middle school. There is no one science sequence, curriculum, instructional methodology or set of expectations that all students in the United States share, and these science standards are not intended to prescribe one. Rather, the standards describe the knowledge, skills and abilities that all students should acquire over the course of their science career, regardless of the specific courses they take or the order in which they take them.

While the standards detail an appropriate continuum of student learning objectives that are intended to prepare students for the demands they will encounter in AP courses and in postsecondary education, they are not intended to recommend grade-specific or course-specific expectations. This is an important point when considering the effective use of these standards. Because it is impossible to align the standards with a science learning experience that is common to all students, curriculum supervisors need to locate their own curriculum on the continuum that is described in the standards and make adjustments to the progression in accordance with their own standards and course sequences. Teachers also must make adjustments to meet the individual learning needs of their students.

The Science Standards Advisory Committee cautions, however, that failing to target a conceptual understanding, focus on core principles, integrate the content and practices specified in the performance expectations, or adhere to any of the goals established by the committee could result in a program that does not adequately prepare students for a seamless transition into postsecondary education or workforce training that is based on a firm foundation of science proficiency. Preparation for such a transition requires that students have developed a solid understanding of the factual, procedural and epistemic knowledge outlined in these standards and that they have had multiple opportunities to apply this knowledge in a variety of contexts.

These college- and career-readiness standards have been reviewed, in draft form and according to accepted standards for academic peer review, by individuals and groups other than the authors. Reviewers, selected for their diverse perspectives of and experience with K–16 science education, were asked to comment on the content, rigor, focus, coherence, progression, clarity and overall design of the standards. The College Board is grateful for their commitment and dedication to this effort.

Science Standards Advisory Committee

Gregory M. Benedis-Grab
Middle School Science Teacher
The School at Columbia University
New York, New York

Meryl W. Bertenthal
Coordinator, Indiana University Institute for Science, Technology, Engineering and Mathematics Education (ISTEME)
Office of the Vice Provost for Research
Bloomington, Indiana

Carolyn Schofield Bronston
Retired AP Biology Teacher
Robert E. Lee High School
Tyler, Texas

Melanie M. Cooper
Alumni Distinguished Professor of Chemistry
Department of Chemistry
Clemson University
Clemson, South Carolina

Marilyn R. Decker
Director, Analytical and Applied Sciences
Jefferson County Public Schools
Louisville, Kentucky

George E. DeBoer
Deputy Director, Project 2061
American Association for the Advancement of Science
Washington, D.C.

Patricia Heller
Retired Associate Professor
Physics Education Department of Curriculum and Instruction
College of Education
University of Minnesota
Minneapolis, Minnesota

Bruce E. Herbert
Professor of Geology
Department of Geology and Geophysics
Texas A&M University
College Station, Texas

Jason D. Hook
Middle School Science Teacher
Austin Independent School District (ISD)
Austin, Texas

Dat Q. Le
Life Science Teacher
H-B Woodlawn Secondary Program
Arlington, Virginia

Ramon E. Lopez
Professor
Department of Physics
University of Texas at Arlington
Arlington, Texas

John L. McKinney
Middle School Science Teacher
Douglas County Schools
Castle Rock, Colorado

Larry Neal
Chemistry Teacher
Rochester City School District
Rochester, New York

Baldomero M. Olivera
Distinguished Professor of Biology
University of Utah
Salt Lake City, Utah

Stephen L. Pruitt
Chief of Staff
Office of the State Superintendent of Schools
Georgia Department of Education
Atlanta, Georgia

Robert W. Ridky
Education Coordinator
U.S. Geological Survey
Reston, Virginia

Nancy Butler Songer
Professor of Science Education and Learning Technologies
School of Education
The University of Michigan
Ann Arbor, Michigan

Paul Speranza
Retired Science Teacher
Lafayette High School
Brooklyn, New York

Gay B. Stewart
Associate Professor of Physics
Department of Physics
University of Arkansas
Fayetteville, Arkansas

College Board Staff

Cynthia Hamen Farrar
Director, Science Product Development
College Readiness Product Development

Donovan Hylton
Assessment Specialist
Research and Development

Christopher Lazzaro
Associate Director, Science Education
Research and Development

Danielle Luisier
Director, Standards and Curriculum Alignment Services
Research and Development

Science Reviewers

Science Academic Advisory Council

Audrey B. Champagne
Professor Emerita
Education and Chemistry
University at Albany, SUNY
Albany, New York

Arthur Eisenkraft
Distinguished Professor of Science Education
Director, Center of Science and Math in Context (COSMIC)
Graduate College of Education
University of Massachusetts Boston
Boston, Massachusetts

John Hnatow
AP Chemistry Consultant
Science Educational Consultant
JH Consulting
Northampton, Pennsylvania

David Hong
Instructional Dean
Department of Science and Mathematics
Diamond Bar High School
Diamond Bar, California

Peggy O'Neill Skinner
Science Department Chair
The Bush School
Seattle, Washington

Achieve, Inc. Staff

Joseph Accongio
Science Consultant
Achieve, Inc.
Rochester, New York

Jean B. Slattery
Senior Associate, Science
Achieve, Inc.
Washington, D.C.

Achieve, Inc. Reviewers

Robert Goodman
Vice Chair
New Jersey Center for Teaching and Learning
Trenton, New Jersey

Henry W. Heikkinen
Professor Emeritus of Chemistry
University of Northern Colorado
Greeley, Colorado

María Alicia López Freeman
Executive Director, California Science Project
UCLA
Los Angeles, California

Eric J. Pyle
Associate Professor of Geology
Department of Geology and Environmental Science
James Madison University
Harrisonburg, Virginia

Susan Singer
Laurence McKinley Gould Professor of Natural Sciences
Department of Biology
Carleton College
Northfield, Minnesota

Cary Sneider
Associate Research Professor
Portland State University
Portland, Oregon

George Wolfe
Director
Loudoun County Science Academy
Sterling, Virginia

Judy Wolfe
Science Teacher, Grades 7–12
Loudoun County Public Schools
Asburn, Virginia

Individual Reviewers

Elizabeth Allan
Assistant Professor
Department of Biology
University of Central Oklahoma
Edmond, Oklahoma

Sherry Anderson
Sixth Grade Science Teacher
West Lafayette Community School Corporation
West Lafayette, Indiana

Ann E. Benbow
Director, Education, Outreach, and Development
American Geological Institute
Alexandria, Virginia

Mari Strand Cary
Research Associate
Pacific Institutes for Research
Eugene, Oregon

Wolfgang Christian
Brown Professor of Physics
Department of Physics
Davidson College
Davidson, North Carolina

Richard A. Duschl
Waterbury Chair Professor
Curriculum and Instruction
Penn State University
University Park, Pennsylvania

Linda Froschauer
Editor, *Science and Children*
National Science Teachers Association
Arlington, Virginia

Ramona Hedrick
Secondary Science Teacher
East Mecklenburg High School
Charlotte, North Carolina

Georgina Koch Hidalgo
Science Teacher
Division of Mathematics and Science
Miami-Dade County Public Schools
Miami, Florida

Robert L. Kolenda
Science Education Consultant
Tucson, Arizona

Carla M. Koretsky
Associate Professor
Department of Geosciences
Western Michigan University
Kalamazoo, Michigan

David A. Kukla
Adjunct Professor
Center for Math and Science Teachers
School of Education
Loyola Marymount University
Los Angeles, California

John W. Layman
Professor Emeritus
Physics and Science Education
University of Maryland
College Park, Maryland

John M. Moore
President of the National Association of Biology Teachers
Professor and Coordinator of Cuenca Ecuador Centre
Department of Biology
Taylor University
Upland, Indiana

Cheryl A. Mosier
Earth Science Educator
Columbine High School
Littleton, Colorado

Brett D. Moulding
Director, Utah Partnership for Effective Science Teaching and Learning
Nebo School District
Springville, Utah

Kristine E. Mueh
Science Teacher
Centennial Middle School
Boulder, Colorado

Suzanne A. Pierce
Research Fellow
Environmental Science Institute
The University of Texas at Austin
Austin, Texas

Kevin J. Richard
Science Education Consultant
Office of School Improvement
Michigan Department of Education
Lansing, Michigan

Terri M. Taylor
Assistant Director, K–12 Science
American Chemical Society
Washington, D.C.

Debra Tomanek
Professor
Molecular and Cellular Biology
University of Arizona
Tucson, Arizona

Kathleen A. Creeden Treibs
Elementary Science and Health Coordinator
Curriculum and Instruction
Fort Bend Independent School District (ISD)
Sugar Land, Texas

Jerry D. Valadez
Director, Central Valley Science Project
California State University, Fresno
Fresno, California

Robert J. Wallace
Coordinator of the Math, Science, and Technology Enhancement Project (MSTEP)
The Math and Science Education Program
The Department of Teaching and Learning
The Steinhardt School of Culture, Education and Human Development
New York University
New York, New York

Gilda Wheeler
Program Supervisor, Education for Environment and Sustainability
Department of Teaching and Learning
Washington State Office of Superintendent of Public Instruction
Olympia, Washington

Brenda Wojnowski
President
Wojnowski and Associates, Inc.
Dallas, Texas

David Yaron
Associate Professor
Department of Chemistry
Carnegie Mellon University
Pittsburgh, Pennsylvania

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Kevin Brewer
Program Associate
Research and Development

Wayne J. Camara
Vice President
Research and Development

John Eggebrecht
Director, Science
Advanced Placement Program

John Marzano
Project Analyst
Research and Development

Colleen McDermott
Senior Assessment Specialist
Research and Development

Mary Morley (former employee)
Associate Professor
Department of Mathematics
Ocean Community College
Toms River, New Jersey

Trevor Packer
Vice President
Advanced Placement Program

Travis Ramdawar
Senior Project Analyst
Research and Development

Tanya Sharpe
Associate Director, Science
Advanced Placement Program

Natasha Vasavada
Senior Director, Standards and Curriculum Alignment Services
Research and Development

Jeremy Wang (former employee)
Graduate Student
Science Education, Curriculum and Instruction
University of Minnesota
Minneapolis, Minnesota

Marcia Wilbur
Executive Director, Curriculum and Content Development
Advanced Placement Program

Kathleen T. Williams
Senior Advisor
College Readiness Products

Steven Wong
Program Associate
Research and Development

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Guide to Using *Science College Board Standards for College Success*

Standards represent the core, overarching ideas of each discipline. Each standard has its own unique code or letter/number combination with the letter(s) representing the relevant discipline. A key word or phrase accompanies each standard to indicate the content covered. A more in-depth description follows each standard.

Glossary terms appear in bold.

Objectives describe the target understanding for college readiness; they explain specific learning goals that relate to the corresponding standard. Like the standards, each objective has a unique code as well as a corresponding key word or phrase.

Suggested connections are provided to show how the content of a given objective links to the content of other objectives within a discipline and across disciplines.

Standard LS.4
Matter and Energy

Biological systems utilize energy and molecular building blocks to carry out life's essential functions.

Students recognize that the interactions between organisms and their environment are dynamic in nature. The processes that define "being alive" involve chemical reactions that require the input of energy and that result in the rearrangement of atoms. Energy, which is ultimately derived from the Sun and transformed into chemical energy, is needed to maintain the activity of an organism. The matter that is involved in these dynamic processes is constantly **recycled** between the organisms and their environment.

Objective LS.4.1
Matter Cycling

Students understand that matter is continuously recycled within the biological system and between the biological (biotic) and physical (abiotic) components of an ecosystem.

*[**BOUNDARY:** At the 6–8 grade band, matter is treated as being made of atoms and molecules. Chemical reactions are presented as the rearrangement of atoms in molecules. Chemical reactions in terms of subatomic structures of atoms are not appropriate.]*

Suggested Connections

Within Life Science: Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3)

Between Life Science and Other Disciplines: Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Water Cycle (ES.4.1); Carbon Cycle (ES.4.2); Humans and the Environment (ES.5.3); Properties of Matter (PS.2.1); Particulate Nature of Matter (PS.2.3); Conservation of Matter (PS.3.1); Physical and Chemical Changes of Matter (PS.3.2); Electric Circuit Interactions (PS.4.2)

Note: For Objective LS.4.1, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.4.1.1 Create a representation to describe the cycling of a carbon atom from the physical (abiotic) environment through the molecules of the biological (biotic) components of an ecosystem back to the physical (abiotic) environment.
*[**BOUNDARY:** The chemical structure of any of the molecules is not appropriate.]*

LSM-PE.4.1.2 Make and justify a claim concerning whether a particular molecule of oxygen inhaled today could be made of the same atoms of oxygen inhaled by someone a hundred years ago. Make and justify a claim concerning whether a particular molecule of water consumed today could be made of the same atoms of hydrogen and oxygen consumed by someone a hundred years ago.

LSM-PE.4.1.3 Predict and justify what might happen to an ecosystem if there were no bacteria or fungi present. Prediction and justification are based on ideas about matter recycling between the biological (biotic) and physical (abiotic) parts of an ecosystem.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Matter is transferred among organisms in an ecosystem when organisms eat, or when they are eaten by others for food. Molecules from food react with oxygen to provide energy that is needed to carry out essential life functions, become incorporated into the body structures of organisms, or are stored for later use. Although matter is transformed in these processes as the atoms of molecules are rearranged, the matter is neither created nor destroyed.
- Matter moves within individual organisms through a series of chemical reactions in which molecules are rearranged to form new molecules. These chemical reactions enable organisms to carry out essential life processes and to build body structures.

LIFE SCIENCE

Performance expectations (PEs) specify what students should know, understand and be able to do in order to be successful in college. They also illustrate how students engage in science practices to develop a better understanding of the essential knowledge statements and the objective.

Objective LS.4.1: Matter Cycling

ESSENTIAL KNOWLEDGE (6–8), *continued*

- All the molecules that make up the food in an ecosystem once existed as other molecules in the physical (abiotic) environment and were transformed and incorporated into the biological (biotic) components of the ecosystem primarily via photosynthesis. Organisms that "produce" this food from molecules in the physical (abiotic) environment (through the process of photosynthesis) are called producers.

- Plants and other photosynthetic organisms take in other essential molecules (**minerals**) from their environment (e.g., soil or water). Although these substances are essential for plants and other photosynthetic organisms to incorporate into food, they are not a source of energy.

- During photosynthesis, carbon dioxide and water from the physical (abiotic) environment change (react) chemically to produce sugar molecules in plants and other photosynthetic organisms. The sugar molecules are used immediately by the organisms as an energy resource for life processes such as growth and reproduction, are incorporated into body structures, or are stored for later use.

- Matter is transferred from organisms to the physical (abiotic) environment when molecules from food react with oxygen to produce carbon dioxide and water in a process called cellular respiration. Cellular respiration takes place in most species.

- Matter is also transferred from the biological (biotic) environment to the physical (abiotic) environment by bacteria or fungi (decomposers). Decomposers consume the remains of organisms as food and break down the molecules into simpler molecules that can no longer be used as food. These simpler molecules are the source of essential molecules that plants and photosynthetic organisms absorb from the soil, and the source of molecules that are incorporated into food during photosynthesis.

Essential knowledge (EK) statements describe conceptual targets for student learning that support the corresponding objective. They provide language and boundaries of the performance expectations.

Objective LS.4.2
Energy Transfer

Students understand that all of the processes that take place within organisms require energy. In most ecosystems, the energy is derived from the Sun and transferred into chemical energy in photosynthetic organisms of that ecosystem.

*[**BOUNDARY:** At the 6–8 grade band, energy transfer, conversion or transformation should be based on the concept of energy conservation. The total energy in any process can be transferred from one object to another across the system boundary and/or transformed within a system from one form to another, but it never disappears. Incorporating system language and boundaries when focusing on ecosystems and organisms is important for accurately understanding energy transfer and transformation.]*

Boundary statements provide instructional guidance by restricting the scope of the content.

Suggested Connections

Within Life Science: Cell Function (LS.2.1); Cell Structure (LS.2.2); Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3); Matter Cycling (LS.4.1)

Between Life Science and Other Disciplines: Planetary Evolution (ES.2.5); Carbon Cycle (ES.4.2); Humans and the Environment (ES.5.3); Physical and Chemical Changes of Matter (PS.3.2); Conservation of Energy (PS.4.4); Thermal Energy (PS.4.5); Periodic Table (C.2.1); Chemical Equilibrium (C.2.4); Chemical Kinetics (C.2.5); Conservation of Energy (C.3.1); Energy Transfers and Transformations (C.3.2); Chemical Energy (C.3.3); Contact Interactions and Energy (P.3.1)

Prepares students for the following AP Enduring Understandings: AP Biology 2A, 2D, 4A, 4B; AP Environmental Science 1A, 1C, 2B, 3A, 3B, 3C, 5E

Most objectives prepare students for ***AP Enduring Understandings***.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.4.2.1 Give examples and classify organisms as producers, consumers or decomposers based on their source of energy for growth and development.

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Each ***PE*** has its own unique code with the letter(s) indicating the relevant discipline and, when appropriate, the grade band (middle school or high school).

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Unifying Concepts

1. Evolution
2. Scale
3. Equilibrium
4. Matter and Energy
5. Interaction
6. Form and Function
7. Models as Explanations, Evidence and Representations

Unifying Concepts

Informed by the *National Science Education Standards* (1996) and *Benchmarks for Science Literacy* (1995), the overarching **concepts*** described below are not only important across the science disciplines but also influence many other fields of study such as mathematics and technology. Spanning the 6–12 grade band, these concepts should serve as guiding **principles** that are presented to students through the contexts of discipline-specific standards. Connecting content to unifying concepts can help students understand how different science disciplines are related to each other. Through their experience with these overarching concepts at each grade band and in each discipline, students can begin to build their own strategies for making these connections. One particular objective in a certain discipline may be connected to several unifying concepts. Following each description of a unifying concept is a list of *suggested* discipline-specific objectives at each grade band that illustrate that unifying concept.

Evolution

Evolution is a series of changes, some gradual and some sporadic, that account for the present form and function of objects, organisms, and natural and designed systems. The general idea of evolution is that the present arises from materials and forms of the past and demonstrates changes in the universe.[1]

Suggested Objectives (6–8)
Earth Science: ES.1.5, ES.2.5, ES.3.2

Life Science: LS.1.1, LS.1.2, LS.1.3, LS.3.1, LS.3.2, LS.3.3, LS.5.2

Physical Science: PS.3.2

Suggested Objectives (9–12)
Earth Science: ES.1.5, ES.2.5, ES.3.2

Life Science: LS.1.1, LS.1.2, LS.1.3, LS.2.3, LS.2.4, LS.3.3, LS.5.2, LS.5.3, LS.5.4

Chemistry: C.1.6

Scale

Some objects, processes and events involve physical dimensions, numbers, time intervals and speeds whose ranges of magnitude vary significantly (e.g., subatomic to planetary size; milliseconds to billions of years). As a result, **models** are used to represent phenomena that extend beyond the everyday experiences of humans.

* Boldfaced words and phrases are defined in the glossary.

1. National Research Council, *National Science Education Standards* (Washington, D.C.: The National Academies Press, 1996), 119.

Scale, *continued*

Suggested Objectives (6–8)
Earth Science: ES.1.1, ES.1.2, ES.1.3, ES.2.1, ES.2.2, ES.2.3, ES.2.5, ES.3.1, ES.3.2, ES.4.1

Life Science: LS.1.1, LS.1.2, LS.1.3, LS.2.1, LS.2.2, LS.2.4, LS.4.2, LS.5.2

Physical Science: PS.1.4, PS.2.1, PS.2.2, PS.2.3, PS.3.2, PS.4.2, PS.4.4

Suggested Objectives (9–12)
Earth Science: ES.1.1, ES.1.2, ES.1.3, ES.2.1, ES.2.2, ES.2.3, ES.2.5, ES.3.1, ES.3.2, ES.4.1

Life Science: LS.1.1, LS.1.2, LS.1.3, LS.2.1, LS.2.2, LS.2.4, LS.3.3, LS.4.2, LS.5.2, LS.5.3, LS.5.4, LS.5.5

Chemistry: C.1.1, C.1.3, C.1.4, C.1.5, C.1.6, C.2.2, C.3.3

Physics: P.1.4, P.2.1, P.2.2, P.2.3, P.3.4, P.4.1

Equilibrium

The term "equilibrium" is used to describe states in which there is no apparent change in the system over time. For example, a system in which two masses are balanced is at equilibrium because there is no net change (in force, energy or mass) occurring. The term "equilibrium" is also used when a system (e.g., a chemical reaction) is at *dynamic equilibrium* (i.e., when two or more opposing processes proceed at the same rate, although there is no net energy change). A system at equilibrium or dynamic equilibrium will remain unchanged unless the **conditions** in the system are changed, at which time the system will respond by moving to a new equilibrium state. The term "equilibrium" is also used for *steady state* or *homeostatic* systems (often biological, e.g., cells, organisms or ecosystems). Even though a homeostatic system appears to be unchanging, unlike dynamic equilibrium, a homeostatic system requires a constant input of energy and/or matter to maintain the system.

Suggested Objectives (6–8)
Life Science: LS.3.3, LS.4.1, LS.4.2

Physical Science: PS.3.1, PS.3.2, PS.4.4

Suggested Objectives (9–12)
Life Science: LS.1.3, LS.2.2, LS.3.3, LS.4.2, LS.5.5

Chemistry: C.2.4

Physics: P.2.1

Matter and Energy

The universe consists of matter and energy. The part of the universe that is being studied is called a system. The investigation of systems of matter and energy acknowledges boundaries that allow one to study changes in the system. Matter in a system cycles through changes. Energy in a system **transforms** from one form to another and **transfers** from one location, across the boundary of a system, to another location. Matter and energy in systems are neither created nor destroyed but may change form.

Matter and Energy, *continued*

Suggested Objectives (6–8)
Earth Science: ES.1.4, ES.2.1, ES.2.2, ES.2.3

Life Science: LS.2.1, LS.2.2, LS.2.3, LS.3.1, LS.3.2, LS.4.1, LS.4.2, LS.5.2

Physical Science: PS.2.1, PS.2.2, PS.2.3, PS.3.1, PS.3.2, PS.4.1, PS.4.2, PS.4.3, PS.4.4, PS.4.5

Suggested Objectives (9–12)
Earth Science: ES.1.4, ES.2.1, ES.2.2, ES.2.3

Life Science: LS.2.1, LS.2.2, LS.2.3, LS.3.3, LS.4.2, LS.5.2

Chemistry: C.1.1, C.1.2, C.1.3, C.1.5, C.1.6, C.2.3, C.2.4, C.2.5, C.3.1, C.3.2, C.3.3

Physics: P.2.1, P.2.2, P.2.3, P.3.1, P.3.2, P.3.3, P.3.4, P.3.5, P.4.1, P.4.2, P.4.3

Interaction

Interaction is a statement of causality in science: Two objects or systems interact when they act on or influence each other to cause some effect. The effect is an observable change (e.g., change in motion, shape, mass, temperature, state or function) to one or both objects or systems. Everyday events and processes usually involve multiple interactions occurring simultaneously and/or chains of interactions. The duration of events and processes varies from very short to very long.

Suggested Objectives (6–8)
Earth Science: ES.1.1, ES.1.2, ES.1.3, ES.1.4, ES.1.5, ES.2.1, ES.2.2, ES.2.3, ES.2.4, ES.2.5, ES.3.2, ES.5.1, ES.5.2

Life Science: LS.1.2, LS.1.3, LS.2.1, LS.2.2, LS.3.1, LS.3.2, LS.3.3, LS.4.1, LS.4.2, LS.5.3, LS.5.4

Physical Science: PS.1.4, PS.1.5, PS.2.1, PS.2.3, PS.3.1, PS.3.2, PS.4.1, PS.4.2, PS.4.3, PS.4.4, PS.4.5

Suggested Objectives (9–12)
Earth Science: ES.1.1, ES.1.2, ES.1.3, ES.1.4, ES.1.5, ES.2.1, ES.2.2, ES.2.3, ES.2.4, ES.2.5, ES.3.2, ES.5.1, ES.5.2

Life Science: LS.1.2, LS.1.3, LS.2.1, LS.2.2, LS.2.3, LS.2.4, LS.3.3, LS.4.2, LS.5.3, LS.5.5

Chemistry: C.1.2, C.1.3, C.1.5, C.1.6, C.2.1, C.2.2, C.2.3, C.2.4, C.2.5, C.3.3

Physics: P.1.1, P.1.2, P.1.3, P.1.4, P.1.5, P.2.1, P.2.2, P.2.3, P.3.1, P.3.2, P.3.3, P.3.4, P.3.5, P.4.1, P.4.2, P.4.3

Form and Function

Form and function are complementary aspects of objects, organisms and systems in the natural and designed world. The form (i.e., shape, composition, symmetry, orientation in space) of an object or system is frequently related to use, operation or function. Function frequently relies on form. Understanding of form and function applies to different levels of organization.[2] Function can be explained in terms of form, and form can be explained in terms of function.

Suggested Objectives (6–8)
Earth Science: ES.1.3, ES.1.5, ES.3.2, ES.4.1, ES.5.2

Life Science: LS.1.1, LS.1.2, LS.2.1, LS.2.2, LS.3.1, LS.3.3

Physical Science: PS.2.1, PS.2.2, PS.2.3, PS.4.1, PS.4.2, PS.4.5

Suggested Objectives (9–12)
Earth Science: ES.1.3, ES.1.5, ES.3.2, ES.4.1, ES.4.2, ES.5.2

Life Science: LS.1.1, LS.1.2, LS.2.1, LS.2.2, LS.2.3, LS.3.3, LS.4.2, LS.5.2, LS.5.3, LS.5.4, LS.5.5

Chemistry: C.1.1, C.1.2, C.1.3, C.1.5, C.1.6, C.2.1, C.2.2, C.3.3

Physics: P.3.3

Models as Explanations, Evidence and Representations

A model represents an object, system, event or idea, and may describe and/or predict the behavior of objects, systems or events. In the course of scientific discovery, models are developed, modified or abandoned based on the available **evidence**. Models and **representations** play a critical role in the development of scientific ideas and understanding.

Suggested Objectives (6–8)
Earth Science: ES.1.2, ES.3.1, ES.4.1

Life Science: LS.1.1, LS.1.2, LS.2.2, LS.3.2, LS.4.1, LS.4.2, LS.5.1, LS.5.2

Physical Science: PS.2.1, PS.2.2, PS.2.3, PS.3.1, PS.3.2, PS.4.1, PS.4.2, PS.4.3, PS.4.4, PS.4.5

Suggested Objectives (9–12)
Earth Science: ES.1.2, ES.3.1, ES.4.1, ES.4.2

Life Science: LS.1.1, LS.1.2, LS.2.2, LS.2.3, LS.2.4, LS.4.2, LS.5.2, LS.5.5

Chemistry: C.1.1, C.1.2, C.1.3, C.1.4, C.1.5, C.1.6, C.2.1, C.2.2, C.2.3, C.2.4, C.2.5, C.3.3

Physics: P.1.1, P.1.2, P.1.4, P.1.5, P.1.6, P.3.2, P.3.3, P.3.4, P.3.5, P.4.1, P.4.2, P.4.3

2. National Research Council, 119.

Standards

1. Asking scientific questions that can be tested empirically and structuring these questions in the form of testable predictions
2. Collecting data to address scientific questions and to support predictions
3. Searching for regularities and patterns in observations and measurements (i.e., data analysis)
4. Using evidence and science knowledge to construct scientific explanations, models and representations
5. Using mathematical reasoning and quantitative applications to interpret and analyze data to solve problems

Science Practices

Science involves the combined efforts of people to understand and explain how the natural world works. Scientists further their understanding by engaging in systematic study of events and organisms in the natural world and by looking for patterns in what they observe. They propose testable explanations based on **evidence*** derived from their work and the work of other scientists, and test and retest these explanations with further observations and study.

Central to science is the goal of establishing lines of evidence and using the evidence to develop and refine testable explanations and to make **predictions** about natural phenomena. The *Science College Board Standards for College Success* reflects this goal of science by focusing on developing, in all students, the competencies necessary for constructing testable, evidence-based explanations and predictions. In the course of learning to construct testable explanations and predictions, students will have opportunities to identify assumptions, to use critical thinking, to engage in problem solving, to determine what constitutes evidence, and to consider alternative explanations of observations. An important goal of school science is helping students to understand how explanations about one part of a system might be applied to thinking about new, or less familiar, **problems** and situations.

Through an instructional focus on student-developed explanations, teachers will be able to address other important aspects of science learning, such as revising students' alternative conceptions about natural phenomena and developing students' modeling skills. They can highlight the importance of accurate measurement; the need to control variables; the usefulness of creating multiple **representations** of the same phenomenon; the importance of re-expressing **data** to identify patterns; and the benefits of using mathematical routines to solve problems — all of these are important science practices that take on greater meaning when they are used in the context of developing testable explanations of natural and human-created phenomena.

Science Practices

Competence in science requires the integration of knowledge about how the natural world works with an understanding of how that knowledge was established, extended and refined, and how it can be used in both familiar and more novel situations. Subsequent sections of this standards document detail the factual and procedural knowledge that is necessary as a foundational knowledge base for college-level study in the earth, life and physical sciences, or for workforce training in related fields. This section describes the ways in which students are expected to apply and deepen their conceptual understanding of discipline-specific content knowledge through engagement in the types of "practices" that scientists use to accomplish a goal or to complete a task. The practices described here are not discrete skills, but rather a rich set of integrated ways of thinking that support the development of conceptual understanding of science **concepts**, develop the habits of mind that are necessary for scientific thinking, and allow students to engage in science in ways that are similar to those used by scientists.

It is important to realize that the science practices described in this section are deeply interconnected and nonlinear. For example, scientists do not always begin with a well-formulated **scientific question**. Sometimes, following careful observation over a period of time, patterns become apparent in the observed phenomena, prompting the scientist to ask specific empirically testable scientific questions. It is also important to note that these practices are almost always iterative. Scientific questions are stated, revised and then restated. Measurements are made multiple times, and then altogether new measurements are made. Data are represented in tables and graphs and then

* Boldfaced words and phrases are defined in the glossary.

re-represented in simulations or **models**. Models are created and modified as new observations are made. Similarly, the body of discourse, which describes the knowledge development and is the thread that holds all of science together, may develop and change.

Students who have a chance to engage in **scientific investigations** or laboratory experiences of many types will encounter these science practices multiple times in different contexts. The investigations included throughout the discipline-specific standards represent opportunities where science practices are developed. These investigations can take many forms. They might be a short-term project that can be completed during one class session, or they might be completed over a longer period of time. In some cases, the investigations may be revisited multiple times as students gain more insight into a particular concept. By developing science practices through multiple investigations of different concepts and scaffolding the different aspects of the practices in these investigations, students develop an appreciation of instances when certain practices should be applied under different **conditions**. In order to build students' appreciation, it is important that teachers and students engage in ongoing reflection and discourse about both the practice and the science content under study, and how they influence each other.

Explanations

A critical focal point of these investigations is the explanation that addresses the scientific question or the prediction that guided the investigation. In this standards document, the term "explanation" means a statement that is composed of the following: at least one **claim**, the evidence that is related to the claim, and the **reasoning** that makes clear the nature of the relationship between them. Scientists in different fields of science may use different vocabulary to describe claim/evidence/reasoning statements, as many things that scientists do (e.g., formulating **hypotheses**, proposing models, drawing conclusions, developing **theories**) involve making claims and justifying them with evidence. In this document, the term "explanation" is used in its most generic sense so that it encompasses these more specialized terms. Throughout the performance expectations, the term "explain" means that students construct an explanation of a natural phenomenon that has all three of the necessary component parts. A simple description of a phenomenon without evidence and reasoning is not explaining as it is used in these standards.

Performance Expectation for an Explanation:

Explain the process of seafloor spreading. Include cross sections of a midocean ridge showing the age of the sea floor, data on the thickness of sediments, and paleomagnetic information.

The Explanation:

Make the claim that convection within Earth's mantle results in seafloor spreading. Use a cross section of a midocean ridge showing the age of the sea floor, data on the thickness of sediments, and paleomagnetic information as evidence to support the claim, in terms of the process leading to the spreading of the sea floor. Construct a justification — based on knowledge of Earth's layers, the properties of these layers, convection, Earth's paleomagnetism and Earth's internal source of thermal energy — that connects the evidence to the process of seafloor spreading. Consider other explanations for seafloor spreading, and articulate why these explanations are not valid — due to type or quality of evidence or to a fault in the reasoning that supports the alternative claim.

Components of an Explanation:

Claim:	Make the claim that convection within Earth's mantle results in seafloor spreading.
Evidence:	Use a cross section of a midocean ridge showing the age of the sea floor, data on the thickness of sediments, and paleomagnetic information as evidence to support the claim, in terms of the process leading to the spreading of the sea floor.
Reasoning:	Construct a justification — based on knowledge of Earth's layers, the properties of these layers, convection, Earth's paleomagnetism and Earth's internal source of thermal energy — that connects the evidence to the process of seafloor spreading. Consider other explanations for seafloor spreading, and articulate why these explanations are not valid — due to type or quality of evidence or to a fault in the reasoning that supports the alternative claim.

Over the course of their science education, students will also learn that scientists in different disciplines (i.e., earth, life and physical sciences) may differ in the scientific questions they ask, in the methodologies they use for acquiring data, in their standards for acceptable evidence, and in the structure of the reasoning that they use as the basis for explanations. Teachers can help students gain this insight by asking them to use the language and the reasoning structure that is accepted in the particular field of science in which they are engaged, and by pointing out similarities and differences in these areas among the sciences that students have studied or will study in school.

Discourse

All scientists must share their explanations and predictions with other scientists so that these explanations and predictions can be subjected to further empirical testing, analysis and refinement. Thus, discourse (i.e., communication within the scientific community) runs through the entire enterprise. For example, science knowledge and the logic of discovery are preserved in the published results of scientific investigations. This knowledge and logic are also shared orally at professional meetings; the proceedings of these meetings are documented, so there is a written (published) record as well. Thus, scientists must be adept at interpreting the communication of others and at communicating the results of their own work to the larger scientific community in ways that will be understood and valued. Students who study science also need to engage in science discourse for purposes of both collaboration and communication.

Although engaging in science discourse is a critical part of the study of science, this document does not contain any standards that are specific to science discourse or communication. There are two reasons for this. First, the *English Language Arts College Board Standards for College Success* details standards for reading, writing, listening and oral communication in ways that can be applied quite readily to science. Second, discourse permeates all of the science standards. For example, modeling is both a form of communication and a tool for making predictions. Models may help others understand the conclusions of a scientist, but they are also a public display of a scientist's understanding of the world, as well as a way for all to test predictions about the world (i.e., what is expected to happen under the conditions described in the model). For example, if the model illustrates conditions that spawn hurricanes, the model can be compared with actual hurricane data to see if it behaves in the same way as a real hurricane. Discourse related to models provides a way to raise new scientific questions about phenomena, to test these questions by using the model, and to validate these questions against actual phenomena.

Teachers and students should be expected to use in their classroom discourse the language, representations and reasoning structures that are accepted by scientists, but science discourse goes beyond proper language. It also engages students in making clear, to themselves and others, not just *what* they know, but *how* they know it — claims are made; evidence is produced; and explanations are formulated, revised and extended through science discourse during which claims, evidence and reasoning are discussed and critiqued.

Science Practices in the Disciplines

Science practices must be taught and learned within the context of discipline-specific science content. The performance expectations detailed in the sections on earth science, life science, physical science, chemistry and physics illustrate how these practices are instantiated in different disciplines and how they might be addressed through instruction. The science practices standards are meant to be consistently integrated with the content knowledge outlined in subsequent sections. Students who engage in these practices over time and across disciplines will learn to construct explanations that go beyond a simple claim supported by a single piece of evidence. They will learn to develop more complex explanations that include multiple, interlocking claims; that address alternative claims; or that consider evidence that does not support the original claim.

By addressing the science practices standards together with discipline-specific concepts, teachers help students to deepen their understanding of the science content knowledge and to use this knowledge to think about new situations and novel problems — an important skill for college success. The integration of these two dimensions of scientific knowledge will also help students understand and engage in the science practices that develop, extend and refine the science content knowledge they are learning — key goals set by both the *National Science Education Standards* (National Research Council, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993).

Using Technology as a Tool to Practice Science

In a society that is technology driven, it is essential for students to use technology-based tools and digital resources that are critical to the generation of evidence, the development of **scientific explanations**, and the initiation — as well as the continuation — of discourse within the science community. Technology is ubiquitous and heavily integrated into every aspect of science; it is impossible to do any experimentation or manipulation of data without using technology. Therefore, throughout the discipline-specific standards there is an assumption that students have access to and use technology as a regular part of their science practice. The *Science College Board Standards for College Success* places a high value on the engagement of students in gathering, analyzing, manipulating, modeling and communicating authentic data by using technology, rather than on students' familiarity with different forms of technology. It is not the intention of this standards document to prescribe specific types of technology or sophisticated equipment that must be used in the classroom environment. However, access to and responsible use of technology are critical for students to be prepared for success in college-level science courses. All of the standards view technology as a tool that provides students with opportunities to practice authentic science so they can appreciate the intricacies of gathering accurate and precise measurements; analyzing complex sets of data; using digital tools to perform large-scale calculations; constructing computer-generated models; analyzing data from these models; and using digital tools for communication and collaboration with peers, teachers, parents and others across the nation and around the world. These technological applications appear in the performance expectations and essential knowledge (EK) statements across all disciplines and at all grade bands.

Structure of the Science Practices Standards

The science practices standards are described at three levels: standard, objective and essential knowledge statements. EK statements focus on aspects of the standards and objectives that should be addressed during instruction.

Standard: There are only five science practices standards, and these are the same for all students in grades 6–12. Each standard includes a detailed description of what students are expected to know and be able to do by the time they graduate from high school. Students may achieve the goals described in the standards in different ways and at different levels of mastery, but all students — given the appropriate instruction, practice, assistance and guidance — are capable of engaging in these science practices.

Because there are only five science practices standards, teachers can focus on the development, support and enhancement of students' understanding of these practices from one grade to the next. Students can perform and develop the same practice in a variety of contexts. This is an important factor in learning when and how to apply a science practice in novel situations or in unfamiliar contexts.

Objective: The science practices objectives specify the ways in which students will demonstrate that they have successfully achieved the goals described in a standard. The objectives provide targets for teaching and learning about testable, evidence-based explanations, and are the focus of student mastery for science college readiness. However, it is important to remember that students cannot achieve these objectives without discipline-specific factual and procedural knowledge and skills. While the science practices objectives are the same for all students in grades 6–12, the expectations for unassisted performance vary across grade levels and over time depending on a student's or a class's independence and experience with a specific practice, content or context. For example, developing models or constructing explanations may occur largely unassisted when associated with concepts that are more concrete (e.g., organism relationships, change in motion, erosion) and with contexts that are more familiar or more simple (e.g., local ecosystem, a ball falling, agricultural erosion). However, developing models or constructing explanations associated with abstract concepts (e.g., protein synthesis, emission spectrum, energy **transfer**) and more unfamiliar or more complex contexts (e.g., organism variation in a population, color of a star, car engine mechanics) may require more comprehensive scaffolding or supports for students.

Essential Knowledge: The knowledge, skills and abilities associated with practicing science are described in the bulleted essential knowledge statements under each objective. This essential knowledge should be explicitly taught and modeled in every science course and in every discipline. For example, students need to be taught about the nature of a scientific question and about how a scientific question differs from other kinds of questions. Students need to learn how to gather data that scientists would find acceptable, as well as learn what makes the data acceptable. They also need to know how the different science practices are interrelated and how they impact each other. Teachers should provide explicit instruction on the creation and application of the graphical, mathematical and symbolic models and representations that are typically used in each discipline, as well as on the purpose of applying these models and representations. The essential knowledge for the science practices must be taught in the context of discipline-specific content knowledge, and teachers are encouraged to identify areas of their curriculum in which this integration can take place.

Performance Expectation: The science practices standards do not include performance expectations; however, the discipline-specific (earth science, life science, physical science, chemistry and physics) standards feature performance expectations that illustrate how these science practices can be integrated with content knowledge.

Standard SP.1
Scientific Questions and Predictions

Asking scientific questions that can be tested empirically and structuring these questions in the form of testable predictions

Students ask scientific questions about phenomena, problems or issues that can be addressed through scientific investigations or with evidence from existing models. All science knowledge is eligible for such questioning. Keeping in mind that each phenomenon or problem occurs under specific conditions, students make predictions based on their science knowledge, observations and measurements of objects and events in the natural world, or data. Their predictions serve as a lens to focus data collection back to the scientific question. Students develop and refine both scientific questions and predictions so that they can be addressed through scientific investigations.

Objective SP.1.1
Scientific Questions

Students recognize, formulate, justify and revise scientific questions that can be addressed by science in order to construct explanations.

ESSENTIAL KNOWLEDGE

- A scientific question is one that is testable and can be supported or refuted with empirical evidence.
- A scientific question has its origins in observations and measurements of objects and events in the natural world, and in what is already known about the world.
- When posing a scientific question or solving a problem, it is important to identify what is known or assumed about the situation or condition being observed or measured.
- Scientific questions are often revised during the process of planning an investigation (see Objective SP.2.1). There is a dynamic relationship among the plan to gather evidence about the phenomenon, problem or issue; the evidence itself; and the development and refinement of a scientific question.
- Information compiled from similar studies, problems and investigations is gathered to provide insight into the formulation or revision of a scientific question, a potential plan to gather evidence, and plausible data to address the phenomenon or problem.
- Scientific questions should be asked of peers, instructors and other resources as a part of science discourse and the evaluation of evidence and explanations. Scientific questions are asked and researched to clarify personal understanding of the natural world.
- Scientific questions are foundational to the construction of an explanation.

Objective SP.1.2
Predictions

Students make and justify predictions concerning natural phenomena. Predictions and justifications are based on observations of the world, on knowledge of the discipline and on empirical evidence.

ESSENTIAL KNOWLEDGE

- A prediction about a natural phenomenon can be based on direct observations and measurements of patterns and regularities in the natural world and on the conditions of the natural phenomenon; data collected by others; knowledge of the discipline; or physical, mental or mathematical models of phenomena.
- Predictions are claims with justification about what might happen under certain conditions. The justification could be based on **principles** and concepts or on previous empirical evidence.
- Predictions should take into account existing scientific theories or models, scientific laws and new data.

ESSENTIAL KNOWLEDGE, *continued*

- A prediction is further refined as new knowledge develops or as empirical evidence is collected.
- Predictions may place boundaries around the experimental parameters (e.g., type and amount of data; frequency and length of data collection).

Standard SP.2
Generation of Evidence

Collecting data to address scientific questions and to support predictions

Students use controlled experiments, naturalistic observations, historic reconstruction, archived data and/or the findings of other scientists as resources to address scientific questions or test predictions. While considering the scientific question or the prediction, students decide what to measure (or which existing measurements to use) and observe, decide what unit of measure to use, develop data or archival data collection methods, and systematically collect and record data. Students recognize that data and evidence are different, and that the determination of which data can be used as evidence to address a particular scientific question or prediction depends on the question being asked, the prediction being made or the explanation.

Students use a variety of strategies (e.g., categorical, descriptive and quantitative) for collecting and recording **valid** and **reliable** data. Students recognize the reasons for multiple measures of the same phenomenon (i.e., repeated measures of the same dependent variable or multiple investigations that measure the same phenomenon in different ways) and, when appropriate, use multiple measures to estimate the validity and reliability of the data. Students use technology and science tools to extend the senses and to enable more sophisticated measurements to be made, and they use technology and mathematics to organize scientific data.

Objective SP.2.1
Data Collection

Students select and use appropriate measurement methods and techniques for gathering data, and systematically record and organize observations and measurements.

ESSENTIAL KNOWLEDGE

- The nature of the scientific question being asked or the prediction being made determines the data (categorical or numerical) that must be gathered, the methods of gathering the data, and the **accuracy** and **precision** that are required to answer the question or test the prediction.
- Some methods of gathering data require the manipulation of variables (independent and dependent) and the control or monitoring of variables. The selection of the variables to be observed or measured, and of appropriate methods of observation and measurement, is determined by the data intended to be used as evidence to address the scientific question or the prediction.
- Data should be recorded in an orderly and systematic way to facilitate later analysis of the selected data and the use of this data as evidence to support an explanation. In all instances, observations and measurements are recorded objectively, avoiding bias.
- Multiple measures (i.e., repeated measures of the same dependent variable, measures of potential intervening variables, or multiple investigations that measure the same phenomenon in different ways) of the same phenomenon should be used to ensure validity and reliability of data.

Objective SP.2.2
Evaluating Data for Evidence

Students determine which data from a specific investigation can be used as evidence to address a scientific question or to support a prediction or an explanation, and distinguish credible data from noncredible data in terms of quality.

ESSENTIAL KNOWLEDGE

- Data are recorded observations or measurements.
- Data that address or are relevant to a specific scientific question or a prediction, and that can be used in relation to a specific explanation, can be used as evidence.

ESSENTIAL KNOWLEDGE, *continued*

- Before data can be used as evidence, the data must be deemed credible. Criteria for determining credibility include, but are not limited to the following:
  - Data are reproducible, or collected in a manner that ensures validity or reliability (e.g., precision of instrument is considered; measurement procedure is carefully followed; sample size is large; bias is avoided; a control sample of data is included when appropriate; other conditions or variables are constant; completeness of data set is considered; source of data is considered).
  - Replication of an investigation confirms accuracy and precision of observations and measurements.
- Inconsistent data help determine which data are good to use as evidence relative to a particular scientific question or a particular prediction. Inconsistent data may be credible (i.e., collected using appropriate methods, instruments, etc.), while still not relevant to the question being asked or the prediction being made.
- Collected data that are not consistent with a scientific question, a prediction or an explanation are also considered valuable for the possible revision of collection methods or scientific questions, and for the evaluation of the precision of the explanation, the prediction, or the conditions of the phenomenon or situation. These data are not considered evidence because they do not address the scientific question or prediction of focus.
- Peer review is an important part of determining credibility of data in that peers need to evaluate the methods used to identify patterns or collect data and the statistics used to interpret data.

Standard SP.3
Data Analysis

Searching for regularities and patterns in observations and measurements (i.e., data analysis)

Students identify patterns or relationships through examination and analysis of data, guided by the scientific question or prediction under consideration. Analysis of data may involve a variety of tasks that overlap and are interdependent, such as the determination of the quality of data used as evidence, the identification of patterns and the statistical analysis of patterns. Students need to determine which data may be either **outliers** or products of inaccurate or inappropriate data collection, as well as the impact of an outlier on the measured variables, correlation or trend. Data analysis requires identification of any uncertainty of a reported value, of sources of error (sampling or measurement) in data collection, of **anomalies** or of the central tendencies or variability of data. The scientific question or prediction assists in the selection of appropriate units or range of data as well as the representation of variables in a graph or chart. Students should use technology and mathematics as often as possible as tools to analyze scientific data or to extend the senses. For detailed knowledge of the mathematical and statistical applications involved in data analysis, see Objectives SP.5.1 and SP.5.2.

Objective SP.3.1
Analyzing Data for Patterns

Students analyze data to discover patterns.

ESSENTIAL KNOWLEDGE

- Mathematical and statistical processes are applied, based on the scientific question and on the data generated, as part of the data analysis. These processes may include calculation of mean, median, mode, range and variance; qualitative representations or patterns involving exponential changes; analysis of linear functions; and treatment and/or expression of experimental error where appropriate.

- Appropriate representation (e.g., line graph instead of histogram, error bars on graphs for best estimate of slopes) is selected and created for organizing data. Appropriate symbols, notation and terminology are used in the representation. (Constructing representations [e.g., maps, tables, graphs] for the purpose of organizing data to find patterns is different from constructing a representation for the purpose of explaining — see Objective SP.4.2.)

- When appropriate, data are re-expressed in a different format to make patterns evident, to address a scientific question or a prediction, and to better understand the data. Re-expression may involve verbal summaries, discipline-specific drawings and diagrams, maps, summary charts and tables, frequency plots, bar graphs (histograms) or scatter plots. All forms of re-expressed data should account for the selected variables, the units of measure and the scale.

Standard SP.4
Evidence-Based Explanations and Models

Using evidence and science knowledge to construct scientific explanations, models and representations

Students use evidence to draw conclusions about the scientific questions asked and the predictions made. Based on patterns in evidence, students develop logical explanations of the phenomena that are under investigation. Students use their knowledge of the relevant science discipline to explain how or why an object or system has its observed properties, or how or why an observed natural or designed phenomenon occurs in different problems. Their explanations should consist of a claim, the evidence, and the reasoning that links the claim with the evidence. Students are expected to ensure that the explanation is based on accurate information and sound reasoning. In addition to being able to make explicit justifications for their own claims, students should also be able to recognize and refute claims that do not reflect the use of scientific evidence and reasoning. In communicating an explanation, students need to distinguish between their description and their overall explanation. Representations and models are tools that help communicate evidence, explanations, theories or predictions. Constructing a representation or model for the purpose of explaining is different from constructing a table, graph or diagram for the purpose of analyzing patterns in data.

Objective SP.4.1
Constructing Explanations

Students construct explanations that are based on observations and measurements of the world, on empirical evidence and on reasoning grounded in the theories, principles and concepts of the discipline.

ESSENTIAL KNOWLEDGE

- A scientific explanation includes (1) a claim about natural or designed objects, systems or phenomena; (2) the evidence, which can consist of empirical evidence or observations; and (3) the reasoning that links the claim with the evidence. A scientific explanation can specify causal relationships, generalizations (inductive and analogical), contrasting relationships or proposed models. An explanation also specifies, based on science knowledge, how or why a natural or designed system has its observed properties, or how an observed phenomenon occurs.
- A claim itself is not a complete explanation because it lacks evidence and reasoning. All claims should be justified by evidence or knowledge of principles or concepts of a discipline. Evidence used in the explanation consists of data (from investigations, scientific observations and measurements, the findings of other scientists, historic reconstruction, and/or archived data) that have been represented, analyzed and interpreted in the context of a specific scientific question or prediction.
- Both the evidence that supports the claim and the evidence that refutes the claim should be accounted for in the explanation. Alternative explanations should also be taken into consideration.
- Science knowledge used in the reasoning of an explanation can include data/information from previous investigations, as well as historical or current models and/or representations, concepts, principles or theories.
- The reasoning that supports an explanation should include a series of logical statements. These interconnected statements should allude to supporting evidence and counterevidence, include an interpretation of data as it relates to the claim, and consider multiple alternative explanations. The explanation might also include an examination of other explanations for which the data might be used and an identification of any anomalous data that was rejected.

Objective SP.4.2
Models and Representations

Students construct, use, re-express and revise models and representations of natural and designed objects, systems, phenomena and scientific ideas in the appropriate context and in formulating their explanation.

ESSENTIAL KNOWLEDGE

- A model or representation may be physical (e.g., diagrams, flow charts, maps, scale models), mathematical (e.g., equations, graphs) or conceptual (e.g., imagery, metaphor, analogy), and it can be specific to a discipline. There are symbols, notations and terminology that are appropriate for specific types of representations within a discipline.

ESSENTIAL KNOWLEDGE, *continued*

- Models or representations can be used to predict or explain natural phenomena and to raise scientific questions about how particular systems work.

- Both models and representations are limited in their ability to accurately depict all aspects of phenomena. There are key elements of the model or representation that are similar to the actual phenomenon, and there are aspects of the model or representation that make it inaccurate.

- When translating between representations (e.g., translating a chemical formula into a representation of electron configuration), there are key components of a representation that must be re-expressed in the new representation. The purpose of the re-expression, as well as the natural phenomenon itself, affects the determination of the key components and how they must be re-expressed for the new purpose.

- Depending on the purpose of constructing the model or representation (e.g., predicting the size of an atom versus predicting the reactivity of an atom), a model or representation is revised if it is too simple or too complicated. In other instances, based on the purpose and phenomenon, multiple models or representations are constructed for clarity.

Objective SP.4.3
Evaluating Explanations

Students evaluate, compare and contrast explanations that are based on observations of the world, on empirical evidence and on reasoning grounded in the theories, principles and concepts of the discipline.

ESSENTIAL KNOWLEDGE

- Evaluation of scientific explanations includes comparing and contrasting, based on whether the two explanations are a result of different evidence but the same claim, the same evidence but different claims, the same claim and the same evidence, or different claims and different evidence.

  *[**BOUNDARY:** At higher grade bands, the comparison between two explanations that are based on completely different claims and evidence can be included.]*

- Criteria for the evaluation of a scientific explanation include, but are not limited to, the following:

  - Explanation is robust and useful for making predictions about new events or about outcomes not yet observed. It is likely that an explanation could be supported or reproduced by others.

  - Integration of **fact** and opinion is avoided.

  - Making conclusions that do not follow logically from the evidence is avoided.

  - Explanation includes an explicit statement about the critical assumptions of the explanation.

  - The claim is appropriately aligned to the scientific question or the prediction it is intended to address.

  - The quality and quantity of the evidence used to support the explanation is appropriate.

  - Data used as evidence are reproduced or reconfirmed with new or contrasting data from other scientific investigations. Adequate and sufficient data are used as evidence to test an explanation. Appropriate numbers are used when reporting evidence.

  - All of the evidence is used, not just selected portions of the evidence.

  - The reasoning linking the claim to the evidence is strong. The reasoning is considered strong if it includes well-established, accurate scientific principles and if the steps of reasoning form a logical progression.

Standard SP.5
Quantitative Applications

Using mathematical reasoning and quantitative applications to interpret and analyze data to solve problems

Students understand that in science, the use of quantitative applications is a process that is integral to all disciplines and at all levels. The study of science relies heavily on observations of the natural world. Quantitative applications are tools and, at times, language that scientists use to understand and explain these observations in a measurable way, to interpret numerical data and to logically evaluate other scientists' observations. Quantitative applications do not require students to come to some numerical conclusion by making complex calculations and crunching numbers. Rather, the purpose of using these quantitative applications is to focus on reasoning among scientific questions, data, evidence and explanations; analyzing data; conceptualizing algorithms; interpreting graphical representations; and finding relationships. These quantitative applications, along with the previous science practices objectives and essential knowledge statements, will aid students in enhancing the tools they need to think more scientifically while learning to examine the world through a more analytical lens.

All of the science standards are based on the assumption that students are enrolled in mathematics courses that meet the goals described in the *Mathematics and Statistics College Board Standards for College Success*. It is not assumed that students can apply these quantitative application skills in science at the same time they are mastering the mathematics performance expectations; however, it is expected that students in grades 9–12 can apply what they learned in grades 6–8 and that students in grades 6–8 can apply what they learned in grades 1–5. As a result, many elementary math concepts (e.g., the four basic mathematical functions, fractions, decimals) are not addressed in the science practices standards.

Objective SP.5.1
Proportionality Between Variables

Students reason about relationships between variables (e.g., data, representations, uncertainty, samples) through the lens of ratios, rates, percentages, probability or proportional relationships when approaching or solving problems or when interpreting results or situations.

ESSENTIAL KNOWLEDGE

- Ratios, rates, percentages, measures of central tendencies (e.g., mean, median, mode), variability (e.g., variance, range, scatter, outliers) or correlation can be used to make comparisons, to interpret results, to solve — or estimate solutions to — problems, and to address scientific questions.

- Representations that are based on geometric figures (e.g., cubed or spherical cell) and characterized by using mathematical techniques (e.g., sketches, figures on grids, models) can help in characterizing the properties, interpreting changes or determining **interactions** of real systems involved in a problem or situation (e.g., cross section of a stream channel to determine discharge).

- Representations (e.g., actual, archived or simulated data) can help in estimating probabilities for events in which theoretical values are difficult or impossible to compute.

- The construction of mathematical formulas and the derivation of units often require dimensional analyses in two and three dimensions (e.g., length x width = area [units squared]).

Objective SP.5.2
Patterns of Bivariate Relationships

Students apply, analyze and create algebraic representations, relationships and patterns of linear functions, systems of linear inequalities, and one- or two-dimensional changes to solve problems, interpret situations and address scientific questions.

ESSENTIAL KNOWLEDGE

- One- and two-step linear equations are interpreted by using data tables, coordinate graphs and symbolic manipulation.
- Formulas are developed using arithmetic as well as geometric sequences of data.
- The concept of vectors in two dimensions is applied to represent, analyze and solve problems.
  *[**BOUNDARY:** Students will only be expected to resolve vectors into their components and apply vector addition and subtraction both graphically and mathematically.]*
- Linear relationships among variables can be represented by graphs and functions.
- Linear patterns in data can be expressed as simple linear equations.

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Standards

1. A critical interdependence exists among science, technology and society.

Science, Technology and Society

It is difficult to define technology due to its pervasiveness in our society and its interdependence with science. The Science Standards Advisory Committee not only values students' use of technology as a tool to practice science, but also believes it is essential for students to begin developing an understanding of the complex relationship among science, technology and society. Consequently, these values and beliefs have been incorporated throughout the standards document. This relationship is completely interwoven into the discipline-specific standards which focus on societal issues that have arisen as a result of science and technology (e.g., environmental impact, ethical use of science) and on society's demands that lead to development in science and technology (e.g., disease, environmental issues). Building students' appreciation for the integration of science, technology and society is based on the **problems*** and situations that they examine or experience both inside and outside of the classroom. The performance expectations in the discipline-specific standards incorporate these real-world problems and situations, presenting students with opportunities to develop an understanding of the interdependence that exists.

Standard STS.1
Science, Technology and Society

A critical interdependence exists among science, technology and society.

Students recognize the importance of how the advancement of technology relies heavily on scientific knowledge and on the advancements of this knowledge, how technological progress informs scientific research, and how society is also integrated into this reciprocal relationship.

Objective STS.1.1
Interdependence of Science and Technology

Students explain the interdependence of science and technology: how the ongoing development of technology relies on the advancements of science while scientific research relies on technological progress. Students understand how the evolution of various technologies (e.g., biotechnology, seismology, computational software, lasers) radically alters the practice of many science disciplines by affecting the quality and quantity of available **data**.

Objective STS.1.2
Advantages and Disadvantages to Society

Students understand how science and technology together can be used for the benefit of society as well as their own lives (e.g., weather **predictions**, development of medications, creation of safety devices in cars), but that some technological capabilities (e.g., cloning, genetic recombination, nuclear energy studies, access to fossil fuels, chemical engineering) create ethical and economic dilemmas for society.

* Boldfaced words and phrases are defined in the glossary.

Objective STS.1.3
Evaluating Online Information

Students recognize that the amount of information, as well as access to information, has exploded since the creation of the Internet. Online information should be judged using the same science practices and critical and skeptical views that reflect the way science is conducted and evaluated. Students also recognize the relationship between digital technology and the **fact** that social networking is a source of information generation and of the determination of "truths" in our current society. Students understand that this information presents a specific perspective that is not backed by research; therefore, the information and the perspective do not represent the empirical reality of science.

Standards

1. Dynamic processes shape and order Earth.
2. Earth is composed of interdependent and interacting systems.
3. Earth's history can be inferred from evidence left from past events.
4. Matter on Earth is finite and moves through various cycles that are driven by the transformation of energy.
5. Humans and the environment impact each other.

Earth Science

Earth science has been part of the science curriculum in American schools for more than 100 years. Yet the tendency has been to regard study only in life science, chemistry and physics as constituting a complete science education. Fortunately, in the 21st century this attitude is changing, as nearly all everyday human activities are connected to or affected by complex relationships with planet Earth. People's lives and civilization depend on how they understand and manage issues relating to water, energy, **mineral*** resources, global climate change and natural hazards. These science-based issues are deeply rooted and interconnected in the earth science discipline. Knowledge of fundamental understandings in earth science is, therefore, necessary for the health and well-being of the citizenry and for making informed judgments on some of today's most important issues.

The *National Science Education Standards* (National Research Council, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) define science literacy and reaffirm the centrality of earth science in the K–12 science curriculum. Both of these national efforts also recognize that topics comprising the discipline of earth science have essential value in providing additional context and meaning for the teaching of all other areas of science. The initiatives also recommend earth science parity with biology, chemistry and physics as part of the country's national strategy for achieving science literacy. A series of subsequent national reports (*Atlas of Science Literacy*, Volumes 1 and 2, Project 2061; *Blueprint for Change: Report of the National Conference on the Revolution in Earth and Space Science Education*, 2001; *Earth Science Literacy Initiative*, prepublication edition supported by National Science Foundation [NSF], 2008) reaffirms the central placement of earth science in the science curriculum. New state science frameworks across the country also recognize the importance of earth science from kindergarten through grade 12.

Organization and Structure of the Earth Science Standards for College Success

The earth science standards are intended to outline the knowledge, skills and abilities that students need in order to be prepared for success in an introductory college-level earth science or environmental science course, or in an Advanced Placement (AP) Environmental Science course. Core ideas, or "big ideas" — identified by the NSF-funded AP committee members as being central to an introductory college-level earth science or environmental science course — were the foundation of the creation of the earth science standards.

The earth science standards are organized around core ideas of the discipline. While there are five standards, they are not meant to represent an equal division of material and **concepts**. These standards aim to promote a broader perspective of usefulness and application of student learning. Earth science courses are uniquely suited for making science relevant to students. Students' immediate environment presents an ideal and readily available laboratory for obtaining information about Earth's systems. There is also an impressive number of real-time and archived geoscience **data** sets — information that scientists work with daily — that are now available to the public. The earth science standards are intended to decrease the emphasis on fact-focused, lecture-style courses while increasing the emphasis on the active engagement of students in questioning, data gathering and interpretation through a wide range of timely and socially relevant issues and life experiences.

* Boldfaced words and phrases are defined in the glossary.

Each standard has two to five objectives that provide detailed descriptions of more specific earth science core **principles** of which students should have knowledge. Similar to the enduring understandings that are the target concepts for the AP courses, the objectives are the focus of student mastery for college readiness and the key elements of the conceptual framework of the earth science standards. An objective is often followed by a list of other objectives — within the discipline as well as from other disciplines — that are connected in some way to that objective. Both the standards and the objectives are preceded by key words and/or phrases that help articulate the content in a more concise manner. This is especially useful when a standard or an objective is referenced either by another discipline or during curriculum or instructional planning.

The objectives are, in turn, supported by a set of performance expectations (PEs) and a set of essential knowledge (EK) statements. The PEs describe what students should know, understand and be able to do in order to apply, as well as build and reason with, the essential knowledge that is necessary to understand the content outlined in the objective. The PEs illustrate how students engage in science practices to develop a better understanding of the objective. Students should be able to successfully engage in, *at the very least*, the performance expectations listed for each objective in order to be considered college ready. These performance expectations, along with the essential knowledge statements, can provide guidance in the development of assessments and curriculum materials. The EK statements are an articulation of the conceptual targets for student learning, providing a more detailed description of the broader knowledge delineated in the objective. These statements should be approached from a holistic perspective, and they should not be viewed as a list of discrete, unrelated **facts** for students to memorize. The EK statements also provide the language and appropriate terminology that should be incorporated into students' completion of the performance expectations.

It should be noted that both the performance expectations and the essential knowledge statements were written based specifically on the objective-level statements. There is not a corresponding relationship between the PEs and the EK statements; the PEs are a representative (but certainly not all inclusive) set of applications of the essential knowledge. Therefore, when interpreting the depth and scope of each PE, the EK statements should be considered.

The number of objectives, as well as the number of performance expectations and essential knowledge statements, varies considerably from standard to standard. It should also be made clear that these objectives, PEs and EK statements are not intended to show a linear progression through the subject. Many of the topics and concepts in earth science rely on more than one objective and on several PEs and EK statements, some of which may come from different standards. In addition, the number of PEs for a given objective does not indicate any level of importance, and it is assumed that some PEs may require a greater amount of instructional time than others.

Foundational Knowledge

Even though these standards are focused on grades 6–12, the College Board recognizes the importance of students' having certain foundational knowledge in earth science upon entering sixth grade. Middle school teachers need to determine whether their students already have this foundational knowledge before they attempt to address the ideas described in the standards document, and they should adjust their instruction in terms of what students already know and what students do not know. Some of the foundational knowledge that students are expected to have by the end of fifth grade is listed below. These statements, organized into four groups, are found in various elementary school benchmarks in *Benchmarks for Science Literacy* (BSL), developed by the American Association for the Advancement of Science (AAAS).

- Earth is a planet that orbits the Sun. Similar to all planets and stars, Earth is approximately spherical in shape. Earth rotates on its axis every 24 hours and revolves around the Sun approximately once every 365 days. These motions (rotation and revolution) explain the night-and-day cycle and the seasonal cycles.

- Processes of erosion and deposition are constantly at work on Earth's surface. Waves, wind, water, and ice shape and reshape the surface of the planet. Some changes, such as earthquakes and volcanic eruptions, are abrupt, while other changes, such as uplift and the wearing down of mountains, happen very slowly.

- Objects can be described in terms of the materials they are made of (e.g., clay, cloth, paper) and their physical properties (e.g., color, size, shape, weight, texture). Some materials may be composed of parts that are too small to be seen without magnification.

- The cycling of water in and out of the atmosphere plays an important role in determining climatic patterns. Water evaporates from Earth's surface, rises and cools, condenses into rain or snow, and falls again to the surface. The water that falls on land collects in rivers and lakes, soil and porous layers of rock, and much of it flows back into the ocean.

Standard ES.1
Dynamic Earth Processes

Dynamic processes shape and order Earth.

Students understand that planet Earth works as a complex, dynamic system of interacting components involving the solid earth, the atmosphere, the hydrosphere and the biosphere. As with any complex system, it is helpful to break down the system into its component parts to see how they work and interact with each other. Because of the dynamic and interactive nature of Earth's processes, Earth's surface is constantly changing. The mechanisms involved in weathering, erosion and plate tectonics combine processes that are in some respects destructive and in other respects constructive. Mountains are built, and rivers cut canyons through these mountains. Wind and water carry rock away and deposit it in new locations. Volcanoes erupt, burying former surfaces under new layers of rock, and flat-lying layers become faulted and folded. Rocks that show **evidence** of past geologic events can be found everywhere.

The images of rivers spilling over their banks and washing away entire towns, of buildings decimated to rubble by the violent shaking of Earth's tectonic plates, and of molten lava flowing up from inside Earth's core are constant and vivid reminders of the power of Earth and of the multiple ways in which these dynamic processes interact. Whether it is from a great natural hazard such as a devastating tsunami, a short-term weather event like a severe drought, or longer-term events such as those associated with plate tectonics, the message is clear — Earth's processes are important because they affect everyone.

EARTH SCIENCE

Objective ES.1.1
Earth's Surface

Students understand that physical and chemical changes in Earth's materials result from the **interactions** of Earth's surface with water, air, gravity, tectonic forces and biological activity. These changes create landscapes on Earth's surface.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.1.1.1 Observe and explain, using observable features in the environment, the dominant physical weathering and erosional processes that take place in a given location.

- **ESM-PE.1.1.1a** Describe and contrast the processes of weathering, erosion and deposition in different environments.
- **ESM-PE.1.1.1b** Give examples of features produced by physical and chemical weathering (e.g., rounded rocks, crumbling on rock, potholes, lichens) and features produced by erosion, deposition and weathering processes (e.g., gullies, talus at the base of cliffs, slumps and landslides, point bars, delta deposits).
- **ESM-PE.1.1.1c** Identify areas of erosion and deposition in a meandering alluvial stream.
- **ESM-PE.1.1.1d** Compare and contrast physical and chemical weathering, and identify geographical areas where each would be more pronounced.

ESSENTIAL KNOWLEDGE (6–8) [Note: See additional essential knowledge statements for this grade band on page 24.]

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Rock that is on or near Earth's surface and that is exposed to water, air, gravity and biological activity is constantly changing as a result of the processes of weathering, erosion and deposition. These changes occur at various rates depending on the properties of Earth's materials, as well as the atmospheric and surface conditions. These weathering, erosional and depositional processes create distinct landforms, including glacial valleys; erosional surfaces; incised terrain; stream valleys; and fluvial, coastal and aeolian features.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.1.1.1 Describe how various factors affect the weathering of rock, and explain the observations that provide evidence.

- **ESH-PE.1.1.1a** Give examples and representative reactions of chemical weathering processes such as hydrolysis, oxidation and carbonation.
- **ESH-PE.1.1.1b** Identify the factors (e.g., temperature, amount of water and dissolved ions, surface area, properties of material being weathered) that affect the rate of weathering and their relationships to weathering.
- **ESH-PE.1.1.1c** Compare the weathering rates of common materials (e.g., mica, feldspar, hornblende, quartz).
- **ESH-PE.1.1.1d** Determine, based on selections from relevant and irrelevant features, the dominant weathering process, or processes, on a given rock.
- **ESH-PE.1.1.1e** Interpret how a change in one variable of stream flow might affect the others, as represented by the expression $Q = V \times A$, where Q is discharge, V is velocity and A is the stream channel's cross-sectional area.
- **ESH-PE.1.1.1f** Determine the major physical components of soil (e.g., amounts of sand, silt, clay and humus) in different locations by separating samples based on settling rates of different **particles'** sizes in water.

ESH-PE.1.1.2 Construct **representations** that illustrate landscape features produced by erosional and depositional processes.

- **ESH-PE.1.1.2a** Construct and interpret a visual representation of a meandering alluvial stream, showing areas of erosion and deposition. Explain how this **model** is limited and simplified.
- **ESH-PE.1.1.2b** Interpret and compare a visual representation of a glacial valley and a visual representation of a stream valley.

ESH-PE.1.1.3 Interpret pictures and images of landscape features produced by erosional and depositional processes.

ESSENTIAL KNOWLEDGE (6–12)

Students apply, as well as reason with, the following concepts in the performance expectations:

- Weathering is the breakdown of rock as a result of physical or chemical changes. In physical weathering, Earth's materials are broken into smaller components through mechanical action. In chemical weathering, Earth's materials are changed into new substances through chemical alteration. Soil is an ultimate end product of weathering.
- Erosion is the transport of sediment caused by the movement of water, wind and ice under the influence of gravity.
- Deposition, the process of transported sediment coming to rest, is affected by particle size, particle shape, particle density and the velocity of the transporting agent.

Objective ES.1.2
Energy Transfer

Students understand that the uneven distribution of thermal energy and materials in Earth's systems, combined with gravity, is the underlying cause of the movement of matter within the lithosphere (plate tectonics), hydrosphere (ocean currents) and atmosphere (winds).

Suggested Connections
Between Earth Science and Other Disciplines: Thermal Energy (PS.4.5); Energy Transfers and Transformations (C.3.2); Gravitational Interactions and Forces (P.1.4)

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.1.2.1 Describe and contrast the processes of convection, conduction and radiation, and give examples of natural phenomena that demonstrate these processes.

ESM-PE.1.2.1a Identify internal and external sources of energy (i.e., solar radiation and geothermal energy) on Earth that drive the movement of air, water and Earth's materials.

ESM-PE.1.2.1b Give examples of natural phenomena that demonstrate radiation, conduction and convection.

ESM-PE.1.2.1c Use representations and models (e.g., a burning candle or a pot of boiling water) to demonstrate how convection currents drive the motion of fluids. Identify areas of uneven heating, relative temperature and density of fluids, and direction of fluid movement.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Thermal energy in Earth's systems is **transferred** through three processes: radiation, conduction and convection. The movement of materials in Earth's systems occurs at different rates, depending on the material and the changes in thermal energy.
- Winds in the lower atmosphere result from pressure differences caused by uneven heating of Earth's surface and of the air above it.
- Ocean currents are driven by differences in temperature, density and atmospheric circulation. This circulation serves to regulate the temperature of Earth.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.1.2.1 Describe and contrast the processes of convection, conduction and radiation, and give examples of natural phenomena that demonstrate these processes.

ESH-PE.1.2.1a Identify internal and external sources of energy (i.e., solar energy, gravity and geothermal radiation) on Earth that drive the movement of air, water and rock.

ESH-PE.1.2.1b Identify examples of natural phenomena that demonstrate radiation, conduction and convection.

ESH-PE.1.2.1c Construct representations and models to demonstrate how convection currents drive the motion of fluids. Identify areas of uneven heating, relative temperature and density of fluids, and direction of fluid movement.

ESH-PE.1.2.2 Explain local wind patterns (e.g., land/sea breezes, mountain/valley breezes) in terms of convection, identifying pressure differences, direction of wind, and areas of uneven heating.

ESH-PE.1.2.3 Construct representations of Earth's systems where convection occurs, identifying areas of uneven heating and the movement of matter.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Convection is caused by uneven heating of Earth's materials that in turn cause differences in density. Gravitational fields and buoyant forces cause more dense materials to sink and less dense materials to rise in relation to Earth's surface.
- Winds in the lower atmosphere result from pressure differences caused by uneven heating of Earth's surface and the air above it.
- Ocean currents are driven by differences in temperature, density and atmospheric circulation. This circulation serves to regulate the temperature of Earth.
- Movement of material in Earth's interior and in the lithosphere is caused by uneven distribution of thermal energy from Earth's core and mantle to Earth's crust.

Objective ES.1.3
Tectonism

Students understand that tectonic plates interact along their boundaries, resulting in folding, faulting, earthquakes and volcanoes.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Interactions and Forces (PS.1.3); Contact Interactions and Energy (P.3.1)

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.1.3.1 Explain and justify the topographic features typically found at each type of tectonic boundary (convergent, divergent, transform).

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Tectonic processes create distinct landforms, such as uplifted, folded, and thrusted mountains and downthrown rift valleys. Most volcanic eruptions and earthquakes occur in distinctive zones that are concentrated along plate boundaries.
- Types of plate boundaries include divergent, convergent and transform (transcurrent). Some plate boundaries result in the formation of new crust, while other boundaries subduct crust and return it to the interior of Earth.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.1.3.1 Analyze earthquake data to find patterns in earthquake behavior and location.

ESH-PE.1.3.1a Locate, using latitude and longitude, earthquake data on a map.

ESH-PE.1.3.1b Analyze annual data on a graph showing earthquake frequency versus magnitude, and describe the correlation between these factors.

ESH-PE.1.3.1c Explain, based on evidence from seismic waves, the internal structure of Earth.

ESH-PE.1.3.2 Explain the process of seafloor spreading. Include cross sections of a midocean ridge showing the age of the sea floor, data on the thickness of sediments, and paleomagnetic information.

PERFORMANCE EXPECTATIONS (9–12), *continued*

ESH-PE.1.3.3 Calculate, using the age of oceanic crust and the distance of a sample from the midocean ridge, average rates of seafloor spreading over geologic time.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Volcanoes are formed as a result of magma rising to Earth's surface; they are the surface expressions of processes that caused magma to rise.
- As plates interact, the buildup of stress over time leads to earthquakes, as well as a number of tectonic processes such as folding, faulting and uplift, all of which release this stress and generate seismic waves. The study of earthquakes involves gathering data on the seismic waves; this data can be used to characterize the interior of Earth and to determine the location, magnitude and depth of earthquakes.

Objective ES.1.4
Weather Processes

Students understand that weather is the result of short-term interactions (days) among the atmosphere, hydrosphere, lithosphere and biosphere.

Suggested Connections
Between Earth Science and Other Disciplines: States of Matter (C.1.5)

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.1.4.1 Predict and justify why weather conditions will change as different types of weather systems pass through a given location.

ESM-PE.1.4.2 Explain, in terms of rate of evaporation and condensation, how clouds form. Compare and contrast basic types of clouds (cirrus, stratus, cumulus) and their characteristics.

ESSENTIAL KNOWLEDGE (6–8) [Note: See additional essential knowledge statements for this grade band on page 28.]

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Interactions between the atmosphere and the hydrosphere create weather conditions that redistribute thermal energy in the lower atmosphere. Convection, advection and changes in the state of water work together to store and transfer thermal energy in the atmosphere.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.1.4.1 Analyze weather-related data.

ESH-PE.1.4.1a Collect, using available instruments, weather-related data, and organize this data for analysis.

ESH-PE.1.4.1b Identify, using archived weather data, patterns in movement of weather systems across North America by looking at a series of daily weather maps.

ESH-PE.1.4.1c Calculate, using a wet bulb/dry bulb thermometer and a phychrometric or Mollier chart, the dew point temperature and the percentage of relative humidity.

PERFORMANCE EXPECTATIONS (9–12), *continued*

ESH-PE.1.4.2 Describe, in terms of temperature, pressure and moisture conditions, the formation of severe weather conditions such as tornadoes, hurricanes and thunderstorms.

ESH-PE.1.4.2a Construct an illustration of a mature thunderstorm that shows how air movement inside the storm leads to the formation of hail and tornadoes.

ESH-PE.1.4.2b Describe how, within storm systems, thermal energy is converted into both mechanical energy (wind) and electrical energy, and link these phenomena to the law of conservation of energy.

ESSENTIAL KNOWLEDGE (6–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Weather is described and predicted using atmospheric measurements such as temperature, pressure, humidity, wind direction and wind speed, and by tracking the movement and interaction of large air masses. The characteristics of air masses depend on where they originate and the influence of the terrain over which they travel.
- Fronts are boundaries between air masses. High-pressure systems are associated with cold, dry air masses and fair weather. Low-pressure systems are often associated with warm, moist air masses and storms. Air moves from higher pressure to lower pressure and is influenced by the rotation of Earth (Coriolis effect).
- Clouds form when air is at a temperature at which the rate of condensation is greater than the rate of evaporation, forcing water vapor in the atmosphere to condense onto nuclei (dust, salt) to form visible liquid cloud droplets. Precipitation, in all of its various forms, results when cloud droplets become too heavy to be suspended in air.
- The movement and interaction of air and water in the atmosphere and hydrosphere result in various weather conditions, sometimes leading to severe weather such as hurricanes, tornadoes and thunderstorms. Thermal energy transfer (heat) is required to change a substance's state (solid, liquid or gas). Warm air can hold more moisture than cold air.

Objective ES.1.5
Rock-Forming Environment

Students understand that the physical and chemical properties of rocks and fossil fuels indicate the environment in which they were formed.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Grades 9–12 only: Evidence of Common Ancestry and Divergence (LS.1.1)

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.1.5.1 Construct a graphical representation of the rock cycle, identifying the processes, types of rock and locations involved.

ESM-PE.1.5.2 Use models to represent the processes that form igneous, sedimentary and metamorphic rocks.

ESM-PE.1.5.3 Perform simple tests to identify common minerals.

ESM-PE.1.5.4 Classify rocks. Classifications are based on observed physical properties of a range of samples of igneous, sedimentary and metamorphic rocks, and on a given simple key.

ESM-PE.1.5.5 Classify minerals. Classifications are based on observed physical properties of a range of samples of common minerals and on a given simple key.

PERFORMANCE EXPECTATIONS (6–8), *continued*

ESM-PE.1.5.6 Identify that coal, oil and natural gas are different from other materials because they are organic and provide fuel.

ESM-PE.1.5.7 Describe the process of coal formation in organic sedimentary rocks.

ESSENTIAL KNOWLEDGE (6–8) [Note: See additional essential knowledge statements for this grade band below.]

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Rocks are composed of one or more minerals. Minerals are naturally occurring, inorganic solids that possess a definite chemical composition.

- There are three principal rock formation processes: igneous, sedimentary and metamorphic. Sedimentary rocks are formed through precipitation and deposition of sediments near or on Earth's surface. Igneous rocks are formed when magma cools below Earth's surface or when lava cools on Earth's surface. Metamorphic rocks are formed when Earth's materials are altered by pressure and temperature over time.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.1.5.1 Explain how the physical and chemical properties of a rock indicate the environment in which it was formed.

ESH-PE.1.5.2 Identify and analyze tectonic environments (e.g., midocean ridges and subduction zones) where igneous rocks are formed.

ESH-PE.1.5.3 Identify and classify, based on observations of physical and chemical characteristics, rocks and minerals. Using knowledge of rock formation environments, make a **claim** about the environments under which different rock samples form.

ESH-PE.1.5.4 Describe the materials and conditions needed for fossil fuel formation.

ESH-PE.1.5.5 Explain, using knowledge of fossil fuel formation and geologic time scales, why fossil fuels are considered a finite resource on Earth.

ESH-PE.1.5.6 Infer, based on knowledge of rock formation processes, the type of rock likely to be found in a given geologic setting.

ESSENTIAL KNOWLEDGE (6–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Each type of rock has physical and chemical characteristics that reflect a wide variety of formation environments and that are the basis for its classification. The formation environments vary in four principal ways: temperature, pressure, time and mineral composition.

- Over time, each rock type can become another rock type through Earth processes. Rock formation can involve more than one of these processes. The rock cycle provides a useful representation of the fundamental processes and environments involved in rock formation.

- The process of organic sedimentation on land and under water has created large reservoirs of valuable fuel in Earth's crust. These fuels are formed over millions of years under certain geological conditions necessary to accumulate large deposits of fossil fuels (e.g., oil/gas traps). During burial, organic material in sediment undergoes changes in its structure and chemistry due to pressure, temperature and time.

Standard ES.2
Independent and Interacting Systems

Earth is composed of interdependent and interacting systems.

Students understand that the areas of study that comprise earth and space sciences promote understanding of Earth as a number of interconnected and dynamic systems. Earth represents a synergistic physical system of interrelated phenomena that is governed by complex processes involving the geosphere, atmosphere, hydrosphere, biosphere and cryosphere. Earth's systems center on relevant interactions of chemical, physical, biological and dynamic processes that extend over a huge range of spatial scales from micron to planetary size, and over time scales from milliseconds to billions of years. Earth's systems provide a framework from which to pose disciplinary and interdisciplinary questions in relation to the important needs of humankind.

Objective ES.2.1
Atmosphere as a System

Students understand that Earth's atmosphere acts as a system that absorbs and distributes matter and energy.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Living Systems and the Physical Environment (LS.3.1); Matter Cycling (LS.4.1); Conservation of Energy (PS.4.4); Energy Transfers and Transformations (C.3.2); Heating and Cooling Interactions and Energy (P.3.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Environmental Science 1A, 1C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.2.1.1 Construct representations, using a data set displaying temperature changes resulting from changing altitude, of physical characteristics of the troposphere (adiabatic lapse rate). Construct representations that demonstrate the relative scale of the atmosphere in relation to the size of Earth.

ESM-PE.2.1.2 Make a claim, using representations and models of <u>in</u>coming <u>sol</u>ar radi<u>ation</u> (**insolation**) and the greenhouse effect, how changes in the atmosphere (i.e., atmospheric composition, cloud coverage) and in Earth's surface (i.e., glacial coverage) will affect the energy budget.

- **ESM-PE.2.1.2a** Identify major greenhouse gases (e.g., water vapor, carbon, methane, ozone) and their natural and anthropogenic sources. Interpret the long-term annual flux of the Keelings Curve.
- **ESM-PE.2.1.2b** Construct a graphic representation that shows the proportion of incoming solar radiation that is absorbed, reflected and scattered as it interacts with the atmosphere and surface of Earth.
- **ESM-PE.2.1.2c** Explain, based on the mechanisms involved in the "greenhouse effect," how the atmosphere is warmed.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The atmosphere, in comparison to the size of Earth, is a relatively thin layer of air that surrounds the planet and is divided into layers that are defined by temperature profiles.
- The atmosphere is made up mostly of gaseous nitrogen and oxygen, along with trace amounts of gases (including water vapor and carbon dioxide [CO_2]), suspended liquids and solids. The composition of the atmosphere is affected by geologic processes and, increasingly, by life on Earth.
- Some incoming solar radiation is reflected back into space, some is absorbed by the atmosphere, some is scattered within the atmosphere, and some is transmitted through the atmosphere to the land and water on Earth's surface. Consequently, the atmosphere moderates surface temperatures and reduces the amount of ultraviolet radiation.

ESSENTIAL KNOWLEDGE (6–8), ***continued***

- Greenhouse gases, such as water vapor, carbon dioxide and methane, allow short-wave insolation to pass through the atmosphere, but trap most infrared (long-wave) radiation from the warmed surface of Earth.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.2.1.1 Locate, by latitude, different zones of global atmospheric circulation patterns, and describe how these patterns interact with ocean systems on Earth.

ESH-PE.2.1.1a Contrast the Coriolis effect on global circulation patterns in the northern and southern hemispheres.

ESH-PE.2.1.1b Describe how surface ocean currents can be driven by global circulation patterns.

ESH-PE.2.1.1c Describe how climate is affected by global circulation patterns.

ESH-PE.2.1.2 Calculate and make **predictions**, using the adiabatic lapse rate, to determine and quantify changes in air temperature due to changing altitude in the lower troposphere.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The atmosphere is an interconnected circulation system that has global patterns of winds due to Earth's rotation, land topography and unequal distribution of thermal energy on Earth's surface. Thermal energy is transferred from warm regions of the atmosphere to cooler regions of the atmosphere.

EARTH SCIENCE

Objective ES.2.2
Oceans as a System

Students understand that Earth's oceans act as a system that absorbs and distributes matter and energy.

Suggested Connections
Between Earth Science and Other Disciplines: Living Systems and the Physical Environment (LS.3.1); Matter Cycling (LS.4.1); Conservation of Energy (PS.4.4); Energy Transfers and Transformations (C.3.2); Heating and Cooling Interactions and Energy (P.3.5)

Prepares students for the following AP Enduring Understandings: AP Environmental Science 1A, 1B, 1C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.2.2.1 Predict, using models and representations, how changes in Earth's systems can affect ocean circulation. Identify factors — such as prevailing winds, uneven heating, the density of ocean water, the Coriolis effect, and the shapes of ocean basins and adjacent land masses — that influence ocean currents.

Objective ES.2.2: Oceans as a System

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.2.2.1 Describe the chemical processes of limestone formation in seafloor sediments (such as limewater/carbon dioxide reactions).

- **ESH-PE.2.2.1a** Identify the variables, such as water temperature, CO_2 content and salinity, that control the rate of sediment deposition.
- **ESH-PE.2.2.1b** Predict how seafloor sediment deposition changes as melting ice sheets cause changes in the chemistry and temperature of seawater.

ESH-PE.2.2.2 Explain how Earth's oceans act as a system that absorbs and distributes matter and energy.

- **ESH-PE.2.2.2a** Explain why Earth's surface heats unevenly at different locations due to variables such as albedo, latitude and surface cover.
- **ESH-PE.2.2.2b** Interpret visual representations of global patterns of ocean currents.
- **ESH-PE.2.2.2c** Evaluate which factors affect global patterns of ocean currents.

ESH-PE.2.2.3 Describe, in terms of convection, how the temperature and density of ocean water influence oceans' circulation.

ESSENTIAL KNOWLEDGE (6–12) [Note: All essential knowledge statements listed below are appropriate for both the 6–8 grade band and the 9–12 grade band.]

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The ocean is an interconnected system that has global patterns of currents that are affected by prevailing winds, temperature, density of ocean water, and the shapes of ocean basins and adjacent land masses.
- Oceans act as major reservoirs of Earth's water, thermal energy and other materials such as carbon dioxide. Water, because of its high specific heat, can store large amounts of thermal energy. As a result, oceans are major influences on Earth's climate and water cycle.
- The products of weathering and erosion on land, the biogeochemical processes that take place in the oceans, and the exchange of chemicals between the atmosphere and the oceans contribute to the composition of ocean water.

Objective ES.2.3
Lithosphere as a System

Students understand that the lithosphere is a system of large plates that move matter and energy in Earth's systems.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Living Systems and the Physical Environment (LS.3.1); Matter Cycling (LS.4.1); Conservation of Energy (PS.4.4); Energy Transfers and Transformations (C.3.2); Heating and Cooling Interactions and Energy (P.3.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Environmental Science 1A, 1C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.2.3.1 Construct models and representations that illustrate the scale and structure of Earth's interior and crust.

ESM-PE.2.3.2 Analyze earthquake and volcano location data on a map or a globe to find global patterns and to relate these patterns to tectonic plate boundaries, interactions and hot spots.

ESM-PE.2.3.3 Explain, using a representation of Earth that shows a cross section of a midocean ridge and a subduction zone, how convection in Earth's mantle drives tectonic plate motion.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The lithosphere is a relatively thin, rigid crustal rock layer at the surface of Earth. It is fractured into a number of tectonic plates that move at various rates. The lithosphere rides on an underlying layer of ductile, more easily deformed rock in the upper mantle (i.e., the asthenosphere).

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.2.3.1 Predict, using a map that shows the direction and relative speed of the major tectonic plates, the locations of future land masses and changes in ocean basins. Calculate where future events are likely to occur.

ESH-PE.2.3.2 Explain the plate tectonic **theory**. Explanation is based on important evidence of ocean topography, paleomagnetism, correlation of rock assemblages, the fossil record and the characteristics of the upper mantle.

ESH-PE.2.3.2a Identify evidence of continental movement, such as fossil links across ocean basins, mountain belts and shapes of continents.

ESH-PE.2.3.2b Predict, given a data set indicating the rate and direction of plate movement, the future positions of continents and ocean basins (e.g., at 10 millions of years, 50 millions of years, 100 millions of years).

ESH-PE.2.3.2c Describe how atmospheric gases are trapped inside ice and can be used to determine changes in the composition of the atmosphere.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The lithosphere is an interconnected system with a surface that illustrates the relationships among weathering, erosion and the tectonic processes.
- The crust is the upper part of the lithosphere that is differentiated by composition into oceanic crust and continental crust. This differentiation is the result of tectonic processes.
- Plate tectonics is a unifying geologic theory that explains a wide range of geologic phenomena, such as the global patterns of continental and ocean basin topography, and the distribution of rock assemblages, earthquakes and volcanoes. The plate tectonic theory is derived from a combination of two theories: continental drift and seafloor spreading.
- Plate motions and the formation of new lithosphere over geologic time have affected the location and size of continents, which in turn affects Earth's climate, ocean currents and the evolution of organisms.

Objective ES.2.4
Climate

Students understand that climate is the result of interactions among the atmosphere, hydrosphere, lithosphere and biosphere.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Natural Selection (LS.1.2); Living Systems and the Physical Environment (LS.3.1); Ecosystem Stability (LS.3.3); Contact Interactions and Energy (P.3.1); Heating and Cooling Interactions and Energy (P.3.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Environmental Science 2A

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.2.4.1 Compare and contrast the climates in different locations, in terms of conditions such as winter and summer temperatures and wet and dry seasons, as well as in terms of unique phenomena such as monsoon conditions.

ESM-PE.2.4.2 Give examples, in terms of settlement and agricultural development, of how climate change has influenced human civilization throughout history.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Climate is the prevailing weather conditions over a long period of time and over a large area (a region, a continent or larger).
- Changes in Earth's climate have influenced human history in profound ways by playing an integral role in whether societies thrive or fail. However, the current consensus of scientific opinion is that human activities now have a profound influence on Earth's climate.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.2.4.1 Explain climatic conditions in different locations, in terms of latitude, elevation, local topography and distance from large bodies of water. Give examples of locations where climate is further influenced by rain shadow, ocean current and lake effects.

ESH-PE.2.4.2 Determine which data should be considered evidence of climate change in both the geologic and historic past.

ESH-PE.2.4.2a Analyze tree-ring data to find changes in annual rainfall in a particular location.

ESH-PE.2.4.2b Infer, based on ice core and the glacial record, climatic conditions that have existed in the past.

ESH-PE.2.4.2c Infer, based on the fossil and rock records, climatic conditions that have existed in the past.

ESH-PE.2.4.3 Give examples of how human activity (e.g., heat islands, deforestation, burning of fossil fuels) has induced climate changes. Include descriptions of cause-and-effect interactions.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Climate zones on Earth are primarily dictated by global wind circulation, ocean currents and temperature, the amount of insolation, latitude, and the local topographic features of a location.
- Earth's climate has changed in the past, is currently changing, and is expected to change in the future. Many types of physical, chemical and biological data provide evidence of past changes in Earth's climate — e.g., ice cores, glacial deposits, tree rings and the rock record (including lithology and fossil assemblages).
- At times, climate changes have been slow, spanning centuries and millennia; these changes have been influenced by changes in Earth's orbital motions or by the movement of crustal plates (e.g., Milankovitch cycles). At other times, climate changes have been abrupt; these changes have been caused by sudden events such as volcanic eruptions, collisions with **bolides**, or shifts in ocean currents.
- Changes in Earth's climate have influenced human history in profound ways by playing an integral role in whether societies thrive or fail. However, the current consensus of scientific opinion is that human activities now have a profound influence on Earth's climate.

Objective ES.2.5
Planetary Evolution

Students understand that Earth is part of a solar system and has unique characteristics that are based on its position and its stage of planetary evolution.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Energy Transfer (LS.4.2); Gravitational Interactions and Forces (P.1.4)
>
> *Prepares students for the following AP Enduring Understandings:* AP Environmental Science 2B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.2.5.1 Explain, using representations of the Earth-Sun-Moon system, phases of the Moon.

ESM-PE.2.5.2 Construct a representation of Earth's orbital path and rotation, and identify the length of time each takes. Identify key positions (solstices and equinoxes; perihelion and aphelion) of Earth throughout its orbit, and link these positions to seasonal changes.

ESM-PE.2.5.3 Predict how changes in rotation might change the length of a day and the amount of insolation.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Earth is part of a solar system in which planets orbit a central star (the Sun). These planets vary in size, composition and surface features. Earth is the third planet from the Sun and has one natural satellite, the Moon. Approximately once every 28 days, the Moon orbits Earth.
- Gravity is responsible for the orbits of planets and the motions of all other objects, such as asteroids, meteoroids and comets, in the solar system. The gravitational force of the Moon is responsible for tidal effects on Earth.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- Earth currently rotates about its tilted (in relation to the ecliptic plane) axis once every 24 hours and revolves around the Sun approximately once every 365 days. Earth's orbit around the Sun is elliptical; however, it closely resembles a perfect circle.
- Energy is transferred from the Sun to Earth through solar radiation. Earth's revolution around the Sun, as well as Earth's rotation and tilt of axis, affect the amount of energy that is transferred to its surface. This results in daily and seasonal weather conditions observed on Earth.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.2.5.1 Explain, using representations and models of the tilt of Earth (to the ecliptic) and the orbit of Earth, changes in insolation in particular locations throughout a year.

ESH-PE.2.5.2 Describe how the angle of solar incidence impacts the following: length of daylight, atmospheric filtration and distribution of sunlight in any location.

ESH-PE.2.5.3 Collect data on surface temperature that illustrates the relationship between the angle of incidence and the absorption of insolation.

ESH-PE.2.5.4 Predict how changes in axial tilt might affect seasonal changes.

ESH-PE.2.5.5 Compare and contrast the differences between Earth and other planets, in terms of composition, density, surface expression of tectonics, climate, and conditions necessary for life.

ESH-PE.2.5.6 Evaluate evidence, such as craters on Earth and on the Moon, of Earth's interaction with asteroids, meteoroids and comets. Evaluate the probability of future interactions.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Gravity is responsible for the orbits of planets and the motions of all other objects, such as asteroids, meteoroids and comets, in the solar system. The gravitational force of the Moon is responsible for tidal effects on Earth.
- Energy is transferred from the Sun to Earth through electromagnetic radiation that peaks in the visible light part of the spectrum (green). Earth's revolution around the Sun, as well as Earth's rotation and tilt of axis, affect the amount of energy received at any given location. This results in daily and seasonal weather conditions observed on Earth.
- Planetary differentiation is a process in which more dense materials of a planet sink to the center, while less dense materials rise to the surface. A major period of planetary differentiation occurred approximately 4.6 billion years ago.

Standard ES.3
Earth's History

Earth's history can be inferred from evidence left from past events.

Students understand that the concept of geologic time is frequently regarded as earth science's greatest contribution to human thought. It is also the basis for a key difference between the ways in which geoscientists and most other scientists conceptualize or approach their scientific studies. Though many chemical reactions and physical processes measured in the laboratory operate over time scales of seconds or fractions of seconds, Earth's processes take place over a much broader time frame — from relatively short time periods measured in seconds to much longer time periods that are measured in millions or even billions of years. Although developing an understanding of geologic time, or "deep time," is as challenging as understanding deep space, the contribution of geologic time to the story of the evolution of Earth and the human ability to reconstruct time lines is enormous. Equally important for unraveling Earth's story is the help provided by the geologic time scale. A relative time scale (chronostratigraphy) is used to unravel and chronicle both Earth's and life's evolution. An absolute time scale (geochronology) is used to interpret times of event occurrences and model processes, such as rates of tectonic deformation or species adaptation, or cycles of the global climate system.

Objective ES.3.1
Relative and Absolute Dating

Students understand that various dating methods — relative and absolute — have been used to determine the age of Earth.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Evidence of Common Ancestry and Divergence (LS.1.1); Living Systems and the Physical Environment (LS.3.1); Nuclear Chemistry (C.1.6); Nuclear Interactions and the Conservation of Mass–Energy (P.2.3)

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.3.1.1 Create a scaled time line (using analogies such as a football field, a calendar year, etc.) that represents geologic time (4.6 billion years), and include significant geologic, biological and human events illustrating the relationship between human and geologic time scales.

ESM-PE.3.1.2 Give examples that illustrate the difference between absolute age and relative age.

ESM-PE.3.1.3 Determine the relative ages of rock layers and stratographic features in relation to one another in a geologic cross section. Consider the following interpretive features in order to make the determination: the law of superposition, the law of cross-cutting relationships, and the principle of original horizontality.

ESSENTIAL KNOWLEDGE (6–8) [Note: See additional essential knowledge statements for this grade band on page 38.]

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Natural processes that took place in the past are the same as those that can be observed taking place in the present (uniformitarianism).
- The geologic time scale is an established record used to describe the sequence of events that have occurred throughout Earth's history. The geologic time scale provides a sequence of divisions for the major changes in geologic conditions and in the evolution of life on Earth.

Objective ES.3.1: Relative and Absolute Dating

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.3.1.1 Calculate, given the half-life and relative amounts of original isotope and daughter product in a rock sample, the estimated age of the sample.

ESSENTIAL KNOWLEDGE (6–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The evidence used to derive the time scale first came from the study of the rock and fossil records, and more recently came from radiometric dating of Earth, lunar rocks and meteorites. Based on this evidence, Earth is estimated to be 4.6 billion years old.
- Relative dating methods, such as the law of superposition, the law of cross-cutting relationships, and the law of faunal succession, establish the relative sequence of geologic events. Scientists have been able to put together a comprehensive understanding of the geologic time scale through combined and collaborative efforts to share and coordinate information.
- Absolute dating methods, utilizing the predictable rate of decay of radioactive elements, provide the specific ages of sample materials in time units.

Objective ES.3.2
Rock and Fossil Records

Students understand that the rock and fossil records provide evidence of the evolution of Earth's environment and the associated changes in life over time.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Evidence of Common Ancestry and Divergence (LS.1.1)
>
> *Prepares students for the following AP Enduring Understandings:* AP Environmental Science 2B, 2C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.3.2.1 Infer the environment in which a fossil formed. Inference is based on the physical characteristics of both the fossil and the rock in which the fossil was found.

ESM-PE.3.2.2 Determine, using the law of superposition and using cross-sectional representations of fossil-bearing rocks, the relative ages of fossils from different locations.

ESSENTIAL KNOWLEDGE (6–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Changes in Earth's environment occur in both short and long time intervals. Large changes are relatively infrequent, and small changes are relatively frequent. Infrequent global catastrophic events, such as impacts from bolides or periods of widespread volcanic activity, leave evidence in the geologic record.
- Fossils are preserved remains or traces of organisms that provide evidence of past life. The collection of all fossils and their placement in chronological order is known as the fossil record. Not all organisms are present in the fossil record because of their removal due to erosion and because of the unique geological conditions that are required for preservation.

ESSENTIAL KNOWLEDGE (6–12), ***continued***

- No one location contains a complete fossil record of life on Earth. However, by correlating rock layers in different locations, a more complete fossil record can be created. The fossil record shows that over 99 percent of species that have lived on Earth are now extinct.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.3.2.1 Explain, based on evidence found in the rock and fossil records, species extinction and evolution.

ESH-PE.3.2.2 Use fossil evidence to make claims about faunal succession and adaptation.

ESSENTIAL KNOWLEDGE (9–12) [Note: The previous list of essential knowledge statements for this objective is also appropriate for this grade band.]

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The fossil record, particularly in invertebrates, provides evidence of biological evolution. Population increases during periods of environmental stability. As population decreases during periods of environmental stress, new species evolve.

Standard ES.4
Cycles of Matter and Energy

Matter on Earth is finite and moves through various cycles that are driven by the **transformation** of energy.

Students understand that interdependent and interactive systems on Earth are characterized not only by feedback mechanisms but also by the circulation of matter and energy in endless loops or cycles. Nearly all matter on Earth is **recycled** over and over again. The geologic cycle is a collective term used to describe the complex interactions among the component tectonic, rock and hydrologic subcycles and the biological cycling of elements known as the biogeochemical cycle.

Early in the geologic history of Earth, the elements that make up the gases, water and rocks that can be found on Earth's surface and atmosphere existed, under extreme temperatures and pressures, at various locations deep underneath Earth's surface. Driven by convective thermal energy transfer (heat), the changes in pressure and temperature conditions — resulting from rock-forming material moving upward — allowed for new mineral assemblages to occur and for the more volatile gases and water to escape, forming the planet's atmosphere. Although the rate of this planetary degassing process may change over geologic time, it is a process that continues to occur on Earth and on all other tectonically active planetary bodies. The rock cycle describes Earth's dynamic transitions among the three main rock types as each type of rock is, over time, altered when these driving forces push rocks out of their equilibrium conditions. The theory of plate tectonics, developed from an understanding of seafloor spreading and continental drift, describes the forces acting on Earth's crustal plates and the resulting movement of the plates. Plate tectonics explains the distribution of many large-scale geologic features — mountain ranges, volcanoes, structures on the seafloor, earthquakes — that results from interactions along plate boundaries and, concomitantly, produces the fundamental forces that drive the geologic cycle.

Changes in the physical and chemical states of Earth's crustal rocks, as well in their locations, generally occur over relatively long periods of geologic time. In contrast, water may change the physical state and location of rocks over relatively short periods of geologic time. The hydrologic cycle describes the pathways of water as it moves from one reservoir to another.

Because Earth does not constantly receive more chemical elements (except, perhaps, from occasional meteorites from outer space), elements must be recycled by processes working throughout all of Earth's systems. Biogeochemical cycles are natural, ongoing processes that recycle elements in various chemical forms, first to organisms and then back to the environment. All chemical elements in organisms are part of biogeochemical cycles. Water, carbon, oxygen, nitrogen, phosphorous and other elements pass through these cycles, connecting the living and nonliving components of Earth.

Objective ES.4.1
Water Cycle

Students understand water cycles at various rates and at various scales within Earth's systems.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Ecosystem Stability (LS.3.3); Matter Cycling (LS.4.1); Conservation of Matter (C.2.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Environmental Science 1B, 4B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.4.1.1 Construct a representation of the water (hydrologic) cycle that identifies the following: component processes, reservoirs and the direction of water movement. Representation should include evaporation, evapotranspiration, precipitation, sublimation, surface runoff as overland flow, streams and rivers, infiltration into the ground, groundwater discharge and temporary storage of water — in solid form as snow and ice; in liquid form in lakes, oceans and organisms; and in gaseous form in the atmosphere.

EARTH SCIENCE

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The amount of water on Earth is essentially fixed, or finite, and is constantly recycled through hydrologic processes (conservation of matter). Water is unique in that it can exist on Earth's surface as a solid, liquid or gas.
- Major hydrologic processes that move water include evaporation, transpiration, condensation, precipitation, surface runoff, infiltration and groundwater flow. Thermal energy derived from the transformation of solar energy and from gravity drives these processes. These processes cause water to change among solid, liquid and gaseous states.
- Water (hydrologic) reservoirs are parts of Earth's systems that store matter and energy. The major reservoirs of water are oceans (97 percent), ice caps and glaciers (2 percent), and ground/surface water and atmosphere (less than 1 percent). Groundwater — water found in open pore spaces between soil and sediment particles, and within fractures in rock — provides the major source of freshwater used by human society.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.4.1.1 Construct a geologic cross section that accurately illustrates the following: an unconfined aquifer, a confined aquifer, a zone of saturation, a water table and an artesian well.

ESH-PE.4.1.2 Analyze water budget data for a watershed to find patterns and significant data.

ESH-PE.4.1.2a Determine the geographic boundary of a watershed.

ESH-PE.4.1.2b Measure the porosity of different types of sediments to predict, based on sediment type, the relative rate of recharge.

ESH-PE.4.1.2c Calculate and plot a water budget, given monthly local precipitation (*P*) and evapotranspiration (*EP*) data.

ESH-PE.4.1.2d Find patterns in water budgets that indicate months (or parts of months) that represent water surplus, recharge and deficit.

ESH-PE.4.1.2e Calculate the residence times or volumes of water for reservoirs such as lakes, watersheds, aquifers or oceans, as well as the averages and fluxes of the amount of water transferred by specific hydrologic processes.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The residence time of water in a reservoir is the average amount of time it takes to cycle once through all of the water stored in the reservoir. The residence time is longest in the ice caps and glaciers, and shortest in the atmosphere.
- Drainage basins (watersheds) are areas of land drained by a river or stream. All surface runoff and groundwater flow of drainage systems can be characterized and studied by measuring their rates of inflow and outflow over time.

Objective ES.4.2
Carbon Cycle

Students understand that the carbon cycle illustrates the transformation and pathways of carbon and carbon compounds through Earth's systems.

Suggested Connections
Between Earth Science and Other Disciplines: Ecosystem Stability (LS.3.3); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); Periodic Table (C.2.1); Conservation of Matter (C.2.3)

Objective ES.4.2: Carbon Cycle

Note: For Objective ES.4.2, there are no performance expectations or essential knowledge statements for grades 6–8.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.4.2.1 Calculate, given authentic data, the following: residence times of carbon (or some other element or molecule) in specific reservoirs; carbon budgets (or budgets of some other element or molecule) for reservoirs such as lakes, soils or oceans; averages and fluxes of the amount of carbon (or some other element or molecule) transferred by specific processes.

ESH-PE.4.2.2 Construct a graphical representation of the global carbon cycle (or the cycle of some other element or molecule), and use this representation to predict the effects of some environmental change (e.g., evolution of life, tectonic change, human activity) on carbon cycling (or the cycling of some other element or molecule).

ESH-PE.4.2.3 Explain, in relation to landform types, climate zones and ecosystem functioning, the global patterns of carbon distribution. Explanation should include the distinction between organic and inorganic carbon sources and sinks.

ESH-PE.4.2.4 Calculate, given appropriate data, estimates of the carbon footprint of some human activity or group.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The carbon cycle involves the chemical transformation of a fixed, or finite, amount of carbon on Earth from inorganic compounds to organic compounds, and back to inorganic compounds. These chemical transformations often include changes in state.
- The major carbon compounds and their reservoirs are inorganic carbonates ($CaCO_3$) found in rocks and dissolved in water, hydrocarbons found in fossil fuels, organic matter stored in soils and sediments, and organic compounds found in living organisms (biomass) as well as carbon dioxide (CO_2) and methane (CH_4) gases.
- Various compounds of carbon can be released through volcanism, dissolution and the use of fossil fuels. The cycling of carbon on short time scales is dominated by the exchange of carbon between the atmosphere and terrestrial or ocean systems through the processes of photosynthesis, respiration and combustion. Throughout geologic time, large amounts of carbon dioxide are sequestered in limestone.
- The carbon cycle is intimately related to climate change through the processes that capture and release carbon dioxide and methane gases into the atmosphere. It is also related to the cycling of other important elements for living organisms, including nitrogen and phosphorus.
- A carbon footprint is the sum of all greenhouse gases that are produced due to human activities that have a negative impact on the environment. A carbon footprint is usually measured in carbon dioxide per unit of time (e.g., CO_2/year).

Standard ES.5
Humans and the Environment

Humans and the environment impact each other.

Students understand that as the global population approaches seven billion, and with the worldwide need for many people to improve their standard of living, there is an increasing demand on Earth's resources. One hundred years ago, people used only 20 of the naturally occurring chemical elements to create materials. Today, people use most of the 92 naturally occurring elements to produce the goods that society uses on a daily basis. The environmental ramifications of an increasing population — coupled with the need for ever-increasing amounts and new sources of minerals, energy, water and productive agricultural soils — are substantial.

Humans now have surpassed all natural processes as agents of environmental change. Increasingly, people move large amounts of rock and sediment during various construction, agricultural and resource-mining activities. Although natural weathering processes are constantly at work altering Earth's surface, studies of the relationship between natural historical erosion rates and modern erosion rates indicate that since the late 1900s, humans have become more important as sediment movers than the sum of all other natural processes. Currently, the rate of global erosion caused by human activity exceeds all natural processes by an order of magnitude.

Humankind has become a geological agent, one that must be taken into account when considering the workings of Earth's systems. The notion that there is a strong human imprint on recent climate change is now compelling, with deforestation, urbanization and human-induced emissions all having a strong influence on Earth's warming. Many of today's most pressing issues — including climate change, water availability, resource and energy consumption, and habitat sustainability — require that humans understand Earth's processes in order to make informed decisions.

Objective ES.5.1
Humans and Natural Resources

Students understand that human societies require natural resources derived from Earth. The amounts and types of resources required are a function of the size, growth and affluence of the human population. The value of a natural resource is dependent on its amount and its ease of extractability from Earth.

Suggested Connections
Between Earth Science and Other Disciplines: Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3)

Prepares students for the following AP Enduring Understandings: AP Environmental Science 5A, 5B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.5.1.1 Analyze a graphical representation of population data to make claims concerning temporal trends in the population.

ESM-PE.5.1.2 Make claims about the relationship between population demographics and resource use. Claims are based on demographic, economic and resource-use data for different countries.

ESM-PE.5.1.3 Construct a representation that illustrates the benefits and consequences of humans' use. Claims are of a specific resource, and identify both the impacts that can result from the extraction, transport and use of the resources, as well as the systems on Earth that are affected by these human activities.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Human society depends on the energy, water and mineral resources that are provided by Earth's systems. Earth's resources required by human society depend on the society's population size, its affluence and the technology available within that society.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- Natural resources can be classified as renewable or nonrenewable resources based on the relative time scales of their formation and their use by human societies.
- Humans' use of resources has environmental consequences. These consequences can be local or global and can change the functioning of Earth's systems.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.5.1.1 Identify the locations of the major sources of industrial minerals. Determine, for a given location or country, which minerals must be imported.

ESH-PE.5.1.2 Differentiate between a resource and a reserve, and explain what makes a mineral resource an ore.

ESH-PE.5.1.3 Identify a local natural resource (e.g., metallic, nonmetallic, water, fossil fuel), and make claims about its benefits to society and about the environmental impacts related to its development.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The spatial distributions and amounts of Earth's resources are a result of past and present Earth processes. Resources tend to be concentrated in specific locations by Earth processes.
- There are tradeoffs between the use of resources and its consequences for Earth's systems. Sustainable use of resources relies on analysis of these tradeoffs.

Objective ES.5.2
Humans and Natural Hazards

Students understand that natural hazards impact human society. Societies try to reduce the impacts of natural hazards through disaster reduction, which entails early warning and engineering projects that seek risk reduction.

> **Suggested Connections**
> *Between Earth Science and Other Disciplines:* Natural Selection (LS.1.2)

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.5.2.1 Identify locally important natural hazards, and predict the impacts of these hazards on humans.

ESM-PE.5.2.2 Use a geologic map of the world to predict areas that are at risk due to geologic hazards such as earthquakes, volcanoes and tsunamis.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Geologic hazards include earthquakes, volcanoes, tsunamis and landslides. Atmospheric hazards include hurricanes, tornadoes, floods and severe thunderstorms.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- Because of the interactions within and among Earth's systems, natural hazards impact human societies in both direct (e.g., death, property destruction) and indirect (e.g., economic disruption, human migration) ways.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.5.2.1 Calculate recurrence interval of floods, earthquakes or other natural hazards. Develop a graphical representation of event frequency.

ESH-PE.5.2.2 Contrast and explain the factors and processes that control the risk of flooding in the two drainage basins, using flood frequency for two drainage basins along with other important basin characteristics (e.g., land use, climate, topography, engineering of the river channel).

ESH-PE.5.2.3 Identify locally important natural hazards, and predict the impacts of these hazards on humans. Evaluate the costs and benefits of different methods of disaster preparation and mitigation.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Risk assessment of natural hazards requires an evaluation of the probability that an event will occur and of the magnitude of the potential impact of the event on human society.
- The recurrence interval quantifies the average number of years between natural hazard events of a certain magnitude. The actual number of years between events of any given size varies because the natural hazards occur randomly.
- Human activities can decrease or increase the risk associated with a natural hazard.
- Engineering efforts that reduce hazard risks include earthquake-proof buildings, sea walls on barrier islands that reduce the risk caused by storm surge, or levees that reduce the risk of flooding. Examples of human activities that increase hazard risks include building in an active fault zone, urbanization of a watershed in a way that enhances flooding, and coastal development that increases the risk of property damage as a result of hurricanes and severe storms.

Objective ES.5.3
Humans' Impact on the Environment

Students understand that all human activities, including use of resources, have environmental consequences that occur over a range of spatial and temporal scales. Because of the complexity of Earth's systems and because of the occurrence of unintended consequences, a systems framework is commonly used to understand important environmental issues such as pollution, climate change or ecosystem disruption. A systems analysis guides **scientific investigations**, decision making and the identification of potential solutions to environmental issues.

Suggested Connections

Between Earth Science and Other Disciplines: Natural Selection (LS.1.2); Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); Structure–Property Relationships (C.2.2)

Prepares students for the following AP Enduring Understandings: AP Environmental Science 5A, 5B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESM-PE.5.3.1 Construct a representation that illustrates the impact of human activities on climate and the impact of climate on natural and anthropogenic systems, as well as interactions that are positive or negative feedback loops.

ESM-PE.5.3.1a Evaluate uncertainties about the cause of Earth's current and ongoing climate change. Evaluate and refine **scientific questions** that could assist in appraising the relative impacts of its contributing factors.

ESM-PE.5.3.1b Justify the selection of data needed to analyze long-term trends in climate change by distinguishing between climate and weather.

ESM-PE.5.3.1c Make claims concerning the effects of anthropogenic carbon on climate change, using temporal data of atmospheric chemistry, global temperature and human activities that release key greenhouse gases and aerosols.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Climate is influenced by interactions of multiple physical, chemical and biological factors, including human actions. Evidence of past changes in climate suggests that natural variations in climate occur over time. In addition to this natural change, the impact of human activities (the release of greenhouse gases and aerosols) on climate is becoming increasingly apparent.

- Human activities, including urbanization, agriculture, industrialization and the management of rivers, impact the hydrologic cycle. Balancing water resource needs for ecosystems and for human society, especially in the more arid western parts of the United States, is a pressing environmental issue.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

ESH-PE.5.3.1 Predict, using models and representations, how changes in a local drainage basin impact the hydrology of the basin. Identify human activities and factors that influence the amount of water available for human and ecosystem use.

ESH-PE.5.3.2 Construct a representation that demonstrates the interactions between agricultural activities and the health of aquatic ecosystems, including those interactions that are positive or negative feedback loops.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Agricultural runoff releases nitrogen and phosphorus to aquatic systems. These important nutrients impact aquatic ecosystems, leading to eutrophication in rivers, estuaries and coastal ocean systems.

Unpacking the Performance Expectations: Earth Science

Why "unpack" a performance expectation?

- The science practices standards appear to be separate from the discipline-specific standards, but they are intended to be integrated with disciplinary content knowledge.
- Unpacking a performance expectation establishes clear, specific targets of learning.
- Unpacking a performance expectation illustrates that any one performance expectation may involve multiple science practices.
- The unpacking is intended to provide a model for interpreting the science practices for a specific discipline.

How should an unpacked performance expectation be used?

- The sample unpacked performance expectation provided should be used as a model so that teachers can unpack all of the performance expectations within the discipline-specific standards.
- All of the unpacked performance expectations can be used for guidance in developing instructional strategies and curricula that offer opportunities for students to develop a robust understanding of the science practices and disciplinary content knowledge.
- All of the unpacked performance expectations can be used to develop curricula, instruction and assessment that are aligned with each other.
- Unpacking all of the performance expectations within a specific discipline enables teachers and curriculum supervisors to delineate the multiple science practices and content knowledge that are facilitated, and ultimately to link or map the performance expectations to existing curricula or to use the performance expectations as a basis for the establishment of a curricular structure.
- All of the unpacked performance expectations allow decisions about instruction and curriculum design to be made in a more principled way.

SAMPLE UNPACKED PERFORMANCE EXPECTATION (6–8)

Describe and contrast the processes of weathering, erosion and deposition in different environments.

This is **ESM-PE.1.1.1a**.

Unpacking the description in the performance expectation:

- Observe the outcomes or common characteristics of the three processes of weathering, erosion and deposition in different environments.
- Describe the general process or mechanism for weathering, erosion and deposition.

This is part of science practices **Objective SP.4.3**.

Unpacking the contrast of the explanations of the processes in the performance expectation:

- Make a claim, in order to explain the mechanism of each process (i.e., weathering, erosion, deposition), about why specific characteristics (e.g., physical contact between water or wind and soil; rate of water flow; wind direction) are associated with each process that transfers material.
- Use observations as evidence to support the claim.

Incorporates science practices **Objective SP.2.2**.

- Justify the claim through **reasoning** — by connecting observations to the specific process or mechanism of transfer of material. Incorporate the relevant aspects of the environment (e.g., geographic characteristics, water flow, water source, soil composition) to connect the observation to the mechanism.

This is part of science practices **Objective SP.4.3**.

- Compare and contrast qualitatively the explanations of the three processes for different environments. Comparison is based on the physical features of the environment (e.g., geographic characteristics, water flow, water source, soil composition) that determine the resulting process (i.e., the angle of the hillside stream determines the rate of water flow, which will result in either erosion or deposition).

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Standards

1. The diversity and unity of life can be explained by the process of evolution.
2. Cells are a fundamental structural and functional unit of life.
3. Interdependent relationships characterize biological ecosystems.
4. Biological systems utilize energy and molecular building blocks to carry out life's essential functions.
5. Living systems have multiple mechanisms that are used to store, retrieve and transmit information.

Life Science

Organization and Structure of the Life Science Standards for College Success

The life science standards are intended to outline the knowledge, skills and abilities that students need in order to be prepared for success in an introductory college-level biology course, or in an Advanced Placement (AP) Biology course. Core ideas, or "big ideas" — identified by the NSF-funded AP committee members as being central to an introductory college-level biology course — were the foundation of the creation of the life science standards.

The life science standards are organized around core ideas of the discipline. While there are five standards, they are not meant to represent an equal division of material and **concepts**.* Each standard has two to five objectives that provide detailed descriptions of more specific life science core **principles** of which students should have knowledge. Similar to the enduring understandings that are the target concepts for the AP courses, the objectives are the focus of student mastery for college readiness and the key elements of the conceptual framework of the life science standards. An objective is often followed by a list of other objectives — within the discipline as well as from other disciplines — that are connected in some way to that objective. Both the standards and the objectives are preceded by key words and/or phrases that help articulate the content in a more concise manner. This is especially helpful when a standard or an objective is referenced either by another discipline or during curriculum or instructional planning.

The objectives are, in turn, supported by a set of performance expectations (PEs) and a set of essential knowledge (EK) statements. The PEs describe what students should know, understand and be able to do in order to apply, as well as build and reason with, the essential knowledge that is necessary to understand the content outlined in the objective. The PEs illustrate how students engage in science practices to develop a better understanding of the objective. Students should be able to successfully engage in, *at the very least,* the performance expectations listed for each objective in order to be considered college ready. These performance expectations, along with the essential knowledge statements, can provide guidance in the development of assessments and curriculum materials. The EK statements are an articulation of the conceptual targets for student learning, providing a more detailed description of the broader knowledge delineated in the objective. These statements should be approached from a holistic perspective, and they should not be viewed as a list of discrete, unrelated **facts** for students to memorize. The EK statements also provide the language and appropriate terminology that should be incorporated into students' completion of the performance expectations.

It should be noted that both the performance expectations and the essential knowledge statements were written based specifically on the objective-level statements. There is not a corresponding relationship between the PEs and the EK statements; the PEs are a representative (but certainly not all inclusive) set of applications of the essential knowledge. Therefore, when interpreting the depth and scope of each PE, the EK statements should be considered.

The number of objectives, as well as the number of performance expectations and essential knowledge statements, varies considerably from standard to standard. For example, Standard 5 contains the largest amount of material because DNA and its transmission lie at the heart of life science. It should also be made clear that these objectives, PEs and EK statements are not intended to show a linear progression through

* Boldfaced words and phrases are defined in the glossary.

the subject. Many of the topics and concepts in life science rely on more than one objective and on several PEs and EK statements, some of which may come from different standards. For example, the process of cell division (mitosis) has purposes associated with growth and development (Objective LS.2.3) as well as with the transmission of genetic information (Objective LS.5.2). In addition, the number of PEs for a given objective does not indicate any level of importance, and it is assumed that some PEs may require a greater amount of instructional time than others.

Goals of Life Science Education

Two current issues within life science education are the ongoing expansion of the breadth of the discipline and students' lack of the foundational knowledge needed to understand some of the current areas of research in the different life science fields. The life science standards are specifically designed to address these issues and, as a result, tough decisions have been made. First, in an effort to address the issue of the expanding breadth of the discipline, the Life Science Standards Advisory Committee decided to include certain objectives at just one of the grade bands. In other words, not all of the objectives for each standard cover both grade bands. For example, because of the concrete nature of the concepts related to ecosystem **interactions**, this area of life science is developed only in the 6–8 grade band. Students in the 9–12 grade band can use their understanding of these interactions and relationships in their study of natural selection.

Second, only one **model** of matter cycling is fully developed using the cycling of carbon. Teachers can expand this model to other elements, such as nitrogen, using the conceptual carbon model as a guide; however, the committee promotes the full development of the carbon cycle as a priority. Students in the 9–12 grade band focus on concepts that are more abstract and at the molecular level. This design narrows the breadth of information and also prepares students for an understanding of the current research in life science.

Finally, DNA (deoxyribonucleic acid) is used throughout the standards as the model for inheritance. The standards show how this model relates to chromosomes and **traits** that are typically used as models for inheritance. The committee believed that using a consistent model of DNA, rather than focusing on those of the past, would enhance students' understanding of the current model of inheritance as well as promote coherence in their understanding of the broader concept of inheritance.

All of these decisions were made with consideration of the following goals: to ensure grade band appropriateness (e.g., protein synthesis for students in grades 9–12 only); to provide adequate time for instructors to teach fewer concepts at each grade band; and to prevent unnecessary repetition of basic ideas (e.g., the annual instruction of the water [H_2O] cycle).

Definition of Rigor

The standards represent the shift in the College Board's view of rigor, from requiring that students know all of the facts, vocabulary and specific examples related to various topics, to ensuring students' understanding and application of core principles for the discipline and the integration of this knowledge with the skills essential for practicing science. The performance expectations were written to provide students with opportunities to make sense of the observed world in terms of the fundamental principles that explain these observations. As the committee members developed the standards, objectives, performance expectations and essential knowledge statements, they also looked for instances where connections could be made among the core principles and within each core principle, so that students' understanding would be more integrated and useful. For example, students should not memorize the details of each separate human body system, or the names and functions of each of the organs of these systems. Instead, students should focus on how the body systems (e.g., the digestive, circulatory and respiratory systems) are interdependent to carry out basic essential life functions such as extracting energy from **food** or eliminating wastes. In addition, in order for students to gain a true conceptual understanding of the principles of life science, they must be exposed to these concepts in multiple contexts that apply to different living systems and across different spatial scales. Rigor is no longer defined in terms of the facts and definitions students know, but in terms of how students can apply their knowledge and make connections among concepts.

The performance expectations also require that students become personally engaged in making sense of the ideas to which they are being introduced. Students are frequently asked to seek and gather information from "print and electronic resources" and to "give examples." The expectation is that students will be exposed to a wide variety of phenomena related to the ideas being taught. Students' experiences must go well beyond the few classic instances typically taught in the classroom or found in a textbook. The expectations regarding independent research of this kind should be appropriate for each grade band and related to the examples presented in the classroom, but they should also expand opportunities for each individual student to take personal initiative to explore the relevance of each idea in depth and in a wide range of new contexts.

Goal of Conceptual Understanding

The goal at both the 6–8 and 9–12 grade bands is conceptual understanding in the best sense of the word. Students are expected to understand the core principles of the life sciences, not only as abstract scientific generalizations but also in terms of how the ideas are related to phenomena that the students will encounter in the natural world. To reinforce the point that conceptual understanding is more important than the memorization of terminology, the standards highlight the optional technical terminology by placing the term in parentheses. Before a technical term is introduced in the classroom, the simpler term or phrase that summarizes the targeted concept should be developed. Whether or not the technical term in parentheses should be taught along with the fundamental idea is left up to the discretion of each individual teacher. These decisions should be based on the maturity and language sophistication of the students involved. In all cases, the most important thing is each student's conceptual understanding of the scientific principle, not the terminology.

Another aspect of rigor and conceptual understanding that is addressed is the extent to which students should know the specific mechanisms behind events and processes. The committee believes that students should be presented with underlying mechanisms as often as possible in order to enhance their understanding. However, there are times when a mechanism is too involved or too complex for most of the students at a certain grade band to comprehend without using excessive amounts of instructional time. There are times when it is more reasonable to "black box" a mechanism, while still providing students with an adequate conceptual understanding of the process. For example, students are expected to know that the sequence of nucleotide bases making up a strand of DNA determines the specific amino acid sequence in a protein molecule. The objective states: "Students understand that genetic information (DNA) is used to produce proteins that largely determine the traits of an organism." Essential knowledge statements that mention transcription and translation are included. However, additional details of the mechanism by which DNA is related to protein synthesis are left undefined. The committee takes the position that each teacher should determine how many of these details are accessible to and appropriate for the students, which details are needed to provide an adequate understanding of the basic concept, and how much should be "black boxed." The important point is that students know that there is a link between the structure of DNA and protein synthesis. This is the conceptual understanding that students need for college readiness. So although an awareness of underlying mechanisms may lead to increased understanding of the targeted concept, there are times when it may be unrealistic to include all of the details of these mechanisms.

Performance expectations should be viewed as representative of the expectations for all students and reflective of the core knowledge all students should have. In life science courses that are based on these expectations, instruction should provide students with many opportunities to work toward meeting the expectations. These opportunities should include a wide range of contexts that encompass the variety of living systems that exist in nature. In addition to being provided opportunities to work toward meeting these particular performance expectations, students should also have opportunities to develop additional practices and knowledge that may not necessarily be highlighted in these standards but still contribute to becoming college ready in life science.

Foundational Knowledge

Even though these standards are focused on grades 6–12, the College Board recognizes the importance of students' having certain foundational knowledge in life science upon entering sixth grade. Middle school teachers need to determine whether their students already have this foundational knowledge before they attempt to address the ideas described in the standards document, and they should adjust their instruction in terms of what students already know and what students do not know. Some of the foundational knowledge that students are expected to have by the end of fifth grade is listed below. These statements, organized into five groups, are found in various elementary school benchmarks in *Benchmarks for Science Literacy* (BSL), developed by the American Association for the Advancement of Science (AAAS).

- Organisms interact with each other in many ways besides providing food. Organisms have a variety of sources of food. Some organisms are more successful in different types of environments. Changes to an organism's habitat are sometimes beneficial and sometimes harmful.
- For offspring to resemble their parents, there must be a reliable way to transfer information from one generation to the next. Some likenesses between children and their parents are inherited, and some are learned.
- Some living systems consist of a single cell that needs all of the necessary life resources. Some organisms are made of a collection of cells that benefit from cooperating. Some organisms' cells vary greatly and perform very different roles.
- People obtain from food the energy and materials needed for body repair and growth. Almost all kinds of animals' food can be traced back to plants.
- Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.

Standard LS.1
Evolution

The diversity and unity of life can be explained by the process of evolution.

Students understand that organisms — both extant and extinct — may have significant differences, but they also have many similarities. A corollary of this idea is that present-day species have descended from earlier, distinctly different species. Because some characteristics of earlier organisms are retained, the degree of similarity and difference can be used as **evidence** to make inferences regarding the lines of descent tracing back to a common ancestor. Research in this area is done at both the molecular level and at the more descriptive trait level.

Objective LS.1.1
Evidence of Common Ancestry and Divergence

Students understand that an analysis over time of both the anatomical structures and the DNA compositions of organisms can be used to infer lines of descent back to a common ancestor.

> **Suggested Connections**
> *Within Life Science:* Genetic Information Transmission (LS.5.2); [Grades 9–12 only: Changing Model of Inheritance (LS.5.1); DNA to Trait (LS.5.3); Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Between Life Science and Other Disciplines:* Rock-Forming Environment (ES.1.5); Relative and Absolute Dating (ES.3.1); Rock and Fossil Records (ES.3.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1C, 2D, 3A, 3C; AP Environmental Science 2A

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.1.1.1 Construct a **representation** that reflects the appropriate time scale of Earth's history and includes the variation of organisms over time. Representation describes major evolutionary developments (e.g., the first organism, oxygen in the atmosphere, the first land plants, appearance of vertebrates, etc.).

LSM-PE.1.1.2 Construct a representation, using information from the fossil record, that describes the organisms present during several different time periods in Earth's history.

LSM-PE.1.1.3 Observe the anatomical structures of a variety of organisms, and describe the similarities and differences among them. Organize the organisms into groups based on their similarities and differences. Make a **claim** about how recently organisms among the groups shared a common ancestor, and justify that claim based on the degree of similarity of their characteristics.

LSM-PE.1.1.4 Construct a simple model (e.g., phylogenetic tree), based on anatomical similarities and differences, of the degree of relatedness of different species. If necessary, revise the model based on new or additional anatomical evidence.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Fossils are preserved remains or traces of organisms that provide evidence of past life. The collection of all fossils and their placement in chronological order (e.g., dating or location in sedimentary layers) is known as the fossil record. Because of the unique geological conditions that are required for preservation, not all organisms left fossils that can be retrieved. *[**BOUNDARY:** Students are not expected to know specific methods for dating fossils or understand how these methods work; however, it is appropriate for students to work with **data** generated using these methods.]*

- The fossil record documents the existence, diversity, extinction and change over time of many life forms throughout Earth's history.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- The existence of different life forms in different time periods led to the idea that newer life forms descended from older life forms.
- Anatomical similarities and differences among various organisms living today are compared to those of organisms in the fossil record in order to reconstruct evolutionary history and infer lines of evolutionary descent.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.1.1.1 Provide evidence — reported in print and electronic resources, and regarding similarities and differences between organisms from the fossil record and preserved DNA — that supports the idea of descent with modification. Explain how similarities and differences among organisms support the idea of descent with modification.

LSH-PE.1.1.2 Construct a simple model (e.g., phylogenetic tree), based on anatomical evidence (physical traits), of the degree of relatedness among various organisms. If necessary, revise the model based on the inclusion of new molecular (i.e., DNA and/or amino acid) evidence.

LSH-PE.1.1.3 Explain, in terms of preserved DNA sequences, why specific extinct or extant organisms within a line of descent are considered to be either closely or more distantly related (i.e., share a common ancestor).

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Organisms resemble their ancestors because genetic information (DNA) is transferred from ancestor to offspring during reproduction.
- The branching that characterizes lines of descent can be inferred from the DNA composition of organisms over time.
- The similarities and differences in DNA sequences, amino acid sequences, anatomical evidence and fossil evidence provide information about the branching sequence of lines of evolutionary descent.

Objective LS.1.2
Natural Selection

Students understand that when a trait is favorable to an organism, the number of organisms with that trait will increase over time; and that when a trait is unfavorable, the number of organisms with that trait will decrease over time. Students understand that as a result, there is an increase in the proportion of individuals with the advantageous trait in a population. Over time, the process of natural selection leads to both the extinction of existing species and the evolution of new species.

> **Suggested Connections**
> *Within Life Science:* Living Systems and the Physical Environment (LS.3.1); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: DNA to Trait (LS.5.3); Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Between Life Science and Other Disciplines:* Climate (ES.2.4); Humans and Natural Hazards (ES.5.2); Humans and the Environment (ES.5.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1C, 2D, 3C, 4C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.1.2.1 Create an appropriately scaled representation that illustrates and traces two or more significant environmental changes (e.g., temperature, amount of carbon dioxide [CO_2] in the environment, presence of water) that have occurred throughout geologic time.

LSM-PE.1.2.2 Give examples, using information gathered from print and electronic resources, of natural environmental changes that have occurred in the recent past. Collect and organize data about the number, kind and/or geographical distribution of organisms before and after these changes occurred. Make a claim about how these environmental changes have affected the number, kind and/or distribution of specific organisms living in these environments. Using these examples of environmental changes and the data on number, kind and/or geographical distribution of organisms, make and justify a claim about the effects of changes in environmental conditions on the survival of some organisms compared to the effects of these changes on the survival of other organisms.

*[**BOUNDARY:** The focus is on the effects of changes in the environment on the survival of organisms. The examples should not only describe the effects on the survival rates of various species but also describe the effects of individual variation on survival within one species.]*

LSM-PE.1.2.3 Give examples, using information gathered from print and electronic resources, of environmental changes that have occurred in the recent past as a result of human actions. Collect and organize data about the number, kind and/or geographical distribution of organisms before and after these changes occurred. Make a claim about how these environmental changes have affected the number, kind and/or distribution of specific organisms living in these environments. Using these examples of environmental changes and the data on number, kind and/or geographical distribution of organisms, make and justify a claim about the effects of changes in environmental conditions on the survival of some organisms compared to the effects of these changes on the survival of other organisms.

LSM-PE.1.2.4 Give examples, using information gathered from print and electronic resources, of observations made by Charles Darwin of variation within species and of changes in environmental conditions that he used in the development of his **theory** of natural selection. For each example, describe the relationship between the variation within species and the changes in the environmental conditions.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Charles Darwin's theory of evolution had a dramatic effect on biology because of his use of clear and understandable argument and because of the inclusion of a massive array of evidence to support the argument.[3]

- Organisms that have certain traits are better suited than other organisms to survive and have offspring in a given environment. If these traits are heritable, the offspring of these organisms will likely have these traits as well; therefore, in that environment, the offspring will also be better suited to survive and reproduce in that environment.

- Changes in Earth's environment occur over both short and long time intervals. Small changes are relatively frequent, and large changes are relatively infrequent.

- Changes in environmental conditions can affect how beneficial a trait (phenotype) will be for the survival and reproductive success of an organism or an entire species.[4]

- Human activity (e.g., deforestation, urbanization, burning fossil fuels, overhunting or overfishing) can impact environmental conditions (e.g., temperature change, habitat and resource availability), which is currently leading to an increase in some populations of organisms but a decrease in many others. Overall, these changes in populations have led to a net extinction of species and thus have reduced biodiversity.

- Most species (approximately 99 percent) that have lived on Earth are now extinct. Throughout Earth's history, extinction of a species has occurred when the environment changes and the individual organisms of that species do not have the traits necessary to survive and reproduce in the changed environment.[5]

3. American Association for the Advancement of Science, *Atlas of Science Literacy Volume 2* (Washington, D.C.: Author, 2007), 85.
4. American Association for the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford University Press, 1993), 124.
5. National Research Council, *National Science Education Standards* (Washington, D.C.: The National Academies Press, 1996), 158.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.1.2.1 Construct a model or run a simulation that represents natural selection in terms of how changes in environmental conditions can result in selective pressure on a population of organisms.

LSH-PE.1.2.1a Gather and record data from the model or simulation on the composition (e.g., distribution of traits, number of organisms, change in environmental conditions) of a population under varying environmental conditions. Complete multiple trials or use class data.

LSH-PE.1.2.1b Represent the data in a way that demonstrates the relationship, if any, between the environmental changes and the population.

LSH-PE.1.2.1c Calculate measures of central tendencies (i.e., mean, median, mode), represent spread of data (e.g., range), and determine error (e.g., number of **outliers**) of each variable in order to analyze the data and make a claim about the patterns observed.

LSH-PE.1.2.1d Explain how each part of the model or simulation is similar to, or different from, the process of natural selection.

LSH-PE.1.2.2 Predict and justify, based on ideas about natural selection, what might happen to a population of organisms after many generations if the population becomes geographically isolated from another population of the same species, and if the two groups experience different **biotic** and/or environmental conditions.

LSH-PE.1.2.3 Give examples, using information gathered from print and electronic resources, of observations made by Charles Darwin of variation within species and of changes in environmental conditions that he used in the development of his theory of natural selection. For each example, explain how the observations support the theory of natural selection.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Natural selection leads to a diversity of organisms that are anatomically, behaviorally and physiologically well suited to survive and reproduce in a specific environment.
- Over time, the differential survival and reproduction of organisms within a population that have an advantageous heritable trait lead to an increase in the proportion of individuals in future generations that have the trait and a decrease in the proportion of individuals that do not.
- Changes in the **abiotic** environment, including climatic and geological processes, have contributed to the decline of some species and the expansion of other species.
- When environmental change — naturally occurring or human induced — happens, extinction can occur. Species become extinct because they cannot survive and reproduce in their environments. If members cannot adjust — because change in the environment is too fast or too drastic — they die or become unable to reproduce, thus negating opportunity for evolution.
- Charles Darwin's theory of evolution had a dramatic effect on biology because of his use of clear and understandable argument and the inclusion of a massive array of evidence to support the argument.[6]

6. American Association for the Advancement of Science, *Atlas of Science Literacy Volume 2*, 85.

Objective LS.1.3
Genetic Variation Within Populations

Students understand that genetic variation within a population is essential for natural selection. Mutations, as well as random assortment of existing genes, can produce genetic variation in a population.

*[**BOUNDARY:** For this objective, genetic variation refers to the variation in the genetic makeup of organisms of the same species. Students are expected to make the connection and, when appropriate, articulate the connection between the variation of genetic information and the resulting variation in traits. The connection among DNA, protein and trait should not be considered a "black box" for the 9–12 grade band.]*

> **Suggested Connections**
> *Within Life Science:* Natural Selection (LS.1.2); Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: DNA to Trait (LS.5.3); Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 3A, 3C, 4C

Note: For Objective LS.1.3, there are no performance expectations or essential knowledge statements for grades 6–8.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.1.3.1 Give examples of how, following a change in environmental conditions, variation in traits within a specific population of organisms might affect the survival and reproductive ability of some of the organisms in that population, but not other organisms in the same population. Give examples of other environmental changes that may not affect the survival and reproduction of any of these organisms. Describe the type of data needed to determine whether the survival or reproductive success of individual organisms was due to the genetic variation within the population.

LSH-PE.1.3.2 Compare the effects of a significant environmental change on a population with great genetic diversity and the effects of such a change on a population with little genetic diversity. In each instance, indicate the environmental change, the organisms within the species that were affected, and the organisms that were not affected. Explain why genetic variation among organisms within the species affected the survival of the species.

LSH-PE.1.3.3 Explain similarities and differences between populations (e.g., dogs, horses, crops) undergoing artificial selection and populations undergoing natural selection. Describe the roles that humans play in artificial selection and how these roles are similar to the natural processes that take place in natural selection.

LSH-PE.1.3.4 Give examples, using information gathered from print and electronic resources, of different organisms whose classification as members of different "species" is questionable. After evaluating the two different proposed definitions of the term "species" that led to the controversial classification of the organisms, make and justify a claim about whether or not the organisms provided as examples should be considered members of different species or of the same species.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Natural selection can occur only if there is variation in the genetic information between organisms of the same species in a population and variation in the expression of that genetic information as a trait. Genetic variation within a population influences the likelihood that a population will survive and produce offspring.[7]

- Sexual reproduction not only allows the continuation of traits (phenotype) in a population but also provides a source of genetic variation among the individuals of a population.

7. American Association for the Advancement of Science, *Benchmarks for Science Literacy*, 125.

ESSENTIAL KNOWLEDGE (9–12), *continued*

- The expression of new anatomical, physiological and behavioral traits (phenotype) in organisms within a population can result from recombining existing genes and random sorting during sex cell production and fertilization. Variation within a population of organisms can also result from genetic mutations that create variation in the expression of traits (phenotype) between organisms of the same species.

- In artificial selection, humans have the capacity to influence certain characteristics of organisms by manipulating the transfer of genetic information from generation to generation.

Standard LS.2
Cells as a System

Cells are a fundamental structural and functional unit of life.

Students understand that all organisms consist of one or more cells, and that many of the basic functions (e.g., energy **transfer** and **transformation**, exchange of gas, disposal of waste, growth, reproduction, and interaction with the environment) of organisms take place within individual cells or within systems of cells. Although there are many types of cells — in terms of size, structure and specialized functions — all cells carry out the fundamental processes that are associated with life.

Objective LS.2.1
Cell Function

Students understand that cells perform the essential functions of life, such as energy transfer and transformation, exchange of gas, disposal of waste, growth, reproduction, and interaction with the environment.

*[**BOUNDARY:** The following cell components — nucleus, mitochondria, chloroplast, ribosome, plasma membrane, vacuole and lysosome — are appropriate for students in grades 6–8. Emphasis should be placed on the function and coordination of these components, as well as on their role in the overall cell function, before introducing and reinforcing the names of these components. For students in grades 9–12, the addition of cytoskeleton, Golgi complex and endoplasmic reticulum is appropriate.]*

> **Suggested Connections**
> *Within Life Science:* Cell Differentiation (LS.2.4); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); Changing Model of Inheritance (LS.5.1); Genetic Information Transmission (LS.5.2); Nongenetic Information Transmission (LS.5.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1B, 2A, 2B, 2D, 3D, 4A, 4B; AP Environmental Science 3B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.1.1 Give examples of organisms that are made of one cell (both non-nucleated and nucleated) and organisms that are made of many cells. Compare and contrast the essential functions occurring in the single-cell organisms and in the cells of multicellular organisms.

LSM-PE.2.1.2 Gather data, based on observations of cell functions made using a microscope or on cell descriptions obtained from print material, that can be used as evidence to support the claim that there are a variety of cell types.

LSM-PE.2.1.3 Compare and contrast, using evidence of different cells and essential life functions, the various processes different cells (e.g., plant, fungi, protist, animal) use to accomplish the same life function (e.g., growing, obtaining energy).

LSM-PE.2.1.4 Construct a scaled model, based on measurements and estimates made using a microscope (when possible), that represents the relative sizes of a molecule, a bacterial cell, an animal cell and a virus.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- There are many types of cells. Organisms may consist of one cell or many different numbers and types of cells.
- Most cells are so small that the cells themselves and their details can be seen only with a microscope.
- The cell is the functional unit of all organisms. All essential life functions (e.g., energy transfer and transformation, exchange of gas, disposal of waste, growth, reproduction, and interaction with the environment) take place within a cell or within a system of cells.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.1.1 Describe the structure and function of at least one organ located in a plant and the analogous organ located in an animal (e.g., organs used for food storage, movement, reproduction, etc.). Description includes the types of cells, the structure of these cells, and the processes they perform to support the function of both the organ and the organism as a whole.

LSH-PE.2.1.2 Describe the function of at least one type of organ located in two different plants or in two different animals. Description includes the similarities and differences in the cells that make up the organ, and the similarities and differences in the processes that the cells perform to support the function of the organ in the two organisms.

LSH-PE.2.1.3 Describe, using information gathered from print and electronic resources, the structure and function of at least two organs that are part of a human body system (e.g., circulatory, digestive, gas exchange). Description includes how the two organs differ regarding the types of cells that make up each organ. Explain, using knowledge of systems of cells, how the cells and organs coordinate and contribute to the overall essential functions of the organism.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- In multicellular organisms, groups of one or more kinds of cells make up different systems of cells (i.e., tissues and organs) that are connected and that cooperate with each other in order to perform the essential functions of life within an organism.
- Different multicellular organisms use different systems of specialized cells to carry out the same basic life functions.
- The human body is made up of cells that are organized into tissues and organs. These tissues and organs make up complex systems that have specialized functions (e.g., circulatory, endocrine, etc.) that support essential life functions of the organism.

Objective LS.2.2
Cell Structure

Students understand that cells have internal structures that carry out specialized life functions, and that these internal structures vary depending on a cell's function.

*[**BOUNDARY:** The following cell components — nucleus, mitochondria, chloroplast, ribosome, plasma membrane, vacuole and lysosome — are appropriate for students in grades 6–8. Emphasis should be placed on the different structures in cells — and on how the number and types of structures vary in different cells that carry out different functions — before introducing and reinforcing the names of these components. For students in grades 9–12, the addition of cytoskeleton, cytosol, Golgi complex and endoplasmic reticulum is appropriate. There is a focus on the molecular level, so connections should be made, when appropriate, between the functions of the different cell subcomponents in terms of chemical reactions.]*

Suggested Connections
Within Life Science: Cell Function (LS.2.1); Cell Differentiation (LS.2.4); [Grades 9–12 only: Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); DNA to Trait (LS.5.3); Nongenetic Information Transmission (LS.5.5)]

Between Life Science and Other Disciplines: Structure–Property Relationships (C.2.2); Chemical Equilibrium (C.2.4); Chemical Kinetics (C.2.5)

Prepares students for the following AP Enduring Understandings: AP Biology 1B, 1D, 2A, 2B, 2D, 2E, 3D, 4A, 4B; AP Environmental Science 3B

Objective LS.2.2: Cell Structure

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.2.1 Describe, based on observations of cells made using a microscope and on information gathered from print and electronic resources, the internal structures (and the functions of these structures) of different cell types (e.g., amoeba, fungi, plant root, plant leaf, animal muscle, animal skin).

LSM-PE.2.2.2 Construct an analogical model (analogy) of the interaction of the internal components of a cell (e.g., working parts of a city, factory or automobile). Predict and justify, using the model, the impact on the cell or on the organism if one of the components fails to function properly.

LSM-PE.2.2.3 Observe patterns in the concentration of molecules of a solution (e.g., dye in water, tea) or across a membrane. Construct a model of the observed patterns.

LSM-PE.2.2.4 Predict **problems** that may arise when certain essential molecules cannot enter a cell. Justification is based on the function of the cell membrane and the role of these molecules in carrying out the essential life functions that take place within a cell.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The cell membrane forms the boundary that controls what enters the cell and what leaves the cell.
- All cells contain genetic information. Some cells (nucleated or eukaryotic) hold the genetic information in a nucleus. However, some cells (non-nucleated or prokaryotic) do not have a nucleus in which genetic information is held.
- Each cell has a specific internal organization of subcellular components that give a cell its shape and structure.
- The specialized subcomponents of nucleated cells perform essential functions such as transport of materials (cell membrane), repository of genetic information (nucleus), energy transfer (mitochondria and chloroplast), protein building (ribosomes), waste disposal (lysosomes), structure and support (cell wall, cytoskeleton), internal movement within the cell and, at times, external movement (cytoskeleton).
- Non-nucleated cells perform the same kinds of functions as nucleated cells, but many of these functions take place within the cytoplasm, not within specialized internal structures. For example, unlike nucleated cells, the genetic material of non-nucleated cells is located within the cytoplasm, not in a separate nucleus. Some of the essential functions of non-nucleated cells and these functions' locations include transport of material (cell membrane), protein building (ribosome), and structure and support (cell wall).

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.2.1 Observe the internal structures of at least three different types of cells (e.g., amoeba, fungi, plant root, plant leaf, animal muscle, animal skin). Describe, using information gathered from print and electronic resources, the functions of these structures. Construct a representation of each cell type, and compare — using gathered information and knowledge of cell structures and functions — the structures and functions across cell types. Explain why the representation is limited and simplified.

LSH-PE.2.2.2 Investigate the movement of molecules across a membrane.

> **LSH-PE.2.2.2a** Formulate a **scientific question** about the movement of molecules across a membrane under differing conditions of temperature, starting concentration, pH, etc.
>
> **LSH-PE.2.2.2b** Plan an investigation to address the variables that might affect the movement of molecules across a membrane.

PERFORMANCE EXPECTATIONS (9–12), *continued*

LSH-PE.2.2.2c Gather and record data on the movement of molecules across a membrane via passive transport under varying conditions of temperature, starting concentration, pH, etc., by completing multiple trials or by using class data. (Movement across the membrane can be measured as the percent change in the mass or volume of liquids on either side of the membrane, or by the degree of color change of liquids on either side of the membrane.)

LSH-PE.2.2.2d Calculate measures of central tendency (i.e., mean), spread of data (i.e., range) and error (i.e., number of outliers) of the concentration of the different molecules on either side of the membrane at different times.

LSH-PE.2.2.2e Make claims about the movement of the different molecules across the membrane and the factors that affect that movement.

LSH-PE.2.2.3 Explain why cells of organisms swell when placed in water and why they shrink when placed in a solution of salt water. Evaluate other student explanations of the same phenomenon. Construct a representation that generalizes the phenomenon to all organisms.

LSH-PE.2.2.4 Construct a representation of a cell membrane undergoing passive and active transport, in terms of difference in concentration, required energy and direction of molecule movement. Explain how the movement of molecules impacts the cell, and, as a result, impacts the organism as well.

LSH-PE.2.2.5 Collect data on the rates of reactions (synthesis and breakdown) via different enzymes and the rates of reactions that occur without each enzyme. Construct tables and graphs to represent the data for each enzyme. Compare the rates of reactions for the different enzymes.

LSH-PE.2.2.6 Give examples of several enzyme-catalyzed reactions that occur in living systems, and describe the importance of each reaction for the organism. Explain why an organism that has a deficiency of one of the enzymes is unable to perform a particular life function.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The essential functions of a cell involve chemical reactions that take place between many different types of molecules (e.g., water, carbohydrates, lipids, nucleic acids and proteins) and that are facilitated by enzymes. Water plays an important role both in reactions and as a major environmental component for all cells.

- Enzymes are proteins that enable chemical reactions to proceed at rates that support life functions. Environmental factors and modulators (inhibitors and activators) influence an enzyme's activity and its ability to regulate chemical reactions (i.e., life's essential functions).

  *[**BOUNDARY:** The targets of understanding are (1) changes in reaction rates due to enzymes, and (2) the factors that affect enzymes. Quantitative treatment of reaction rates is out of the scope of this objective. The molecular orientation of molecules (i.e., tertiary structure) and the specific enzyme mechanism (i.e., induced fit) are also not appropriate.]*

- Due to differences in concentration of molecules, molecules move in and out of a cell and among cells through specialized mechanisms called passive transport and active transport. The concentration of molecules and energy are factors in type and direction of transport.

Objective LS.2.3
Cell Growth and Repair

Students understand that cells of multicellular organisms repeatedly divide to make more cells for growth and repair.

> **Suggested Connections**
> *Within Life Science:* Cell Function (LS.2.1); Cell Differentiation (LS.2.4); Living Systems and the Physical Environment (LS.3.1); Changing Model of Inheritance (LS.5.1); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: Nongenetic Information Transmission (LS.5.5)]
>
> *Between Life Science and Other Disciplines:* Conservation of Matter (C.2.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 2C, 2D, 2E, 3A, 3C, 4A

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.3.1 Give examples of cell types that divide, cell types that do not divide at all, and cell types that divide only under very unusual circumstances.

LSM-PE.2.3.2 Organize and represent information gathered from print and electronic resources to compare the cell cycles of several cell types that undergo cell division. Representation(s) include the frequency of division, the typical duration of the cell cycle, the specialized function of the cell, and any special conditions that stimulate cell division and cell death. Make a claim about, and justify the relationship between, characteristics of cell cycles and the function of the cell.

*[**BOUNDARY:** Types of cells appropriate for grades 6–8 could include fungi, plant leaf, nerve, skin, muscle and plant root.]*

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- For growth and repair of multicellular organisms, each cell divides using a process (mitosis) that results in two new cells that carry the same genetic information (DNA) as the parent cell.
- Length of cell cycle and frequency of cell division typically vary among different cell types.
  *[**BOUNDARY:** Cell cycle at this level should be the time between the completion of cell divisions; the phases are not appropriate.]*

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.3.1 Make a claim about and justify, using ideas about conservation of matter, why new atoms and molecules must be added to cells in order for them to grow.

LSH-PE.2.3.2 Construct a representation of the changes that occur in a cell in terms of its size and internal components, and of the number of cells produced as a cell goes through a single cycle of cell growth and division. Predict, based on the representation, what might happen to a cell (e.g., increase in size, change in internal structure) that does not go through the entire cell cycle but still goes through division.

LSH-PE.2.3.3 Describe, using information gathered from print and electronic resources, examples of the following cell types from any multicellular organism: a cell type that divides, a cell type that does not divide at all, or a cell type that divides only under very unusual circumstances. Description includes information about the consequences and significance to an organism of having some cells that divide and some that do not.

LSH-PE.2.3.4 Identify, using information gathered from print and electronic resources, several specific parts of the cell cycle that are monitored by check point systems, and describe some of the problems that might occur if abnormal cells were allowed to continue cycling.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Cells typically undergo a continuous cycle of cell growth and division. Although most cells share the same cell cycle phases (e.g., cell growth, DNA replication, preparation for division, separation of chromosomes, cell membrane pinching off two daughters), the length of each cell cycle phase, and therefore the frequency of cell division, varies among different cell types.

  *[**BOUNDARY:** Detailed descriptions of the actions taking place during the different phases are not as important as the overall impact of these actions on the cell (changes that take place to the cell and its internal components) throughout the cycle.]*

- Normal progression through the cell cycle and readiness to initiate reproduction are constantly evaluated at check points throughout the cell cycle; abnormal or damaged cells are targeted for repair or for intentional destruction (apoptosis). Malfunctions in the check point feedback system may allow defective cells to continue cycling and the number of abnormal or damaged cells to proliferate, resulting in cancer.

Objective LS.2.4
Cell Differentiation

LIFE SCIENCE

Students understand that in multicellular organisms, the single cell (zygote) ultimately divides and differentiates into specialized cells that form the various tissues and organs of the organism.

*[**BOUNDARY:** The purpose of this objective is to emphasize DNA's role in the process of cell differentiation. It is not intended to focus on the memorization of the stages of differentiation, the timing of a certain stage, or specific mechanisms of DNA activation or inactivation. The specifics of the process of differentiation are also not appropriate for students in grades 6–8.]*

Suggested Connections

Within Life Science: Cell Function (LS.2.1); Cell Structure (LS.2.2); Cell Growth and Repair (LS.2.3); Changing Model of Inheritance (LS.5.1); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: DNA to Trait (LS.5.3); Nongenetic Information Transmission (LS.5.5)]

Prepares students for the following AP Enduring Understandings: AP Biology 2A, 2E, 3A, 3B, 3D, 4A

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.4.1 Observe and document the development of an organism (e.g., sea urchin). Construct a representation, using appropriate time scale, of the sequence of general stages of cell differentiation that begins immediately after fertilization and ends with the development of a simple multicellular organism. Representation includes major milestones of cell differentiation and growth.

*[**BOUNDARY:** Students do not need to know terms (e.g., cleavage, blastula, gastrula) that identify specific stages.]*

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- A single cell can develop into an entire organism with many types of cells.
- In multicellular organisms, the original cell (zygote) produced during fertilization goes through a series of cell divisions, leading to the formation of a cluster of cells. The cells in these cell clusters eventually differentiate into specialized cells that become the organism's tissues and organs.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.4.1 Construct a representation to demonstrate how gene activation and gene inactivation lead to cell differentiation. Representation includes the transmission of genetic information from DNA to protein to cell traits.

LSH-PE.2.4.2 Give examples, using information gathered from print and electronic resources, of situations in which errors that occur during gene activation or gene inactivation lead to errors in cell differentiation.

LSH-PE.2.4.3 Gather, from print and electronic resources, data that can be used as evidence to support or refute the claim that some kinds of stem cells have a greater potential than other kinds of stem cells to develop into a variety of different tissue types. Include comparisons between embryonic stem cells and adult or body stem cells, and comparisons among different types of adult stem cells.

LSH-PE.2.4.4 Identify current applications of plant and animal stem cells, and describe problems surrounding the use of these cells.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- During the successive division of an embryo's cells, activation or inactivation of different genes in these cells causes the cells to develop in different ways.

- The stem cells of plants and animals divide through mitosis. After the cells divide, at least one of the daughter cells remains undifferentiated. At specific times, some daughter cells will differentiate to become a specific type of cell with a specialized function, while others will continue as nonspecialized cells. There are stem cells at all stages of development (e.g., in embryos as well as in adults). Adult stem cells continue to divide, generating both a differentiated daughter cell of a specific tissue type and an undifferentiated daughter cell.

Standard LS.3
Interdependent Relationships

Interdependent relationships characterize biological ecosystems.

Students understand that biological systems are not isolated entities. The systems interact with other living and nonliving systems in interdependent relationships. Using a systems approach for ecosystems allows students to study the boundaries of an ecosystem, the components of an ecosystem, and the interactions between the living and nonliving components of an ecosystem. Data collected about the inputs and outputs of, and interactions within, an ecosystem are used to create models of the dynamic processes in an ecosystem that can be used to make **predictions** and evaluate the health or stability of an ecosystem. A stable system has various mechanisms that maintain a state of relative constancy in the system as these dynamic processes occur, but the interactions of living systems with each other and with nonliving components can also result in permanent changes to an ecosystem, both over long periods of time (e.g., evolution) and short periods of time (e.g., climate change, invasive species).

Objective LS.3.1
Living Systems and the Physical Environment

Students understand that in all ecosystems, living organisms interact with and depend on the physical (abiotic) conditions of their environment for survival.

Suggested Connections
Within Life Science: Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); [Grades 9–12 only: Nongenetic Information Transmission (LS.5.5)]

Between Life Science and Other Disciplines: Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Climate (ES.2.4); Relative and Absolute Dating (ES.3.1); Humans and Natural Resources (ES.5.1); Humans and the Environment (ES.5.3)

<u>Note</u>: For Objective LS.3.1, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.3.1.1 Give examples of physical (abiotic) conditions (e.g., light, temperature, water, soil type, sites for shelter and reproduction) that affect a specific organism's survival, and describe how the physical (abiotic) conditions affect the organism's survival.

LSM-PE.3.1.2 Give examples of instances when specific organisms impact their local environment, and describe how other organisms are affected by the environmental change.

LSM-PE.3.1.3 Give examples of physical (abiotic) conditions that affect the survival of specific kinds or groups of organisms (e.g., fish that live in salt water versus those that live in fresh water; algae that can survive only within a certain range of light; fungi and plants that require a certain amount of water to survive). Use these examples to make and justify a claim about the effect of physical (abiotic) conditions on a specific organism's survival.

LSM-PE.3.1.4 Use data as evidence to make and justify a claim concerning whether or not a population of organisms is affected by varying environmental conditions in an ecosystem. Data show information regarding the number of organisms of each species in an ecosystem under varying environmental conditions (e.g., what happens to the number of a particular species — including organisms that can survive significant changes and those that cannot — when temperature, soil, moisture or sunlight varies over time). Using these data, predict the survival of a particular species in a specific ecosystem when certain changes occur to the physical (abiotic) environment.

LSM-PE.3.1.5 Make a general claim about the relationship between organisms' traits and their chances of survival. Justification for the claim is based on data from several populations of organisms with varying traits and under a variety of environmental conditions.

*[**BOUNDARY:** The traits presented in the data table should be appropriate for students in grades 6–8 in that the students are able to identify the connection between each trait and the environmental factors.]*

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.3.1.6 Investigate the relationship(s) between a population of organisms and the physical (abiotic) factors of an environment.

*[**BOUNDARY:** The preferred method of conducting an investigation for this concept is participation in a field experience; however, a lab-based experience is appropriate when investigating certain organisms (e.g., algae, duckweed, fruit flies, insects, fungi, bacteria). The physical (abiotic) factors used in the lab can be those that are introduced into the environment as a result of human activity. Any investigation conducted should not purposely intend to harm or kill the organisms.]*

LSM-PE.3.1.6a Formulate a scientific question that addresses the relationship between the number of organisms in a population and the physical (abiotic) factors of their environment.

LSM-PE.3.1.6b Plan an investigation of the relationship between the number of organisms in a population and a single variable of their environment. Investigation could include random sampling (e.g., measurements at different times or locations) of the population size within the ecosystem and, when possible, controlling other relevant variables (e.g., time of day, time of year).

LSM-PE.3.1.6c Gather and record data on the number of organisms, the environmental variable that is being investigated and other variables that could impact the conclusion about the relationship between environmental factors and population size.

LSM-PE.3.1.6d Organize the data (e.g., using a data table) in order to demonstrate the relationship, if any, between environmental factors and population size.

LSM-PE.3.1.6e Calculate the mean size of the population at different locations in the ecosystem or at different times, and rate of change of population size. Make a claim about the relationship between population size and each environmental factor investigated.

LSM-PE.3.1.7 Construct representations, using data and information gathered from print and electronic resources, of the different physical (abiotic) conditions that exist on Earth and the diverse environments (biomes) that arise from these varying physical (abiotic) conditions. Collect and organize data on the number and types of organisms (plant and animal) that exist in these diverse environments, and find patterns between the number and types of organisms based on physical (abiotic) conditions.

LSM-PE.3.1.8 Analyze the characteristics of different species (both plant and animal) within the same environment. Based on this analysis, identify the characteristics that allow them to successfully survive in that environment.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- An organism's survival depends on physical (abiotic) factors such as light, temperature, water, soil and the availability of sites for shelter and reproduction.
- Organisms have traits that enable them to be more successful in some physical (abiotic) environments than in others. Changes in environmental conditions result in changes to the number and types of organisms that survive in these environments.
- The variety of physical (abiotic) conditions that exists on Earth gives rise to diverse environments (e.g., deserts, rain forests, coral reefs, swamps) and allows for the existence of a wide variety of organisms (biodiversity).
- Organisms impact their local environment as they interact with other organisms and with their physical (abiotic) environment (e.g., building shelter, depositing waste, foraging, and using water and dissolved oxygen).

Objective LS.3.2
Interactions of Living Systems

Students understand that organisms in all ecosystems interact with and depend on each other, and that organisms with similar needs compete for limited resources.

> **Suggested Connections**
> *Within Life Science:* Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2)
>
> *Between Life Science and Other Disciplines:* Humans and Natural Resources (ES.5.1); Humans and the Environment (ES.5.3)

<u>Note</u>: For Objective LS.3.2, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.3.2.1 Give examples and distinguishing features of different ecosystems.

LSM-PE.3.2.2 Give examples of organisms that depend on other particular organisms for food, shelter or reproduction, and describe these interdependent relationships.

LSM-PE.3.2.3 Give examples, based on empirical observations, of competition between specific organisms in an ecosystem, including competition for food, shelter and nesting sites (e.g., plants may compete for light, water or nutrients; animals may compete for food or shelter). Examples include competition within a species, as well as competition among different species**.** Make and justify a claim, using knowledge of the behaviors and characteristics of specific organisms, concerning whether the organisms in the examples are in fact competing, and identify the resource that is the basis of the potential competition.

LSM-PE.3.2.4 Construct a food web diagram, based on observations of or information on feeding relationships among specific organisms, to describe the feeding relationships among organisms. Identify assumptions made about the feeding relationships, and identify ways in which the food web diagram differs from the actual ecosystem interrelationships.

LSM-PE.3.2.5 Analyze data (e.g., construct a graph or calculate rate of change) that show changes — increases or decreases — in the number of organisms within a population in an ecosystem relative to particular resource information. Explain, in terms of resources that may or may not be available to the organisms and potential limits to these resources, the pattern and rates of growth of the population. Make and justify a claim, based on these data, concerning whether or not a population of organisms in a given area can grow to be infinitely large.

LSM-PE.3.2.6 Predict, based on a food web representation, the effects that a change — increase or decrease — in the number of organisms of one species will have on the numbers of organisms of other species within the ecosystem. Prediction includes effects involving two organisms that are in a direct feeding relationship with each other, and effects involving two organisms whose relationship is mediated by one or more organisms.

LSM-PE.3.2.7 Give examples, using information gathered from print and electronic resources, of invasive species in a particular environment. Explain, using information about the needs and behaviors of the invasive species, why invasive species are often able to increase rapidly and why the numbers of other organisms either increase or decrease when invasive species enter an ecosystem.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The network of organisms, the relationships among these organisms, and the nonliving environment in which these organisms live is called an ecosystem.
- The relationships (e.g., mutualism, commensalism, parasitism, predator–prey, herbivore–autotroph) within an ecosystem vary. Some organisms depend so much on a particular organism for food and shelter that they cannot survive without this other organism.
- There are limits to the number and types of organisms and populations an ecosystem can support (carrying capacity), depending in part on how the particular organisms involved interact with each other. These limits are determined by factors such as disease, predation, competition, and availability of biological (biotic) resources and physical (abiotic) factors.[8]
- All organisms interact with each other to obtain food. This type of interdependent relationship among organisms can be represented in a food web diagram.
- All resources are finite. Therefore, if a resource is used up by one organism, it is unavailable to another organism. Competition for these limited resources may occur among members of the same species, or among members of different species. Competition may involve one organism obtaining the resource before another organism can get to it. This may involve direct contact or fighting between the organisms, or it may involve one organism obtaining the resource before another organism can get to it, in which case there is no confrontation between the organisms.

Objective LS.3.3
Ecosystem Stability

Students understand that a complex set of interactions within an ecosystem can maintain the number and types of organisms in an ecosystem that is relatively constant over long periods of time.

Suggested Connections
Within Life Science: Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2)

Between Life Science and Other Disciplines: Climate (ES.2.4); Water Cycle (ES.4.1); Carbon Cycle (ES.4.2); Humans and Natural Resources (ES.5.1); Humans and the Environment (ES.5.3); Conservation of Matter (C.2.3)

Prepares students for the following AP Enduring Understandings: AP Biology 1C, 2A, 2D, 4A, 4B, 4C; AP Environmental Science 2A, 2B, 5A, 5B, 5C, 5E

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.3.3.1 Investigate the biodiversity of two or more ecosystems and/or two or more areas of an ecosystem.

LSM-PE.3.3.1a Make observations and gather data on the number of different kinds of organisms and the total number of organisms in the different ecosystems or in the areas of the ecosystem.

LSM-PE.3.3.1b Re-express and organize data in a graph that represents the number and kinds of species.

8. WestEd and the Council of Chief State School Officers, *Science Assessment and Item Specifications for the 2009 National Assessment of Educational Progress (Prepublication Edition)* (Washington, D.C.: National Assessment Governing Board), 58.

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.3.3.1c Calculate measures of central tendencies (i.e., mean, mode), spread of data (i.e., range) and sampling error for the number of different kinds of organisms and the total number of organisms in the different ecosystems or in the areas of the ecosystem. Analyze data, and make a claim, based on the data collected, as to which area of the ecosystem is more biodiverse.

LSM-PE.3.3.2 Predict and justify, based on knowledge of interaction between organisms and their physical (abiotic) environment, what might happen to the number of organisms of a given species in an ecosystem following a temporary biological (biotic) or physical (abiotic) change in that ecosystem (e.g., a very cold winter or a disease that kills large numbers of one of the species in the ecosystem).

LSM-PE.3.3.3 Give examples, using information gathered from print and electronic resources, of human-induced disruptions to an ecosystem that can affect the composition of that ecosystem. Explain, using evidence of the relationships among different organisms and using knowledge of the interaction of organisms with the physical (abiotic) environment, why one disruption can impact the composition of the ecosystem.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Ecosystems are dynamic in nature; the number and types of species fluctuate over time. Disruptions, deliberate or inadvertent, to the physical (abiotic) or biological (biotic) components of an ecosystem impact the composition of an ecosystem.
- Biodiversity is often used as a measure of the health of an ecosystem.

LIFE SCIENCE

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.3.3.1 Describe the abiotic characteristics of an ecosystem: its boundaries, its components, its inputs and outputs, and its interactions, as well as the boundaries and other characteristics of overlapping ecosystems.

LSH-PE.3.3.2 Analyze data (e.g., mean, mode, spread of data, sampling error) that show the number of different species and the number of organisms within a species in two or more ecosystems over time (one of the ecosystems has more fluctuations than the other). Make a claim about the relative stability of each ecosystem. Devise a measure of relative stability, taking into account whether the stability is simply a lack of fluctuation of organism numbers, or if the stability should be measured based on a regular recurrence of a cyclical pattern of variation in an ecosystem.

*[**BOUNDARY:** There is no standard measure of relative stability for biodiversity. The measure of relative stability is generated by the student to give him or her an appreciation of the complexity of the factors involved.]*

LSH-PE.3.3.3 Gather information — and, when appropriate, numerical data — from print and electronic resources about the stability of various ecosystems, in terms of changes in the biotic and abiotic components of those ecosystems over time. Make a claim, based on this information and/or data, about whether the ecosystem is stable or unstable, and describe which conditions/factors indicate stability or instability.

LSH-PE.3.3.4 Analyze data that depict changes in the abiotic components of an ecosystem and changes in the biotic components of an ecosystem over time (e.g., percent change, average change, correlation and proportionality). Evaluate claims of possible relationships between the changes in the abiotic components and the biotic components of the environment.

LSH-PE.3.3.5 Predict what will happen to the number of organisms of a given species in an ecosystem following a temporary biotic or abiotic change in that ecosystem (e.g., a very cold winter or a disease that kills large numbers of one of the species in the ecosystem) and what will happen after conditions return to what they were before the disruption. Justification for the prediction is based on knowledge of how ecosystems typically respond to temporary changes in environmental conditions, how this particular ecosystem has responded to such changes in the past, and the scale of these particular changes.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The number of organisms in ecosystems fluctuates over time as a result of mechanisms such as migration, birth and death. These fluctuations are essential for ecosystem stability and characterize the dynamic nature of ecosystems. Extreme fluctuations in the size of populations offset the stability of ecosystems in terms of habitat and resource availability.

- Ecosystems can be reasonably stable over hundreds or thousands of years.[9] If a disturbance to the biotic or abiotic components of an ecosystem occurs, the affected ecosystem may return to a system similar to the original one, or it may take a new direction and become a very different type of ecosystem.

- Ecosystems are not always stable over short periods of time. Changes in climate, migration by an invading species into an ecosystem, and human activity can impact the stability of an ecosystem.

9. American Association for the Advancement of Science, *Benchmarks for Science Literacy*, 117.

Standard LS.4
Matter and Energy

Biological systems utilize energy and molecular building blocks to carry out life's essential functions.

Students recognize that the interactions between organisms and their environment are dynamic in nature. The processes that define "being alive" involve chemical reactions that require the input of energy and that result in the rearrangement of atoms. Energy, which is ultimately derived from the Sun and transformed into chemical energy, is needed to maintain the activity of an organism. The matter that is involved in these dynamic processes is constantly **recycled** between the organisms and their environment.

Objective LS.4.1
Matter Cycling

Students understand that matter is continuously recycled within the biological system and between the biological (biotic) and physical (abiotic) components of an ecosystem.

*[**BOUNDARY:** At the 6–8 grade band, matter is treated as being made of atoms and molecules. Chemical reactions are presented as the rearrangement of atoms in molecules. Chemical reactions in terms of subatomic structures of atoms are not appropriate.]*

Suggested Connections

Within Life Science: Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3)

Between Life Science and Other Disciplines: Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Water Cycle (ES.4.1); Carbon Cycle (ES.4.2); Humans and the Environment (ES.5.3); Properties of Matter (PS.2.1); Particulate Nature of Matter (PS.2.3); Conservation of Matter (PS.3.1); Physical and Chemical Changes of Matter (PS.3.2); Electric Circuit Interactions (PS.4.2)

LIFE SCIENCE

Note: For Objective LS.4.1, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.4.1.1 Create a representation to describe the cycling of a carbon atom from the physical (abiotic) environment through the molecules of the biological (biotic) components of an ecosystem back to the physical (abiotic) environment.

*[**BOUNDARY:** The chemical structure of any of the molecules is not appropriate.]*

LSM-PE.4.1.2 Make and justify a claim concerning whether a particular molecule of oxygen inhaled today could be made of the same atoms of oxygen inhaled by someone a hundred years ago. Make and justify a claim concerning whether a particular molecule of water consumed today could be made of the same atoms of hydrogen and oxygen consumed by someone a hundred years ago.

LSM-PE.4.1.3 Predict and justify what might happen to an ecosystem if there were no bacteria or fungi present. Prediction and justification are based on ideas about matter recycling between the biological (biotic) and physical (abiotic) parts of an ecosystem.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Matter is transferred among organisms in an ecosystem when organisms eat, or when they are eaten by others for food. Molecules from food react with oxygen to provide energy that is needed to carry out essential life functions, become incorporated into the body structures of organisms, or are stored for later use. Although matter is transformed in these processes as the atoms of molecules are rearranged, the matter is neither created nor destroyed.

- Matter moves within individual organisms through a series of chemical reactions in which molecules are rearranged to form new molecules. These chemical reactions enable organisms to carry out essential life processes and to build body structures.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- All the molecules that make up the food in an ecosystem once existed as other molecules in the physical (abiotic) environment and were transformed and incorporated into the biological (biotic) components of the ecosystem primarily via photosynthesis. Organisms that "produce" this food from molecules in the physical (abiotic) environment (through the process of photosynthesis) are called producers.
- Plants and other photosynthetic organisms take in other essential molecules (**minerals**) from their environment (e.g., soil or water). Although these substances are essential for plants and other photosynthetic organisms to incorporate into food, they are not a source of energy.
- During photosynthesis, carbon dioxide and water from the physical (abiotic) environment change (react) chemically to produce sugar molecules in plants and other photosynthetic organisms. The sugar molecules are used immediately by the organisms as an energy resource for life processes such as growth and reproduction, are incorporated into body structures, or are stored for later use.
- Matter is transferred from organisms to the physical (abiotic) environment when molecules from food react with oxygen to produce carbon dioxide and water in a process called cellular respiration. Cellular respiration takes place in most species.
- Matter is also transferred from the biological (biotic) environment to the physical (abiotic) environment by bacteria or fungi (decomposers). Decomposers consume the remains of organisms as food and break down the molecules into simpler molecules that can no longer be used as food. These simpler molecules are the source of essential molecules that plants and photosynthetic organisms absorb from the soil, and the source of molecules that are incorporated into food during photosynthesis.

Objective LS.4.2
Energy Transfer

Students understand that all of the processes that take place within organisms require energy. In most ecosystems, the energy is derived from the Sun and transferred into chemical energy in photosynthetic organisms of that ecosystem.

*[**BOUNDARY:** At the 6–8 grade band, energy transfer, conversion or transformation should be based on the concept of energy conservation. The total energy in any process can be transferred from one object to another across the system boundary and/or transformed within a system from one form to another, but it never disappears. Incorporating system language and boundaries when focusing on ecosystems and organisms is important for accurately understanding energy transfer and transformation.]*

Suggested Connections

Within Life Science: Cell Function (LS.2.1); Cell Structure (LS.2.2); Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3); Matter Cycling (LS.4.1)

Between Life Science and Other Disciplines: Planetary Evolution (ES.2.5); Carbon Cycle (ES.4.2); Humans and the Environment (ES.5.3); Physical and Chemical Changes of Matter (PS.3.2); Conservation of Energy (PS.4.4); Thermal Energy (PS.4.5); Periodic Table (C.2.1); Chemical Equilibrium (C.2.4); Chemical Kinetics (C.2.5); Conservation of Energy (C.3.1); Energy Transfers and Transformations (C.3.2); Chemical Energy (C.3.3); Contact Interactions and Energy (P.3.1)

Prepares students for the following AP Enduring Understandings: AP Biology 2A, 2D, 4A, 4B; AP Environmental Science 1A, 1C, 2B, 3A, 3B, 3C, 5E

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.4.2.1 Give examples and classify organisms as producers, consumers or decomposers based on their source of energy for growth and development.

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.4.2.2 Describe, using a representation, the transfer of energy through an ecosystem. Representation includes the Sun, producers, consumers, decomposers and the transformation of chemical energy to thermal energy at each trophic level of an ecosystem.

LSM-PE.4.2.3 Predict which trophic level, or levels, in any given ecosystem will have the greatest number of organisms, and which will have the least. Justifications are based on ideas about energy transfers in ecosystems.

LSM-PE.4.2.4 Investigate the relationship between energy from the Sun and plant growth and health.

LSM-PE.4.2.4a Formulate a scientific question about the relationship between energy from the Sun and plant growth and health (e.g., number of leaves, number of flowers, color of leaves).

LSM-PE.4.2.4b Gather and record data, using tools to improve **accuracy** and **precision** of measurements, and complete multiple trials or use class data, for plants grown in varying conditions (e.g., light intensity, duration).

LSM-PE.4.2.4c Construct graphs and/or tables of data for plants grown in the different variable conditions.

LSM-PE.4.2.4d Calculate average change, rate of change, spread of data (i.e., range) and measurement error in order to analyze data, and describe the data in terms of the accuracy and precision of the data.

LSM-PE.4.2.4e Make a claim about the relationship between plant growth and health and energy from the Sun. Justification is based on collected evidence and on the understanding of photosynthesis and the cycling of matter.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Light energy is an essential source of energy for most ecosystems. Some organisms utilize the energy transferred from the Sun to convert carbon dioxide and water into molecules in which carbon atoms are linked together (sugar) and oxygen is released. This process is called photosynthesis.

  *[**BOUNDARY:** Students are not expected to know that chemosynthesis is a process in which the energy needed for the synthesis of sugar molecules from carbon dioxide and water in an ecosystem comes from another chemical reaction, not from the Sun.]*

- All organisms require energy to live, and the energy that organisms need to perform essential life functions is chemical energy that is stored in a system of reacting molecules. Molecules from food, in which carbon atoms are linked to other carbon atoms and to hydrogen atoms, are the source of chemical energy for organisms as they react chemically with oxygen.

- Chemical energy is transferred from one organism in an ecosystem to another as the organisms interact with each other for food. Because an organism's entire body is not used as food by organisms at the next trophic level, and because much of the chemical energy is transferred to the environment as thermal energy (heat), only a fraction of the energy at any given trophic level is used for growth, reproduction and other body functions of organisms at the next trophic level.

- Photosynthetic organisms (producers) at the lowest trophic level transform energy from the Sun to chemical energy. At the next trophic level, the chemical energy in producers is transferred to organisms (consumers) that eat the producers. Consumers that use other consumers for food make up the next trophic level. Other organisms (decomposers) consume the remains of both producers and consumers as food. Decomposers transfer any remaining chemical energy to molecules that can no longer be used as food.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.4.2.1 Construct a graphical representation of the number of sugar molecules that are broken down into carbon dioxide and the amount of ATP (adenosine triphosphate) that is produced during fermentation (when oxygen is limited) and during cellular respiration (when oxygen is available). Explain, using the representation, common exercise phenomena (e.g., lactic acid buildup, changes in breathing during and after exercise, cool down after exercise).

LSH-PE.4.2.2 Investigate variables that affect the processes of fermentation and/or cellular respiration in living organisms.

*[**BOUNDARY:** The context of this investigation is purposely open so that experiences that best fit students' interest and level of understanding can be selected.]*

LSH-PE.4.2.2a Formulate a scientific question about the relationship between variables (e.g., type of food, temperature, process input, process output) that impact fermentation and/or cellular respiration.

LSH-PE.4.2.2b Gather and record data (e.g., color indicator change, pulse rate, amount and type of product or reactant), using tools to improve accuracy and precision of measurements, and complete multiple trials or use class data.

LSH-PE.4.2.2c Construct graphs and tables of data for changes in the different variable conditions.

LSH-PE.4.2.2d Calculate changes in rate, percent change, averages and measurement error in order to analyze data and discover patterns. Evaluate the data as it relates to the formulated scientific question.

LSH-PE.4.2.2e Coordinate the results of different investigations that have analyzed different variables that impact either fermentation or cellular respiration. Construct a representation of all of the evidence collected from the various studies.

LSH-PE.4.2.2f Make a claim, based on evidence collected from all investigations, about real-world phenomena (e.g., ethanol production, wine or bread making, exercise).

LSH-PE.4.2.3 Give examples of functions (e.g., removal of wastes, muscular activity, cell division) that are carried out by organisms and that involve the conversion of ATP to ADP (adenosine diphosphate) and an inorganic phosphate.

LSH-PE.4.2.4 Give examples of chemical reactions (e.g., synthesis of glycogen, oxidation of glucose) involved in basic functions of organisms in which the reactants and products of the reaction are paired with reactions involving ATP and ADP and an inorganic phosphate. Construct an illustration, in terms of reactants and products, of the chemical reactions of basic functions and ATP and ADP with an inorganic phosphate.

*[**BOUNDARY:** The molecular structure of molecules is not appropriate for this PE.]*

LSH-PE.4.2.5 Construct a representation of the transfer of energy through an ecosystem, starting with the Sun and ending with increased motion of molecules in the environment. Representation should reflect the idea that energy is conserved. Explain, based on the transformation of chemical energy to thermal energy at various trophic levels and on the nature of reactions, the need for constant input of energy into an ecosystem.

LSH-PE.4.2.6 Construct a representation that links the movement of matter (i.e., carbon atom, water molecule) and the transfer of energy through the processes of photosynthesis and cellular respiration. Predict and justify, based on knowledge of energy transfer and matter cycling, what might happen to the mass of a biosystem if the source of energy were limited.

LSH-PE.4.2.7 Construct a model of a food chain that includes a quantification of the distribution and buildup of a potentially damaging chemical that is introduced into an ecosystem. Predict, using the model, consequences at each trophic level as the relative concentration of the chemical increases. Justification includes changes in the number of organisms at each trophic level, matter cycling, and energy transfer from one level to another.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Life processes involve a complex sequence of chemical reactions in which chemical energy is transferred from one system of interacting molecules to another. Some of the energy in these reactions is transferred to the environment as thermal energy (heat).

- All living systems require an input of energy to drive the reactions in essential life functions and to compensate for the inefficient transfer of energy. The chemical reactions in living systems involve the transfer of thermal energy (heat) to the environment. The thermal energy is no longer available to drive chemical reactions; therefore, a continuous source of energy is needed. In many organisms, the energy that keeps the chemical reactions in organisms going comes from food that reacts with oxygen. The energy stored in that food ultimately comes from the Sun.

  *[**BOUNDARY:** Students are not expected to know that chemosynthesis is a process that supplies energy for the synthesis of food in an ecosystem.]*

- The transfer of chemical energy within living systems involves chemical reactions among ATP, ADP and an inorganic phosphate. The conversion of ATP to ADP and an inorganic phosphate drives other essential reactions in living systems.

  *[**BOUNDARY:** Students are not required to know the chemical names or the molecular structures of ATP and ADP.]*

- During cellular respiration, molecules from food — mainly sugars and fats — are converted in the presence of oxygen into carbon dioxide and water, and the chemical energy of that reaction is used to combine ADP and an inorganic phosphate to make ATP.

- During fermentation, molecules from food are partially broken down in cells in the absence of oxygen into smaller molecules (but not completely into carbon dioxide and water). Compared to the chemical reactions that take place during cellular respiration, these reactions result in less ADP being combined with an inorganic phosphate to produce ATP; therefore, less energy is made available during fermentation than during cellular respiration for the chemical reactions that maintain an organism's body functions.

Standard LS.5
Information Transmission, Storage and Retrieval

Living systems have multiple mechanisms that are used to store, retrieve and transmit information.

Students understand that living systems have a variety of ways of communicating information among systems and from one part of a system to another. A special kind of information — that which is transmitted by means of DNA — is transmitted from one generation of organism to another during reproduction. The DNA contains information that determines the structure of various molecules that are responsible for many of the physical (abiotic) and behavioral characteristics of organisms.

Objective LS.5.1
Changing Model of Inheritance

Students describe the historic ideas that led to the identification of DNA as the molecule that contains and transmits genetic information.

*[**BOUNDARY:** The dates and names involved in the historic work are not the focus of this objective. Rather, the historical development of the current understanding of genetic information, as well as the understanding of the transfer of this information, is important.]*

> **Suggested Connections**
> *Within Life Science:* Evidence of Common Ancestry and Divergence (LS.1.1); Cell Function (LS.2.1); Cell Growth and Repair (LS.2.3); Cell Differentiation (LS.2.4)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1D, 3A

Note: For Objective LS.5.1, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.5.1.1 Describe the problem or scientific question that various scientists investigated and the scientists' contributions to the development of the model of inheritance toward modern genetics.

*[**BOUNDARY:** It is suggested that students study Mendel, Watson and Crick, and Franklin; students can, but do not have to, study Sutton and Bateson.]*

LSM-PE.5.1.2 Observe patterns (similar to those observed by Mendel), using data from parent–generation crosses, in traits of parents and offspring.

LSM-PE.5.1.3 Give examples of various scientists whose ideas built upon and/or revised Mendel's model of inheritance.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Gregor Mendel demonstrated that the inheritance of physical traits in pea plants follows simple mathematical laws.
- The behavior of chromosomes during the division process of sexual reproduction (meiosis) established a physical basis for Mendel's mathematical laws of heredity.
- It was not until the middle of the 20th century that genes were shown to be segments of DNA. The Watson–Crick double-helix model of DNA structure explained how genes are passed on from one generation to the next.

Objective LS.5.2
Genetic Information Transmission

Students understand that during reproduction, genetic information (DNA) is transmitted between parent and offspring. In asexual reproduction the lone parent contributes DNA to the offspring, and in sexual reproduction both parents contribute DNA to the offspring.

*[**BOUNDARY:** There is an assumption that the mechanisms involved in the transmission of genetic information from DNA to protein to trait are a "black box" for students in grades 6–8. The focus should be that there is a link between DNA and traits without being explicit about the mechanisms involved. Students are not expected to know any of the ways in which bacteria reproduce.]*

> **Suggested Connections**
> *Within Life Science:* Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Cell Function (LS.2.1); Cell Growth and Repair (LS.2.3); Cell Differentiation (LS.2.4); [Grades 9–12 only: Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1D, 2E, 3A, 3B, 3C, 4A, 4B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.5.2.1 Evaluate consistency and accuracy of representations illustrating the major components of the Watson–Crick double-helix model of DNA.

LSM-PE.5.2.2 Construct a representation of DNA replication, showing how the helical DNA molecule unzips and how nucleotide bases pair with the DNA template to form a duplicate of the DNA molecule.

LSM-PE.5.2.3 Construct a representation that shows what happens to the chromosomes of the parent organisms during both the process of fertilization and the first stages of cell division of a zygote.

LSM-PE.5.2.4 Explain and justify, using representations, why the DNA of the daughter cells of asexually reproducing organisms are identical to the DNA of parent cells. Explanation and justification are based on knowledge of the mechanisms (e.g., asexual reproduction, DNA replication) of DNA transmission from generation to generation in asexually reproducing organisms.

LSM-PE.5.2.5 Explain and justify why the DNA of the offspring of sexually reproducing organisms are not identical to the DNA of either parent organism. Explanation and justification are based on knowledge of the mechanisms (e.g., fertilization, cell division) of DNA transfer between generations in sexually reproducing organisms.

LIFE SCIENCE

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- DNA is a long, double-stranded, helical molecule that is the primary source of genetic information. Genetic information is contained within the sequence of nucleotide bases (A, C, T and G are the symbols used to represent these bases) that make up a DNA molecule.
- DNA is the source of genetic information that determines an organism's traits.
- Prior to reproduction, each individual DNA molecule makes a copy of itself. This process ensures that the genetic information is copied into each new organism.
- DNA molecules are packaged and organized as chromosomes within cells. There is a single chromosome in some organisms; there is more than one chromosome in other organisms. Every chromosome has a single molecule of DNA.
- In some organisms, all of the DNA molecules come from a single parent (asexual reproduction).[10] These organisms go through a division process (mitosis) that ensures the direct transfer of the genetic information (DNA) from one generation to another.

10. American Association for the Advancement of Science, *Benchmarks for Science Literacy*, 108.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- Sexual reproduction occurs when two different sex cells combine in a process called fertilization. Since each sex cell contains only half of the normal amount of cellular DNA present in body cells, the single cell (zygote) produced will now have a complete complement of genetic information containing two sets of DNA, one set from each sex cell.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.2.1 Estimate and justify how many variations are possible in the set of chromosomes (DNA molecules) that the sex cells of a particular organism (e.g., mosquito, fruit fly or other organism with a low number of chromosomes) receive during sex cell formation. Construct a model that includes a label for each chromosome and that illustrates some of the possible combinations of chromosomes that will be present in the sex cells that are produced.

LSH-PE.5.2.2 Explain, based on knowledge of how sex cells form in sexually reproducing organisms, why there is variation among offspring, even within the same family.

LSH-PE.5.2.3 Observe the variation of traits among the individual organisms within a population. Explain, based on the transmission of genetic information, why there is so much variation within the population.

LSH-PE.5.2.4 Construct a representation — or several representations — of sex cell formation, demonstrating that the DNA of the daughter cells is different from the DNA of the parent cell. Representation includes the process of replication, the separation of homologous chromosomes (first stage of meiosis), and the separation of the replicated chromosomes to create cells with just a single version of each chromosome (second stage of meiosis).

LSH-PE.5.2.5 Construct a model of a particular gene on a pair of DNA molecules. Construct a new model that incorporates the DNA molecule model into a model of homologous chromosomes in a cell nucleus.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Sex cells are formed by a process of division (meiosis) in which the number of chromosomes, and thus the amount of DNA, per cell is halved after replication.

- With the exception of sex chromosomes, for each DNA molecule (chromosome) in the body cells of a multicellular organism, there is a similar, but not identical, chromosome (homologous pair). Although these pairs of similar chromosomes can carry the same genes, they may have slightly different versions of the genes (alleles). During the formation of sex cells (meiosis), one chromosome from each pair is randomly passed on (independent assortment) to form sex cells, resulting in a multitude of possible genetic combinations.

- The cell produced during fertilization has one "set" of DNA molecules from each parent. The cell (zygote) then divides asexually as the organism grows and develops so that the body cells of the organism have two "sets" of DNA molecules.

Objective LS.5.3
DNA to Trait

Students understand that genetic information (DNA) is used to produce proteins that largely determine the traits of an organism. These traits often result from the interactions and expression of many genes.

> **Suggested Connections**
> *Within Life Science:* Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Cell Structure (LS.2.2); Cell Differentiation (LS.2.4)
>
> *Between Life Science and Other Disciplines:* Bonding (C.1.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 3A, 3B, 3C, 4A, 4B, 4C

Note: For Objective LS.5.3, there are no performance expectations or essential knowledge statements for grades 6–8.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.3.1 Analyze the primary structure (amino acid sequence) of specific proteins (e.g., insulin and hemoglobin). Create a table showing which amino acids make up each protein molecule, and the numbers of each amino acid that make up these proteins.

*[**BOUNDARY:** Emphasis should be placed on the differences among protein composition, NOT on the memorization of amino acid structure, types or sequence.]*

LSH-PE.5.3.2 Evaluate and, if necessary, revise representations that illustrate the processes of transcription and translation to show how the sequence of nucleotide bases produces a complementary strand of bases in RNA (ribonucleic acid), and how each sequence of three bases in RNA codes for specific amino acids that are linked together to make proteins.

*[**BOUNDARY:** Emphasis should be placed on the bigger ideas of form and function and following the transmission of information, not on the details (e.g., components of a ribosome, structure of tRNA, directionality) of the mechanism.]*

LSH-PE.5.3.3 Construct a representation that illustrates the process of the production of the amino acid sequence of a section of a given protein molecule from an organism. Representation should first show the relationship between these amino acids and a sequence of nucleotide bases in RNA, and then show the relationship between that sequence of nucleotide bases in RNA and the sequence of bases in DNA.

LSH-PE.5.3.4 Give examples, using information gathered from print and electronic resources, of traits that result from specific proteins. Include examples of the following types of proteins: structural, regulatory and enzymatic. Examples should span structural, behavioral and physiological traits.

*[**BOUNDARY:** This performance expectation is intended to focus on the fact that proteins in the form of enzymes determine traits, not on the details of the cascade of reactions or the chemical structures involved.]*

LSH-PE.5.3.5 Describe how traits in organisms are the result of DNA structure. Include ideas about the connection between traits and proteins, the connection between protein structure and the sequence of bases in RNA, and the connection between RNA sequence and DNA sequence.

LSH-PE.5.3.6 Give examples, using information gathered from print and electronic resources, of traits that depend on the quantity of protein produced, which, in turn, is dependent on the number of copies of a particular version of a gene. Predict and justify how zero, one or two copies of a particular version of a gene might affect the expression of a particular trait.

*[**BOUNDARY:** Emphasis should not be placed on the mechanisms of gene expression, the cascade of reactions, or any specific details of mechanisms. The amount of protein produced also depends on the type of promoter and the rate of synthesis, but these concepts are not within the scope of the 9–12 grade band.]*

LSH-PE.5.3.7 Identify functions performed by DNA segments that do not code for proteins.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Genes are segments of DNA that are in locatable regions on the DNA molecules that specify protein sequence and, in turn, an organism's traits.
- Not all DNA segments specify proteins; some segments of DNA are involved in regulation or structural functions. Some segments of DNA have no known function.
- The protein information contained in the sequence of nucleotide bases that makes up a strand of DNA is transmitted to a messenger RNA molecule (transcription). The messenger RNA molecule, with the help of other RNA molecules (ribosomal and transfer), then guides the production of a specific amino acid sequence of a particular protein (translation). These messenger RNA molecules degrade into nucleotide bases, which are then recycled into new RNA.

  *[**BOUNDARY:** In order for this statement to be accurate, the following concepts must be understood: Not all DNA is transcribed, and not all RNA is translated. However, this is not essential knowledge for the student.]*
- Proteins are long, folded chains (polymers) composed of 20 different amino acids (monomers). Amino acid sequence determines the shape and function of the protein molecule that is produced.
- Protein molecules are responsible for the observable traits of an organism and for most of the life functions that take place within an organism. The enzymes that catalyze chemical reactions in organisms are proteins.
- Traits (phenotype) can be structural, physiological or behavioral; they can include readily observable features at the organism level as well as less observable features at the cellular and molecular levels.
- Sexually reproducing organisms contain two similar, but not identical, versions of each chromosome (i.e., the chromosomes have some genes [alleles] that are the same on both versions of the chromosome and some that are not). Each trait that results from these different gene combinations depends on the nature and amount of the protein that each gene produces, as well as on the interactions among those proteins.

Objective LS.5.4
Imperfect Transmission of Genetic Information

Students understand that there are various ways in which the transmission of genetic information can be imperfect, and that these imperfections may have positive, negative or no consequences to the organism.

Suggested Connections
Within Life Science: Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Cell Growth and Repair (LS.2.3); Genetic Information Transmission (LS.5.2)

Prepares students for the following AP Enduring Understandings: AP Biology 1A, 1B, 1C, 3A, 3B, 3C, 4B, 4C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.5.4.1 Describe three ways (e.g., insertion, deletion or substitution) that changes in DNA (mutations) can occur during replication.

LSM-PE.5.4.2 Predict and justify, based on the type of cell, whether a particular error in copying DNA during replication will be transmitted to the offspring.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- DNA is transmitted from one generation to the next during both sexual and asexual reproduction. However, mistakes that involve changes in the sequence of nucleotide bases (mutations) may occur during DNA replication or during the division process. These changes can be transmitted to the offspring, depending on the organism and cell type.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.4.1 Explain why an insertion, deletion or substitution of an individual nucleotide base affects not only the amino acid sequence of the proteins that are produced but also the protein structure that results from the altered amino acid sequence.

LSH-PE.5.4.2 Explain, using information on a particular error in copying DNA during replication for a specific trait (e.g., insertion, deletion or substitution), why there could be an alteration in that trait. Justification is based on knowledge of the relationship among DNA, proteins and traits.

LSH-PE.5.4.3 Give examples, using evidence gathered from print and electronic resources, of genetic diseases (e.g., cystic fibrosis, sickle-cell anemia, Tay-Sachs disease or phenylketonuria) that result from mutations to a single gene. Identify, for each example, the specific type of mutation that causes the change in amino acid sequence and ultimately the change in the protein that is produced.

LSH-PE.5.4.4 Give examples, using evidence gathered from print and electronic resources, of instances when viruses are linked to cancer. Explain, based on knowledge of viral gene insertions and of the relationship among DNA, proteins and traits, how a viral insertion into DNA can cause cancer.

LSH-PE.5.4.5 Give examples, using evidence gathered from print and electronic resources, of the potential of using viruses for curing genetic diseases via gene therapy. Make a claim about, and justify, based on knowledge of viral DNA and viral insertions, why some viruses are appropriate for this application.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Mutations involve changes to an organism's DNA and may be caused by internal factors (i.e., errors that occur during DNA replication or the division process) or by external factors (i.e., radiation or chemicals). Mutations may occur at the individual gene level or at the chromosomal level, but all mutations involve changes to DNA.
- Mutations may cause no change in an organism's traits (phenotype), cause a detrimental change or cause a beneficial change.
- Mutations that alter the sequence of DNA may lead to a change in the protein produced. Changes to any of the proteins responsible for traits may result in an alternative trait (phenotype).
- Not everything that carries genetic information is a cell. A virus, which is not a cell, contains either DNA or RNA as its genetic information. To reproduce, a virus uses its own DNA or RNA but also uses the cellular machinery of the host cell. Often, the viral genes are incorporated into the host DNA or RNA, disrupting the DNA sequence within the host cell.

Objective LS.5.5
Nongenetic Information Transmission

Students understand that nongenetic transmission of information within and among organisms involves specialized molecules, cell structures and cell systems.

*[**BOUNDARY:** Only very basic models (e.g., single receptor and single transmitter) and a very basic distinction between direct communication and distance communication via molecules are necessary. Focus should be on the basic input/output regulation of a system; model of communication or feedback should be very simple (e.g., few steps and a small number of molecules involved in the mechanism).]*

> **Suggested Connections**
> *Within Life Science:* Cell Function (LS.2.1); Cell Structure (LS.2.2); [Grades 9–12 only: Cell Growth and Repair (LS.2.3); Cell Differentiation (LS.2.4); DNA to Trait (LS.5.3)]
>
> *Between Life Science and Other Disciplines:* Structure–Property Relationships (C.2.2); Chemical Kinetics (C.2.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 2B, 2C, 3B, 3D, 3E, 4A, 4B

Note: For Objective LS.5.5, there are no performance expectations or essential knowledge statements for grades 6–8.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.5.1 Construct a model that represents the molecular communication that takes place between cells that are in direct cell-to-cell contact, and a model that represents the molecular communication among cells in which molecules are released from one cell and target other cells in the vicinity of the emitting cell (e.g., neurotransmitters, local hormones, growth factors).

LSH-PE.5.5.2 Construct a model to describe the communication between distant cells (e.g., hormones, pheromones, chemotaxis) and the process by which molecular communication between distant cells leads to particular outcomes.

LSH-PE.5.5.3 Evaluate and, if necessary, revise representations of how drugs such as alcohol, nicotine, morphine, tetrahydrocannabinol (THC) and methamphetamines affect neurotransmitters and the communication that normally takes place between and/or among cells.

LSH-PE.5.5.4 Construct a simple representation of a feedback mechanism that maintains the internal conditions of a living system within certain limits as the external conditions change. Describe, using the representation, the response of the system to some particular system imbalance (e.g., lack of water causing stomata to contract).

LSH-PE.5.5.5 Construct a representation of the interaction of the endocrine and nervous systems (e.g., hormones and electrochemical impulses) as they interact with other body systems to respond to a change in the environment (e.g., touching a hot stove). Explain how the representation is like and unlike the phenomenon it is representing.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Communication takes place at the molecular level by means of specialized molecules that send and receive information.
- Molecular communication takes place when molecules from one cell interact with molecules from other cells; these interactions often take place with the help of proteins in the cell membrane.
- There are systems (e.g., endocrine and nervous [sensory]) within and between organisms that send, receive and process information over short and long distances by using specialized molecules.
- The output of one system can be the input to another system. Molecules produced in one system can encourage or discourage what is going on in another system.

ESSENTIAL KNOWLEDGE (9–12), ***continued***

- Feedback communication maintains a living system's internal conditions within certain limits (e.g., temperature, molecular concentration, pH), allowing it to remain alive and functional even as external conditions are changing.
- Feedback systems may involve enzymes, membrane proteins and/or gene regulators, and their communication can be affected by environmental conditions.
- Many drugs affect the normal communication among cells by interacting with or altering the proteins in the cell's membranes, or by altering the molecule that is transmitting information.

Unpacking the Performance Expectations: Life Science

Why "unpack" a performance expectation?

- The science practices standards appear to be separate from the discipline-specific standards, but they are intended to be integrated with disciplinary content knowledge.
- Unpacking a performance expectation establishes clear, specific targets of learning.
- Unpacking a performance expectation illustrates that any one performance expectation may involve multiple science practices.
- The unpacking is intended to provide a model for interpreting the science practices for a specific discipline.

How should an unpacked performance expectation be used?

- The sample unpacked performance expectation provided should be used as a model so that teachers can unpack all of the performance expectations within the discipline-specific standards.
- All of the unpacked performance expectations can be used for guidance in developing instructional strategies and curricula that offer opportunities for students to develop a robust understanding of the science practices and disciplinary content knowledge.
- All of the unpacked performance expectations can be used to develop curricula, instruction and assessments that are aligned with each other.
- Unpacking all of the performance expectations within a specific discipline enables teachers and curriculum supervisors to delineate the multiple science practices and content knowledge that are facilitated, and ultimately to link or map the performance expectations to existing curricula or to use the performance expectations as a basis for the establishment of curricular structure.
- All of the unpacked performance expectations allow decisions about instruction and curriculum design to be made in a more principled way.

SAMPLE UNPACKED PERFORMANCE EXPECTATION (6–8)

Construct an analogical model (analogy) of the interaction of the internal components of a cell (e.g., working parts of a city, factory or automobile. Predict and justify, using the model, the impact on the cell or on the organism if one of the components fails to function properly.

> This is **LSM-PE.2.2.2**. The two components should be performed together.

> This is part of science practices **Objective SP.4.2**.

Unpacking the construction of an analogy in the performance expectation:

- Describe the phenomenon to be modeled (i.e., the components of a cell system interact for the greater good of an organism).
- Identify the purpose for constructing the analogy (to make a prediction), and identify the key components of interactions within a cell system that must be present in the representation to meet the purpose of making a prediction about the failure of a cellular component.
- Select an analogy (e.g., cell as a city or factory) that best represents the phenomenon, and articulate how the analogy best fits the phenomenon of cell system interactions as well as the purpose of making a prediction about the failure of a cellular component.
- Ensure that the key components (e.g., appropriate subcellular structures) and processes (e.g., protein synthesis, lysosome waste removal) of the phenomenon are represented in the selected analogy.

> The **essential knowledge from the science practices** informed these interrelated activities associated with constructing an analogy.

Unpacking the prediction in the performance expectation:

This is science practices **Objective SP.1.2**.

- Select from the key components of the phenomenon which one is going to fail.
- Predict the effect on the cell if the cellular component fails, or predict the effect on the organism if the cellular component fails.

Unpacking the justification of the prediction in the performance expectation:

Including a **justification with all predictions** demonstrates students' thought patterns as they make their predictions.

- Connect the failed component to the outcome of the cell or the organism.
- Support the justification by articulating the connection between the terms of the analogy to the actual function of the component of the cell.
- Describe how the key elements of the analogy and the cell are similar.
- Describe how the analogy and the actual function are inaccurate.

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Standards

1. Changes in the natural and designed world are caused by interactions. Interactions of an object with other objects can be described by forces that can cause a change in motion of one or both interacting objects.
2. Matter has mass and volume and can exist as a solid, liquid or gas. All pure substances have their own unique set of physical and chemical properties that can be used to identify them.
3. Matter can be transformed by a change of state or by undergoing chemical reactions, but it can never be created or destroyed.
4. When any change occurs, energy is transferred and/or transformed, but it is never lost.

Physical Science

Physical science is the study of matter and energy, and it is on these two **concepts*** that the four physical science standards focus. Wherever appropriate, the link between chemistry and physics is emphasized, and connections to everyday life are made. These standards reflect current research about student learning by identifying and building on previous knowledge in a cumulative manner and by requiring higher levels of abstract thinking as the transition is made from middle school to high school. The physical science standards are not intended to provide a list of topics that must be covered; rather, they are designed to address and connect the underlying concepts of chemistry and physics that will lead students to a greater understanding of high school science.

Organization and Structure of the Physical Science Standards for College Success

The physical science standards are intended to outline the knowledge, skills and abilities that students need in order to be prepared for success in an introductory college-level chemistry or physics course, or in an Advanced Placement (AP) Chemistry or Physics course. Core ideas, or "big ideas" — identified by the NSF-funded AP committee members as being central to an introductory college-level chemistry or physics course — were the foundation of the creation of the physical science standards.

The physical science standards are organized around core ideas of the discipline. While there are four standards, they are not meant to represent an equal division of material and concepts. These standards aim to promote a broader perspective of usefulness and application of student learning. By combining chemistry and physics at the 6–8 grade band, physical science courses are uniquely suited for making science relevant to students.

Each standard has two to five objectives that provide detailed descriptions of more specific physical science core **principles** of which students should have knowledge. Similar to the enduring understandings that are the target concepts for the AP courses, the objectives are the focus of student mastery for college readiness and the key elements of the conceptual framework of the physical science standards. An objective is often followed by a list of other objectives — within the discipline as well as from other disciplines — that are connected in some way to that objective. Both the standards and the objectives are preceded by key words and/or phrases that help articulate the content in a more concise manner. This is especially useful when a standard or an objective is referenced either by another discipline or during curriculum or instructional planning.

The objectives are, in turn, supported by a set of performance expectations (PEs) and a set of essential knowledge (EK) statements. The PEs describe what students should know, understand and be able to do in order to apply, as well as build and reason with, the essential knowledge that is necessary to understand the content outlined in the objective. The PEs illustrate how students engage in science practices to develop a better understanding of the objective. Students should be able to successfully engage in, *at the very least,* the performance expectations listed for each objective in order to be considered college ready. These performance expectations, along with the essential knowledge statements, can provide guidance in the development of assessments and curriculum materials. The EK statements are an articulation of the conceptual targets for student learning, providing a more detailed description of the broader knowledge delineated in the objective. These statements should be approached from a holistic perspective, and they should not be viewed as a list of discrete, unrelated **facts** for

PHYSICAL SCIENCE

* Boldfaced words and phrases are defined in the glossary.

students to memorize. The EK statements also provide the language and appropriate terminology that should be incorporated into students' completion of the performance expectations.

It should be noted that both the performance expectations and the essential knowledge statements were written based specifically on the objective-level statements. There is not a corresponding relationship between the PEs and the EK statements; the PEs are a representative (but certainly not all inclusive) set of applications of the essential knowledge. Therefore, when interpreting the depth and scope of each PE, the EK statements should be considered.

The number of objectives, as well as the number of performance expectations and essential knowledge statements, varies considerably from standard to standard. It should also be made clear that these objectives, PEs and EK statements are not intended to show a linear progression through the subject. Many of the topics and concepts in physical science rely on more than one objective and on several PEs and EK statements, some of which may come from different standards. In addition, the number of PEs for a given objective does not indicate any level of importance, and it is assumed that some PEs may require a greater amount of instructional time than others.

Foundational Knowledge

Even though these physical science standards are focused on grades 6–8, the College Board recognizes the importance of students' having certain foundational knowledge in physical science upon entering sixth grade. Middle school teachers need to determine whether their students already have this foundational knowledge before they attempt to address the ideas described in the standards document, and they should adjust their instruction in terms of what students already know and what students do not know. Some of the foundational knowledge that students are expected to have by the end of fifth grade is listed below. These statements, organized into eight groups, are found in various elementary school benchmarks in *Benchmarks for Science Literacy* (BSL), developed by the American Association for the Advancement of Science (AAAS).

- Changes in speed or direction of motion are caused by forces. A force is a push or a pull. The greater the force is, the greater the change in motion will be. One way that forces act on objects is through direct contact. Forces such as magnets, Earth's gravity or electrically charged objects can also act on objects over a distance by not touching the objects.

- Earth's gravity pulls any object on or near Earth toward Earth without touching it.

- A substance can be described by its properties. These properties can change when the substance is heated or cooled, or when it interacts with another substance.

- Heating and cooling a substance can cause changes in the properties of the substance, such as a change in state (i.e., solid, liquid, gas). Some of the features of the substance remain the same even though the properties change. For example, when liquid water disappears, it turns into a gas in the air and can reappear as a liquid when cooled, or as a solid if cooled below the freezing point of water.

- When a warm object is placed in direct contact with or at a distance from a cooler object, thermal energy is **transferred** from the warm object to the cooler object. The cooler object becomes warmer and the warm object becomes cooler until they are both the same temperature.

- Materials are composed of basic parts that are too small to be seen without magnification. These basic parts make up many different materials. A collection of these basic parts may have properties that the individual parts do not. When a new material is made by combining two or more materials, it has properties that are different from the original materials. No matter how parts of an object are assembled, the weight of the whole resulting object is always the same as the sum of the parts' weights.

- Substances may move from place to place, but they never appear out of nowhere and never just disappear.

- Air is a substance that surrounds us and takes up space.

Standard PS.1
Interactions, Forces and Motion

Changes in the natural and designed world are caused by **interactions**. Interactions of an object with other objects can be described by forces that can cause a change in motion of one or both interacting objects.

Students understand that the term "interaction" is used to describe causality in science: Two objects interact when they act on or influence each other to cause some effect. Students understand that observable objects, changes and events occur in consistent patterns that are comprehensible through careful, systematic investigations. To search for consistent patterns in the multitude of observable changes, interactions can be classified as different types (e.g., mechanical interactions, gravitational interactions, magnetic interactions and electric charge interactions). The three defining **characteristics of an interaction** are: (1) the **conditions** necessary for the interaction to occur; (2) the **evidence** of the interaction (i.e., the observed changes); and (3) the variables that influence the strength of the interaction.

Objective PS.1.1
Patterns of Straight-Line Motion

Students understand that there are different patterns of straight-line motion that can be represented using different **models**.

*[**BOUNDARY:** Motion is limited to one dimension, which can include objects on an inclined plane. Excluded are the terms "velocity" and "acceleration," which are introduced at the 9–12 grade band.]*

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.1.1.1 Investigate the patterns of motion of objects in different experimental situations.

- **PS-PE.1.1.1a** Ask and refine a **scientific question** about the basic pattern of motion of the object.
- **PS-PE.1.1.1b** Determine and justify the **data** needed to answer the scientific question about the pattern of motion of the object.
- **PS-PE.1.1.1c** Follow a protocol to collect, record and organize data about the position of the moving object at different times (clock readings). Data include estimates of measurement errors.
- **PS-PE.1.1.1d** Analyze the data for **outliers**, and represent the motion of the object on a graph showing distance versus time, and with a **motion diagram**.
- **PS-PE.1.1.1e** Determine whether the data can be used as evidence to support a **claim** about the pattern of motion.
- **PS-PE.1.1.1f** Make a claim about the pattern of motion of the object. Justification should include the evidence and knowledge of the different patterns of motion of objects.

PS-PE.1.1.2 Translate among different **representations** (e.g., verbal descriptions, motion diagrams, data tables, distance versus time graphs) of the patterns of motion of objects.

PS-PE.1.1.3 Explain what is changing and what is not changing for an object moving at a constant speed. Justify the explanation by constructing sketches of distance versus time graphs.

PS-PE.1.1.4 Predict numerically the distance traveled, the time interval, or the initial or final clock readings for different situations involving motion with constant speed. Justify the **prediction** by using the mathematical representation for constant speed.

PS-PE.1.1.5 Analyze different **problems** to determine whether the **average speed** of an object has been calculated correctly or incorrectly.

PS-PE.1.1.6 Calculate, using the mathematical representation, the average speed of an object for problems in which an object is speeding up, slowing down or traveling in a series of constant speeds.

PS-PE.1.1.7 Explain the differences between the average speed and constant speed for objects undergoing a change in motion. Justification is based on observations, sketches of motion diagrams and of distance versus time graphs, and knowledge of rates of change and changes in motion.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The basic patterns of the straight-line motion of objects are no motion, moving with a constant speed, speeding up, slowing down and changing (reversing) direction of motion. Sometimes an object's motion can be described as a repetition and/or combination of the basic patterns of motion.
- An object that moves with a constant speed travels the same distance in each successive unit of time. The constant speed of an object can be represented by and calculated from the mathematical representation, data tables, a motion diagram and the slope of the linear distance versus time graph.
- The relationship between distance and time is nonlinear when an object's speed is changing and when it is moving in a series with different constant speeds (average speed). When an object is speeding up, the distance it travels increases with each successive unit of time; when an object is slowing down, the distance it travels decreases with each successive unit of time.
- For objects traveling to a final destination in a series of different constant speeds, the average speed is not the same as the average of the constant speeds. Average speed can be represented and calculated from the mathematical representation, data tables and the slope of the nonlinear distance versus time graph.

Objective PS.1.2
Forces and Motion

Students understand that when the sum of the forces is equal to zero, either the object is not moving and it will continue to not move, or the object is moving and it will always continue to move at a constant speed in a straight line (Newton's first law).

*[**BOUNDARY:** Interactions are limited to one dimension and to uniform circular motion (tangential velocity). Newton's third law is excluded from grades 6–8.]*

Suggested Connections
Within Physical Science: Mechanical Energy Transfer (Work) and Energy Changes (PS.4.1); Conservation of Energy (PS.4.4)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.1.2.1 Give examples of how to change the motion of an object (i.e., change speed, change direction or move in a circle) in different situations, and explain each example. Explanation is based on knowledge of interaction and forces.

PS-PE.1.2.2 Analyze **force diagrams** to determine if they accurately represent different real-world situations.

PS-PE.1.2.3 Determine, given a force diagram and the initial motion of an object, the change in motion of an object, and explain why the change occurs.

PS-PE.1.2.4 Given real-world situations involving contact, gravitational, magnetic or electric charge forces and an identified object of interest:

PS-PE.1.2.4a Identify the objects involved in the interaction, and identify the pattern of motion (no motion, moving with a constant speed, speeding up, slowing down or changing [reversing] direction of motion) for each object.

PS-PE.1.2.4b Make a claim about the types of interactions involved in the various situations. Justification is based on the defining characteristics of each type of interaction.

PS-PE.1.2.4c Represent the forces acting on the object of interest by drawing a force diagram.

PS-PE.1.2.4d Explain the observed motion of the object. Justification is based on the forces acting on the object.

PERFORMANCE EXPECTATIONS, *continued*

PS-PE.1.2.5 Identify all of the forces on an observed object, and make a claim as to why, in different real-world situations, friction and **drag** interactions must be taken into consideration (e.g., why a driver in a car needs to keep his foot on the accelerator when driving at a constant speed down a highway). Justification should be based on the sum of the forces and Newton's first law.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- A force is a push or a pull applied on an object by the interacting object.
- When multiple forces are acting on an object, the change in the object's motion is determined by the sum of these multiple forces (i.e., net force).

  *[**BOUNDARY:** Interactions are limited to one dimension.]*
- The forces acting on an object can be represented by arrows drawn on an isolated picture of the object (i.e., a force diagram). The direction of each arrow shows the direction of the push or the pull.

  *[**BOUNDARY:** All forces are limited to the same dimension, but may be in different directions.]*
- When two objects in contact exert forces on each other, the interaction stops as soon as the objects stop touching and the forces as a result of the interaction are gone. There is no transfer of force from one object to another during an interaction.
- A force of constant magnitude acting at right angles to the direction of the object's motion causes the object to move in a circle at a constant speed.
- A force is required to change the motion of an object.
  - If the force is applied in the same direction of the object's motion, the object's speed will increase.
  - If the force is applied in the opposite direction of the object's motion, the object's speed will decrease.
  - A force can also change an object's direction of motion.
  - If two opposing forces are equal in magnitude, then the motion of the object does not change.

Objective PS.1.3
Interactions and Forces

Students understand that interactions can be described in terms of forces. These interactions occur when two objects in contact push or pull on each other, which can cause a change in motion of one or both objects.

*[**BOUNDARY:** The situations are limited to one dimension and to horizontal motion and forces.]*

Suggested Connections

Within Physical Science: Mechanical Energy Transfer (Work) and Energy Changes (PS.4.1)

Between Physical Science and Other Disciplines: Tectonism (ES.1.3)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.1.3.1 Given real-world situations involving simple contact interactions between two objects:

PERFORMANCE EXPECTATIONS, *continued*

PS-PE.1.3.1a Identify the objects involved in the contact interaction, and observe the changes in motion of each object.

PS-PE.1.3.1b Make a claim about the defining characteristics of each type of contact interaction.

PS-PE.1.3.1c Represent the force on the object of interest by drawing a force diagram.

PS-PE.1.3.2 Investigate, given a contact interaction, the variables that could affect the magnitude of the **kinetic friction** or elastic force on an object.

PS-PE.1.3.2a Ask and refine a scientific question about a variable that could affect the magnitude of the kinetic friction or elastic force.

PS-PE.1.3.2b Follow a structured protocol for observing the motion of the object for different values of the variable and for recording the observations on data tables.

PS-PE.1.3.2c Analyze and represent the data on graphs.

PS-PE.1.3.2d Make a claim, based on the evidence and Newton's second law, about the relationship (if any) between the variable and the magnitude of the kinetic friction or elastic force.

PS-PE.1.3.3 Predict qualitatively what happens to the elastic force on an object (decreases, stays the same, increases) when the "stiffness" of the interacting elastic object changes or when the distance the elastic object is stretched or compressed changes. Justification is based on knowledge of the variables that affect the magnitude of elastic forces.

PS-PE.1.3.4 Identify all of the forces on an object, and make a claim as to why, in different situations, air resistance can be ignored. Justification is based on the size and/or relative speed of the object as it moves through the air.

ESSENTIAL KNOWLEDEGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The change in motion of an object depends on the magnitude of the force applied to the object by an interaction and decreases as the mass of the object increases (Newton's second law).

- A force is applied when two objects in contact (e.g., humans, baseballs) interact by pushing or pulling on each other. Forces are not transferred to objects — the interaction stops as soon as the objects stop touching.

  *[**BOUNDARY:** At the 6–8 grade band, ordinary-size objects should retain their size and shape and not break during the interaction. Only contact interactions will be investigated at this grade band.]*

- When two objects in contact interact by pushing or pulling, the magnitude of the force that an elastic object exerts on another object depends on the "stiffness" of the elastic object and on the distance that the elastic object is stretched or compressed.

- Kinetic friction is a force that opposes the motion of an object when two objects in contact interact by sliding past one another. The force on an object is applied to the sliding surface in the direction of motion of the object.

- Drag is a force that opposes the motion of an object when an object moves through a fluid (e.g., gas or liquid) or when a fluid moves around an object. The force on an object is applied to the surface area facing the direction of motion of the object or fluid.

Objective PS.1.4
Gravitational Force

Students understand that gravity is an attractive interaction between any two objects with mass, which can cause a change in motion of the objects.

*[**BOUNDARY:** Motions are limited to one dimension and to vertical motions of ordinary objects on Earth and circular motions of moons and planets — projectile motion is excluded.]*

Suggested Connections
Within Physical Science: Conservation of Energy (PS.4.4)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.1.4.1 Provide evidence, gathered from print and electronic resources, that supports the idea that a gravitational interaction is not caused by Earth's magnetism, Earth's rotation or air pressure.

PS-PE.1.4.2 Given real-world situations involving gravitational interactions between two objects, and an identified object of interest (e.g., a small falling object, a planet circling a star):

- **PS-PE.1.4.2a** Identify the relative masses of the objects involved and the change in motion of each object.
- **PS-PE.1.4.2b** Make a claim about the type of interaction. Claim is based on the evidence and the defining characteristics of each type of interaction.
- **PS-PE.1.4.2c** Represent the force(s) on the object of interest by drawing a force diagram.

PS-PE.1.4.3 Investigate the magnitude of the gravitational force of Earth, compared to the strength of a magnetic force and of the electric charge force.

- **PS-PE.1.4.3a** Observe and record what happens when a small magnet is held above one or more small-mass objects made of a magnetic material (e.g., paper clips) and when a charged object is held above one or more small-mass objects made of an electric insulator (e.g., small pieces of paper).
- **PS-PE.1.4.3b** Represent the motion of the magnetic-material object(s) and electric-insulator objects with a motion diagram. Represent the forces acting on these object(s) by drawing force diagrams.
- **PS-PE.1.4.3c** Make a claim, based on the evidence of change in motion, about the magnitude of the gravitational force compared to that of the magnetic force and the electric charge force.

PS-PE.1.4.4 Explain qualitatively why the gravitational forces between two ordinary-size objects (e.g., pencils, cars) are not noticeable. Justification is based on the defining characteristics of the gravitational interaction.

PS-PE.1.4.5 Explain qualitatively the difference between the mass and weight of an object. Justification is based on the defining characteristics of the gravitational interaction.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- A gravitational interaction is an attraction that occurs between any two objects with mass. The magnitude of gravitational forces increases with the masses of the two objects and decreases with the distance between the two objects.
- In the gravitational interaction between a planet or moon and an ordinary-size object, the planet or moon pulls on every atom in the object. The gravitational force of a planet or moon on an object is actually the net force on all of the atoms of the object.

ESSENTIAL KNOWLEDGE, *continued*

- Compared to other interactions (e.g., electrostatic), the gravitational interaction is extremely weak. Gravitational interactions are difficult to observe unless at least one of the objects is very massive (e.g., the Sun, planets, moons). The gravitational force exerted by a planet on its moon(s) points toward the center of the planet.

- "Weight" is the everyday term for the gravitational force (pull) of Earth (or other planet or moon) on objects located on or near Earth's surface (or other planet or moon). Like all forces, gravitational forces on ordinary objects on Earth are measured with calibrated spring scales that are not moving with respect to Earth.

Objective PS.1.5
Magnetic and Electric Charge Interactions

Students understand that magnetic and electric charge interactions occur between mutually attracting or repelling objects, which can cause a change in motion of one or both objects. Materials can be classified as magnetic or nonmagnetic, depending on how they interact with a magnet.

*[**BOUNDARY:** The focus of charge and magnetism should be on the observations of the interactions. A discussion of subatomic **particles** will occur at the 9–12 grade band. **Charging by induction** is excluded at the 6–8 grade band.]*

Suggested Connections
Within Physical Science: Electric Circuit Interactions (PS.4.2)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.1.5.1 Make a claim, using simple household materials, concerning whether an unknown object is made of magnetic material. Justification is based on the evidence and the defining characteristics of magnetic interactions.

PS-PE.1.5.2 Make a claim concerning whether an unknown object is charged or uncharged. Use simple household objects to charge an object and to determine the charge (positive, negative or no charge) from a known charged object. Justification is based on observational evidence and the defining characteristics of electric charge interactions.

PS-PE.1.5.3 Given real-world situations involving magnetic or electric interactions between two objects, and an identified object of interest:

PS-PE.1.5.3a Identify the type of objects involved in the interaction, and observe the change in motion (if any) of each object.

PS-PE.1.5.3b Make a claim about the type of interaction (e.g., magnetic or gravitational). Claim is based on the evidence and the defining characteristics of each type of interaction.

PS-PE.1.5.3c Represent the force on the object of interest by drawing a force diagram.

PS-PE.1.5.4 Investigate the motion of charges when certain materials are charged by contact (touching or rubbing).

PS-PE.1.5.4a Predict, based on the concept of charges, whether or not charges move when certain materials are charged.

PS-PE.1.5.4b Follow a structured protocol for determining whether the charges move and for recording observations on data tables.

PS-PE.1.5.4c Analyze and represent data with diagrams.

PS-PE.1.5.4d Make a claim, based on the evidence, about whether or not charges move when certain materials are charged.

PS-PE.1.5.5 Predict qualitatively what happens to the magnetic force on an object (decreases, stays the same or increases) when the strength of the magnet changes or when the distance between the magnet and the other interacting object changes. Justification is based on a defining characteristic of magnetic interactions.

PERFORMANCE EXPECTATIONS, *continued*

PS-PE.1.5.6 Predict qualitatively what happens to the electric force on an object (decreases, stays the same or increases) when the amount of charge changes or when the distance between the two interacting objects changes. Justification is based on a defining characteristic of electric charge interactions.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- All bar magnets (e.g., a compass) line up in the north–south direction when freely suspended. The end of the magnet that points approximately toward the geographical north is defined as the magnet's north end. The other end of the magnet that points approximately toward the geographical south is defined as the south end.
- Magnetic interactions occur when one magnet is close to, or touching, another magnet or a magnetic material (e.g., a substance that contains iron, nickel or cobalt).
    - Two magnets with opposite ends near each other will move toward each other (attract). Two magnets with the same ends near each other will move away from each other (repel). A magnet and an object made of magnetic material will move toward each other (attract).
    - The strength of the magnet–magnetic material force and the strength of the magnet–magnet force depend on the strength of the magnet(s) (the more magnetic one or both magnets is, the greater the forces) and on the distance between the two objects (the greater the distance, the weaker the magnetic forces).
- Objects are typically uncharged. Any charged object (e.g., a comb that has been rubbed on a sweater) attracts uncharged objects such as bits of paper or a thin stream of water.
- Electric charge interactions occur when a charged object is close to another charged object or an uncharged object.
    - Two objects with different types of charge will move toward each other (attract). When two charged objects have the same type of charge, they move away from each other (repel). A charged object will move toward an uncharged object (attract).
    - The strength of the electric charge force depends on the amount of charge on one or both interacting objects and decreases with increasing distance between the charged object and the other charged or uncharged object.
- In certain materials, charges do not appear to move as freely as charges in other materials. These observations provide evidence that some materials (i.e., conductors) allow electric charge to move easily and that some materials (i.e., insulators) do not allow electric charge to move as freely.

Standard PS.2
Physical and Chemical Properties of Matter

Matter has mass and volume and can exist as a solid, liquid or gas. All pure substances have their own unique set of physical and chemical properties that can be used to identify them.

Students understand that scientists have defined properties of substances through observation, through experimentation and through analysis of the resulting data. Students use their observations and their analysis of data on physical and chemical properties to identify substances. Students use the concept of atoms and molecules as particles in constant motion to explain properties of matter.

Clarification: For the purposes of these physical science standards, the terms "matter" and "pure substance" are described in the following manner: Matter has two properties: It takes up space and it has mass. It includes all solids, liquids and gases of both living and nonliving things. A pure substance is a sample of matter (compound or element) that has a specific chemical composition and definable properties. A more advanced description of the structure of matter, including concepts such as ions, subatomic particles, etc., will be addressed at the 9–12 grade band.

Objective PS.2.1
Properties of Matter

Students understand that pure substances are composed of matter that has definable properties. Through macroscopic observation and measurement of these properties, students can describe and identify these substances.

Suggested Connections
Between Physical Science and Other Disciplines: Matter Cycling (LS.4.1)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.2.1.1 Measure, using different methods, the volume of gases and liquids; the inside volume of solid containers; and the volume of regular and irregular solid objects. Estimate the measurement errors, and report the appropriate value and the measurement error.

PS-PE.2.1.2 Investigate the relationship between the mass and the volume of a given substance.

- **PS-PE.2.1.2a** Develop an appropriate method of measuring the mass and the volume of different amounts of a substance.
- **PS-PE.2.1.2b** Record measurements of the mass and the volume of different amounts of the substance, and organize this data in a table.
- **PS-PE.2.1.2c** Construct a graph, using collected data, to show the relationship between mass and volume, and find a best fit representation.
- **PS-PE.2.1.2d** Use the relationship between mass and volume to define density. Calculate the density of the substance.

PS-PE.2.1.3 Use the mathematical relationship between mass, volume and density in different situations to calculate the mass of objects by using a given volume or measuring the volume, and by using a table of densities.

PS-PE.2.1.4 Use the mathematical relationship between mass, volume and density in different situations to calculate the volume of objects by using a given mass or measuring the mass, and by using a table of densities.

PS-PE.2.1.5 Describe a substance in terms of its properties (e.g., temperature, state, density, conductivity, color, hardness and magnetic properties).

PS-PE.2.1.6 Identify which properties of a substance are dependent on the amount of the sample and which are not.

PS-PE.2.1.7 Give examples of evidence that supports the idea that gases have mass and volume, and that different gases (e.g., oxygen, hydrogen, carbon dioxide) have different properties.

*[**BOUNDARY:** A quantitative treatment of properties will be discussed at the 9–12 grade band.]*

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Matter can be observed and measured directly and has properties of mass and volume.
- Mass is the measure of the amount of matter, and volume is the measure of the three-dimensional space that matter occupies.
- The density of any object can be measured and calculated by dividing the mass of the object by the volume of the object.
- A pure substance has properties (e.g., melting point, boiling point, density, color, hardness, conductivity) that can be used to identify it. Under all conditions, these properties do not depend on the amount (mass or volume) of the substance.
- Instruments (e.g., ruler, thermometer, graduated cylinder, mass balance) are used to measure the properties of substances.
- When measurements are performed, a true (or exact) value is never obtained; there is always some uncertainty associated with a measurement. Several trials should be conducted to find the average (mean), and an appropriate value for a measurement should be reported.

Objective PS.2.2
States of Matter

Students understand through observation that matter can exist in three common states: solid, liquid or gas. Students understand that these macroscopic observations serve as evidence of the concept that matter can exist as elements, compounds or mixtures.

> **Suggested Connections**
> *Within Physical Science:* Conservation of Matter (PS.3.1); Physical and Chemical Changes of Matter (PS.3.2); Thermal Energy (PS.4.5)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.2.2.1 Give common real-world examples of solids, liquids and gases.

PS-PE.2.2.2 Make a claim about the state of a pure substance, and justify the claim by using the definitions of solid, liquid and/or gas.

PS-PE.2.2.3 Identify the individual elements that make up a familiar compound such as water or carbon dioxide.

PS-PE.2.2.4 Make a claim, given a set of substances (e.g., food coloring and water, sulfur and iron filings, calcium chloride), concerning whether each substance is a pure substance or a mixture. Justification is based on observed properties and the definition of a pure substance.

PS-PE.2.2.5 Investigate a mixture consisting of two substances.

- **PS-PE.2.2.5a** Develop a method (e.g., filtration, evaporation or magnetic separation) of separating the two substances in a mixture.
- **PS-PE.2.2.5b** Record observations by writing, constructing representations and creating tables.
- **PS-PE.2.2.5c** Make a claim, based on the results of the investigation, about the effectiveness of the separation method, and suggest how the method could be improved.

PS-PE.2.2.6 Use observations of properties of various elements as evidence in order to predict, based on these properties, their placement in the periodic table.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Matter can exist in three common states: solid, liquid or gas. The state of matter depends on the temperature and pressure.
- Solids are identified as having a fixed shape with a volume that can vary depending on the temperature. A pure solid has a melting point that is characteristic of the substance.
- Liquids are identified as having the ability to flow and to take the shape of the bottom of their containers. A pure liquid has a freezing point and a boiling point that are characteristic of the substance.
- Gases are identified as having the ability to expand to fill any container. All gases have mass and volume, and different gases have different properties. A pure gas condenses to a liquid at a characteristic temperature at any given pressure.
- As the temperature increases at constant pressure, many pure substances change from a solid to a liquid to a gas and retain the same chemical composition.
- Stable elements are not easily broken down by nature or by common laboratory techniques into simpler substances. Each element has its own unique composition and properties.
- Elements are arranged in groups based on patterns of common properties that can be predicted by an element's location on the periodic table.
- Compounds consist of more than one kind of element, and each compound has its own unique, unchanging composition and unique properties.
- The properties of a compound are different than those of each element that makes up the compound.
- Mixtures consist of more than one kind of element or compound and can have different compositions.
- The properties of a mixture may or may not be different than those of each element or compound that make up the mixture.

Objective PS.2.3
Particulate Nature of Matter

Students understand that matter is composed of atoms that can interact in different ways to form molecules and crystals. The structure, behavior and properties of matter can be explained by using models that depict particles in constant motion as well as the strength of the interacting forces among the particles.

*[**BOUNDARY:** Students at the 9–12 grade band will be exposed to a more advanced definition of the structure of matter, including concepts such as ions, subatomic particles, etc.]*

> **Suggested Connections**
> *Within Physical Science:* Conservation of Matter (PS.3.1); Physical and Chemical Changes of Matter (PS.3.2)
>
> *Between Physical Science and Other Disciplines:* Matter Cycling (LS.4.1)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.2.3.1 Construct a representation of the different states of matter, including the arrangement and motion of particles. Justify the differences among the states in terms of the average kinetic energy of the particles of a substance at different temperatures.

PERFORMANCE EXPECTATIONS, *continued*

PS-PE.2.3.2 Rank the strength of the attractions between the particles of three room-temperature substances (a solid, a liquid and a gas) in order from greatest to least.

PS-PE.2.3.3 Compare and contrast different representations of a small-particle model of solids, liquids and/or gases.

PS-PE.2.3.4 Explain why solids, liquids and gases have different physical properties (e.g., shape, volume or thermal expansion) at room temperature. Justification is based on the small-particle model of substances.

PS-PE.2.3.5 Explain why a syringe filled with air can be compressed, but the same syringe filled with water cannot be easily compressed. Justification includes a discussion of the definitions of liquid and gas states.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Atoms are represented by models because they are too small to see with the naked eye or with traditional visible-light microscopes.
- All atoms have mass, take up space, and are in constant motion.
- The properties of matter can be explained by using the concept of small particles in constant motion.
- Atoms may combine (bond) to form molecules or crystals (three-dimensional networks). Most atoms become more stable after they have combined (bonded).
- When atoms of different elements combine (bond), compounds with new and different properties are formed.
- Although the mass of an individual atom is very small, the mass of a sample of material is the sum of the masses of its large number of component atoms.
- There are attractive forces between particles in a substance. The strength of these attractions helps to explain many physical properties of substances, including why different substances exist as solids, liquids or gases at given temperatures.
- In the solid state, the particles are in a fixed arrangement relative to one another; therefore, a solid has a fixed shape and volume at any given temperature. Although the average positions of the particles are fixed, the particles vibrate in place.
- In the liquid state, the particles are in close proximity and can move relative to one another with a range of speeds. Because the particles can move in this manner, a liquid is able to flow and take the shape of the bottom of a container.
- In the gas state, the particles are relatively far apart and are in constant motion with a wide range of speeds. Because the particles move in this manner, a gas expands to fill any container.

Standard PS.3
Conservation of Matter

Matter can be transformed by a change of state or by undergoing chemical reactions, but it can never be created or destroyed.

Students understand that in a chemical system, the number and types of atoms in the system are constant and can never be created or destroyed, but the arrangement of these atoms can be changed. The type of change that occurs depends on whether the identity of the substance changes or only the state of the substance changes.

Clarification: For the purposes of these physical science standards, the terms "matter" and "pure substance" are described in the following manner: Matter has two properties: It takes up space and it has mass. It includes all solids, liquids, and gases of both living and nonliving things. A pure substance is a sample of matter (compound or element) that has a specific chemical composition and definable properties. A more advanced description of the structure of matter, including concepts such as ions, subatomic particles, etc., will be addressed at the 9–12 grade band.

Objective PS.3.1
Conservation of Matter

Students understand that matter can neither be created nor destroyed during any interaction, including change of state or a change that takes place as a result of a chemical reaction.

*[**BOUNDARY:** Conservation of mass–energy will not be addressed at the 6–8 grade band.]*

> **Suggested Connections**
> *Within Physical Science:* States of Matter (PS.2.2); Particulate Nature of Matter (PS.2.3); Conservation of Energy (PS.4.4)
>
> *Between Physical Science and Other Disciplines:* Matter Cycling (LS.4.1)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.3.1.1 Predict, using the conservation of mass principle, whether the mass of a defined system will change for different physical and chemical interactions (e.g., when the defined system is closed or when the rate of mass transfer into the system is the same as the rate of mass transfer out of the system).

PS-PE.3.1.2 Investigate a change of state of a given substance (e.g., water, wax).

- **PS-PE.3.1.2a** Develop an appropriate method of changing the state of a substance.
- **PS-PE.3.1.2b** Identify the initial state of the substance, and record detailed observations, including the temperature and the amount of substance in the container.
- **PS-PE.3.1.2c** Identify the observed final state of the substance. Compare and contrast the behavior and properties of the substance in different states.
- **PS-PE.3.1.2d** Make a claim, based on data from the investigation, about a factor that could change the results.

PS-PE.3.1.3 Given a simple chemical reaction, such as the combination of baking soda and vinegar:

*[**BOUNDARY:** Students are not expected to write chemical formulas or to balance chemical reactions. All reactions at the 6–8 grade band are assumed to be in closed (isolated) systems.]*

- **PS-PE.3.1.3a** Record detailed observations.
- **PS-PE.3.1.3b** Predict the relationship between the starting mass and the ending mass.
- **PS-PE.3.1.3c** Make a claim, based on observations, concerning whether a chemical reaction or a change of state occurred.
- **PS-PE.3.1.3d** Plan an investigation of an observed change to address the variables involved with the change.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Scientists use the concept of a system to help in their study of processes. A real boundary (e.g., hydrosphere, lithosphere, calorimetry cup, spatial and temporal scales) or an imaginary boundary (e.g., spatial and temporal dimensions [scales]) separates a system from its surroundings. By defining a system, any change that takes place in the system can be tracked.

- A closed system does not interact with its surroundings: Matter and energy cannot get into or out of the system. Most systems of interest in our everyday lives are open systems: Matter and energy can be transferred into or out of the system.

- A quantity is conserved when the total change of the quantity within a defined system (i.e., defining the spatial and temporal boundaries of a system) is equal to the total transfer of the quantity into or out of the system (change in quantity $= \Delta Q = Quantity_{in} - Quantity_{out}$) or is equal to the difference between the end quantity and start quantity (change in quantity $= \Delta Q = Quantity_{final} - Quantity_{initial}$).

- Mass is conserved when the total change of the mass within a defined system (open or closed) is equal to the total transfer of the mass into or out of the system.

- Mass is always conserved for all types of interactions (with the exception of nuclear interactions) and for all defined systems (open or closed).

  *[**BOUNDARY:** Most quantities (e.g., surface area, perimeter, volume, density) are not conserved for all types of interactions.]*

- When two or more pure substances undergo a chemical reaction, the masses of the products are the same as those of the reactants; thus, the total mass never changes.

- When a pure substance changes from a solid to a liquid to a gas (i.e., undergoes a change of state), neither the identity nor the mass of the substance changes.

- In chemical reactions, the atoms present in the reactants are all present in the products, but the atoms are found in different combinations (bonds) that result in the formation of different substances.

Objective PS.3.2
Physical and Chemical Changes of Matter

Students understand that chemical reactions produce new substances with new properties, whereas changes of state alter the appearance of a substance, not the identity of a substance.

> **Suggested Connections**
> *Within Physical Science:* States of Matter (PS.2.2)
>
> *Between Physical Science and Other Disciplines:* Matter Cycling (LS.4.1); Energy Transfer (LS.4.2)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.3.2.1 Compare and contrast the properties of elements and the properties of those same elements when they are combined to form a compound (e.g., hydrogen and oxygen are combustible, but when combined they form water).

PS-PE.3.2.2 Compare and contrast the properties of a given set of elements (magnesium [Mg], zinc [Zn], iron [Fe] and copper [Cu]). Observe what happens when each element is treated with dilute acid. Make a claim, based on these observations, about the relative reactivity of these elements.

PERFORMANCE EXPECTATIONS, *continued*

PS-PE.3.2.3 Given a solid (e.g., sugar, table salt) and water:

*[**BOUNDARY:** Students are not expected to write chemical formulas or to balance chemical reactions.]*

- **PS-PE.3.2.3a** Determine the amount of solid that can dissolve in the water at room temperature.
- **PS-PE.3.2.3b** Construct a representation of the change that takes place when the solid dissolves in the water.
- **PS-PE.3.2.3c** Predict, based on the starting mass of the substances, the ending mass. Justification includes a discussion of the law of conservation of mass and of the particulate nature of matter.

PS-PE.3.2.4 Give examples of familiar chemical reactions that produce energy (e.g., burning gasoline).

PS-PE.3.2.5 Investigate a change in mass and volume when two miscible liquids (e.g., ethanol and water) are mixed.

- **PS-PE.3.2.5a** Follow a structured protocol to gather and record data on the masses and volumes of the given liquids before and after mixing.
- **PS-PE.3.2.5b** Make a claim, using the data as evidence, concerning whether mass and volume are conserved when a change occurs.
- **PS-PE.3.2.5c** Explain, using representations, why mass is always conserved and why volume may not be conserved.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- There are two commonly observed changes in matter: chemical changes and changes of state.
- Chemical changes involve rearrangements of atoms in molecules to produce new substances with different properties.
- Changes of state (e.g., melting, boiling, freezing, condensing) involve changes in the relative positions and motions of particles. The substance retains the same chemical composition and mass is conserved, even though some physical properties (e.g., density, volume, shape) of the substance change.
- A chemical change is often accompanied by observable phenomena such as precipitation, gas evolution, change in temperature or change in color. However, the chemical change is sometimes difficult to detect through direct observation.
- Many substances dissolve in water. Consequently, water is a very useful and familiar solvent.
- When a substance dissolves in a solvent, the mass of the solution is equal to the total mass of the substance plus the solvent. However, the volume of the solution may be different from the sum of the original volume of substance and the solvent.
- A common chemical change occurs when a system containing oxygen and other substances (e.g., fossil fuels) reacts and energy is produced. These reactions often are the sources of energy for living systems.

Standard PS.4
Conservation of Energy

When any change occurs, energy is transferred and/or **transformed**, but it is never lost.

Energy can be converted from one form to another, but can never be created or destroyed. Energy may appear to have been lost or gained in systems because the changes in energy may be difficult to detect.

<u>Clarification</u>: For the purposes of these physical science standards, the terms "matter" and "pure substance" are described in the following manner. Matter has two properties: It takes up space and it has mass. It includes all solids, liquids and gases of both living and nonliving things. A pure substance is a sample of matter (compound or element) that has a specific chemical composition and definable properties. A more advanced description of the structure of matter, including concepts such as ions, subatomic particles, etc., will be addressed at the 9–12 grade band.

<u>Clarification</u>: This standard does not include nuclear interactions, which are covered at the 9–12 grade band.

Objective PS.4.1
Mechanical Energy Transfer (Work) and Energy Changes

Students understand that interactions between objects can be described not only in terms of forces but also in terms of energy transfers between the objects. Energy can be transferred from one object to the other by means of pushes or pulls that result in changes in motion. *[**BOUNDARY:** Problems are limited to events involving horizontal, straight-line contact interactions. Excluded are situations that require Newton's third law, such as a person who is walking or a car that is moving.]*

> **Suggested Connections**
> *Within Physical Science:* Forces and Motion (PS.1.2); Interactions and Forces (PS.1.3)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.4.1.1 Give real-world examples of mechanical interactions in which there are changes in the elastic energy (e.g., a stretched rubber band or a compressed rubber ball) of one of the interacting objects.

PS-PE.4.1.2 Describe, using words and a representation, the transfer of energy in different situations involving chains of mechanical interactions (e.g., the object acting as the energy receiver during the first interaction is the object acting as the energy source during the next interaction).

PS-PE.4.1.3 Given a real-world situation involving an interaction between two objects defined as a system:

- **PS-PE.4.1.3a** Observe changes in each object during the interaction.
- **PS-PE.4.1.3b** Make a claim about the direction of the energy transfer. Justification is based on observations of which object is acting as the energy source and which object is acting as the energy receiver.
- **PS-PE.4.1.3c** Represent the energy transfer and the energy changes within the system.

PS-PE.4.1.4 Explain, predict and represent how changing the size of the force or the distance over which the force acts changes the amount of mechanical energy transferred during the interaction.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- During an interaction between two objects, energy is transferred from one object, which acts as the energy source, to the other object, which acts as the energy receiver. The energy of the source decreases, and the energy of the receiver increases.

ESSENTIAL KNOWLEDGE, *continued*

- The amount of energy transferred when one object pushes or pulls on another object depends on the strength of the force and the distance covered by the acting force. A mechanical energy transfer (work) stops as soon as the objects are no longer in contact.
- Kinetic energy is associated with the mass and speed of an object. Changes in the speed of an object are evidence that the kinetic energy has changed.
- A change in elastic energy is associated with the compression or stretching of an object and the difficulty involved in compressing or stretching the object.

Objective PS.4.2
Electric Circuit Interactions

Students understand that during electric circuit interactions, electrical energy is transferred from the source of electric current to the electrical device, or devices, in the circuit.

Suggested Connections
Within Physical Science: Magnetic and Electric Charge Interactions (PS.1.5)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.4.2.1 Make a claim concerning whether the bulb or bulbs in a given circuit will light. Justification is based on tracing the path of conductors through the circuit and determining whether the circuit is open or closed.

PS-PE.4.2.2 Investigate the variables (e.g., the number of series batteries, the length of a wire, the diameter of a wire, the metal composition of a wire) that affect the current flow through a wire.

- **PS-PE.4.2.2a** Ask and refine a scientific question about a variable that could affect the current flow through a wire.
- **PS-PE.4.2.2b** Follow a structured protocol for observing the current flow through the wire for different values of the variable.
- **PS-PE.4.2.2c** Analyze and represent the data on graphs.
- **PS-PE.4.2.2d** Make a claim, based on the evidence, about the relationship between the variable and the amount of current.

PS-PE.4.2.3 Investigate the current in a one-battery, one-bulb circuit.

- **PS-PE.4.2.3a** Predict, based on a model of current flow through the circuit, the relative sizes of the electric current through the wire before the bulb and after the bulb.
- **PS-PE.4.2.3b** Follow a structured protocol for observing the relative sizes of the electric current in the wire before and after the bulb.
- **PS-PE.4.2.3c** Make a claim, based on the evidence, about the relative sizes of the electric current before and after the bulb.
- **PS-PE.4.2.3d** Describe alternative models (i.e., changes in circuit construction) of current flow, and describe which of these models represent(s) a complete circuit.

PS-PE.4.2.4 Given a real-world situation involving simple electric circuits, with the electrical energy source and device(s) identified as the system:

- **PS-PE.4.2.4a** Observe changes in the objects and the surroundings during the interaction.

PERFORMANCE EXPECTATIONS, *continued*

PS-PE.4.2.4b Make a claim about the direction of the energy transfer. Justification is based on observations of which object is acting as the energy source and which object is acting as the energy receiver.

PS-PE.4.2.4c Represent the energy transfers and the energy changes within the system (i.e., the circuit).

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- An electric circuit interaction occurs when an electrical energy source (e.g., battery, generator, solar cell) is connected with conducting wires in a complete loop (closed circuit) to an electrical device (e.g., light bulb, motor). If a circuit loop is broken (open circuit), the electric circuit interaction stops in that loop.
- Electric current is the flow of charges through the conductors and is measured with an instrument called an ammeter.
- Electrical conductors (e.g., metals, acidic or salt solutions) are materials through which charges can flow easily. Electrical insulators (e.g., plastic, glass, wood) are materials through which charges cannot flow easily.
- The electric current through metal wires (conductors) depends on the type of metal, the length of the wire and the diameter of the wire.
- The electric current in a circuit loop is the same everywhere in the loop (i.e., electric current is not used up). The wires and other conductors are always filled with electric charges. A battery moves electric charge through the circuit but does not create electric charges.
- Electrical devices can be hooked up to an electrical energy source in two different ways — in series and in parallel. As the number of devices in a single-series loop decreases, the electric current in the loop decreases. In a parallel circuit, the electric currents in each loop are the same as they would be if each loop were by itself — the only loop in the circuit.
- Electrical energy transfer is a process that occurs when an electrical energy source (e.g., battery, generator, solar cell) in a circuit transfers electrical energy to the device or devices acting as the energy receiver in the circuit. The energy of the source decreases. All electrical devices transfer energy out of the system to the surroundings.

Objective PS.4.3
Mechanical Wave Interactions

Students understand that during mechanical wave interactions, mechanical energy is transferred through a material without a transfer of matter.

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.4.3.1 Investigate the relationship between wave speed in a uniform medium and the **frequency**, **wavelength** and **amplitude** of the wave.

PS-PE.4.3.1a Ask and refine a scientific question about the variables that could affect the wave speed.

PS-PE.4.3.1b Gather data on how the wave speed changes when the variable changes.

PS-PE.4.3.1c Analyze and represent the data by using diagrams that show the frequency, wavelength and amplitude of a wave for a given time interval before and after a change in the variable.

PERFORMANCE EXPECTATIONS, *continued*

PS-PE.4.3.1d Make a claim, based on the empirical evidence, about the relationship (if any) between the variable and the wave speed.

PS-PE.4.3.1e Represent and calculate, using a wave diagram and the wave speed equation, the frequency, wavelength, amplitude or wave speed in different situations.

PS-PE.4.3.2 Given real-world situations involving mechanical wave interactions between two objects identified as the defined system:

PS-PE.4.3.2a Identify the wave as a **transverse wave** or a **compressional (longitudinal) wave**.

PS-PE.4.3.2b Observe changes in the objects and the surroundings during the interaction.

PS-PE.4.3.2c Make a claim about the direction of the energy transfer. Justification is based on observations of which object is acting as the energy source and which object is acting as the energy receiver.

PS-PE.4.3.2d Represent the energy transfers and the energy changes within the system and in the surroundings.

PS-PE.4.3.3 Represent and calculate, given the time interval for a sound wave to travel to and from a fixed object, the distance of a vibrating energy source from a fixed object. Give examples of how some animals and humans use this phenomenon to navigate (e.g., sonar) or to search for objects.

PS-PE.4.3.4 Predict what happens to the wave speed when the frequency, wavelength and/or amplitude change. Justification is based on the relationship among wave speed, frequency and wavelength. For sound waves, interpret changes in the pitch and loudness of the sound.

PS-PE.4.3.5 Predict what happens to the amount of energy transfer when the frequency, wavelength and/or amplitude change. Justification is based on knowledge of the conditions that change the amount of mechanical wave energy transfer.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- A mechanical wave requires a medium (solid, liquid or gas) in which to travel and is characterized by three variables: frequency, wavelength and amplitude.
- There are two types of waves: transverse waves (e.g., ropes) and compressional (longitudinal) waves (e.g., slinky, sound waves). Some waves, such as seismic waves, have both components.
- A mechanical wave interaction occurs when a vibrating object, acting as the energy source, produces a wave disturbance that travels through a medium. This wave disturbance transfers energy to an object at a distance, acting as the energy receiver, by displacing matter but not transferring it. Although the medium is temporarily displaced, it returns to its original (undisturbed) position.
- For a given medium, the amount of energy transfer during mechanical wave interaction during a time interval depends on the frequency and amplitude of the vibrating energy source.
- A wave disturbance travels approximately at a constant speed through a uniform material. The speed of the wave depends on the nature of the material (e.g., the wave travels faster through a solid than through a gas). As the wavelength (λ) of a wave through a material is decreased, the frequency (f) of the wave increases. The mathematical representation is $v_{wave} \approx constant = \lambda f$. The constant wave speed differs depending on the uniform material.
- A sound wave traveling through a solid, liquid or gas is an example of a compressional (longitudinal) wave. The pitch of a sound wave is related to the frequency of the wave, and the loudness of a sound wave is related to the amplitude of the wave.

Objective PS.4.4
Conservation of Energy

Students understand that energy can be transferred from one object to another within a system or across a system boundary and/or transformed within a system from one form to another, but it never disappears.

Suggested Connections
Within Physical Science: Forces and Motion (PS.1.2); Gravitational Force (PS.1.4); Conservation of Matter (PS.3.1)

Between Physical Science and Other Disciplines: Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Energy Transfer (LS.4.2)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.4.4.1 Investigate the thermal properties of a defined system (e.g., a Styrofoam cup filled with liquid).

- **PS-PE.4.4.1a** Describe the system and its surroundings.
- **PS-PE.4.4.1b** Measure the temperature change of the system over time.
- **PS-PE.4.4.1c** Make a claim, using temperature data, about the direction of the energy transfer and the energy change in the system.
- **PS-PE.4.4.1d** Predict and justify what will happen to the energy of the surroundings.

PS-PE.4.4.2 Given a real-world situation (e.g., a cup of ice, a cup of hot chocolate):
*[**BOUNDARY:** Students may choose the system they wish to study.]*

- **PS-PE.4.4.2a** Identify a system and its surroundings.
- **PS-PE.4.4.2b** Predict the direction of the energy transfer.
- **PS-PE.4.4.2c** Identify, in terms of energy transfer, whether the system is open or closed.
- **PS-PE.4.4.2d** Define a new system by changing the boundary of the system, and define whether the new system is open or closed. Identify energy transfers based on this alternative.
- **PS-PE.4.4.2e** Construct a representation of the transfer of energy from the given system to its surroundings.

PHYSICAL SCIENCE

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- There can be different forms of energy (e.g., kinetic energy, thermal energy) within a system.
- Energy can be stored in a system (e.g., elastic potential energy, chemical potential energy, gravitational potential energy) and is associated with different observable changes that can indicate an increase or decrease in the stored energy within a system.
  *[**BOUNDARY:** The concept of potential energy will be developed at the 9–12 grade band. There are no performance expectations addressing chemical potential energy or gravitational potential energy at the 6–8 grade band.]*
- Chemical energy is associated with a system of chemical reactants. The amount of chemical energy in a system changes when the chemicals are allowed to react. The energy transferred when a chemical system undergoes a reaction often appears as thermal energy.

ESSENTIAL KNOWLEDGE, *continued*

- Whenever energy appears in one place, it must have disappeared from another. Whenever energy is lost from somewhere, it must have gone somewhere else. Sometimes when energy appears to be lost, it actually has been transferred to a system that is so large that the effect of the transferred energy is imperceptible.[11]

Objective PS.4.5
Thermal Energy

Students understand that thermal energy can be transferred and/or transformed by different mechanisms (i.e., conduction, convection and radiation).

> **Suggested Connections**
> *Within Physical Science:* States of Matter (PS.2.2)
>
> *Between Physical Science and Other Disciplines:* Energy Transfer (ES.1.2); Energy Transfer (LS.4.2)

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PS-PE.4.5.1 Predict, given two different amounts of water, which amount of water will boil first when the two are heated at the same rate. Explain, in terms of thermal energy transfer (heat), why the larger amount of water takes longer to boil despite being heated to the same temperature as the smaller amount of water.

PS-PE.4.5.2 Give real-world examples of situations of thermal energy transfer (heat) by conduction, convection and radiation.

PS-PE.4.5.3 Identify, given a real-world example (e.g., a hot cup of water sitting on a table, the warming of the ocean in the summer, a metal spoon in hot soup), the mechanisms of thermal energy transfers (heat) that are taking place. Compare and contrast, in terms of movement of particles, how convection and conduction occur.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Temperature is the measure of the average kinetic energy of the particles making up a substance.

- Thermal energy is the energy associated with the mass of a substance, the nature of the material making up a substance and the average kinetic energy of the particles of a substance. As the thermal energy increases, the total kinetic energy of the particles in the system increases.

  *[**BOUNDARY:** In the "real world," thermal energy and heat are often used synonymously; however, in the physical sciences the term "heat" is reserved for the transfer of thermal energy (e.g., from a hot object to a cold object). For the purposes of this standards document, and in order to avoid misunderstandings, the terms "thermal energy" and "thermal energy transfer" are used.]*

- Thermal energy cannot be directly measured; however, changes in thermal energy can be inferred based on changes in temperature or changes of state.

- The thermal energy of a substance depends on the amount of the substance, whereas the temperature of a substance does not depend on the amount of the substance.

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11. American Association for the Advancement of Science, "The Physical Setting," *Benchmarks On-line*, http://www.project2061.org/publications/bsl/online/index.php?chapter=4#chaptoc.

ESSENTIAL KNOWLEDGE, *continued*

- Thermal energy always transfers from a warm object to a cooler object, unless additional energy is used to reverse the transfer.
  - ◆ Conduction is a thermal energy transfer (heat) that occurs when there is a temperature difference between two objects in contact.
  - ◆ Convection is a thermal energy transfer (heat) that occurs when a fluid (i.e., a gas or liquid) moves from one location to another.
  - ◆ Radiation is a thermal energy transfer (heat) that does not require matter to transfer the energy (e.g., the energy from the Sun reaches Earth through empty space, and radiant energy can be radiated from objects to space).
- At the atomic scale, thermal energy transfer (heat) by conduction occurs when fast-moving particles of a warm substance collide with slower-moving particles of a cooler substance and transfer energy to the slower-moving particles.

Unpacking the Performance Expectations: Physical Science

Why "unpack" a performance expectation?

- The science practices standards appear to be separate from the discipline-specific standards, but they are intended to be integrated with disciplinary content knowledge.
- Unpacking a performance expectation establishes clear, specific targets of learning.
- Unpacking a performance expectation illustrates that any one performance expectation may involve multiple science practices.
- The unpacking is intended to provide a model for interpreting the science practices for a specific discipline.

How should an unpacked performance expectation be used?

- The sample unpacked performance expectation provided should be used as a model so that teachers can unpack all of the performance expectations within the discipline-specific standards.
- All of the unpacked performance expectations can be used for guidance in developing instructional strategies and curricula that offer opportunities for students to develop a robust understanding of the science practices and disciplinary content knowledge.
- All of the unpacked performance expectations can be used to develop curricula, instruction and assessments that are aligned with each other.
- Unpacking all of the performance expectations within a specific discipline enables teachers and curriculum supervisors to delineate the multiple science practices and content knowledge that are facilitated, and ultimately to link or map the performance expectations to existing curricula or to use the performance expectations as a basis for the establishment of curricular structure.
- All of the unpacked performance expectations allow decisions about instruction and curriculum design to be made in a more principled way.

SAMPLE UNPACKED PERFORMANCE EXPECTATION

Explain why solids, liquids and gases have different physical properties (e.g., shape, volume or thermal expansion) at room temperature. Justification is based on the small-particle model of substances.

This is **PS-PE.2.3.4**.

Unpacking the explanation in the performance expectation:

This is part of science practices **Objective SP.4.1**.

- Make a claim about the differences in a property (e.g., shape, volume or thermal expansion) of a general representation of solids, liquids and gases all at room temperature. Identify the appropriate conditions (e.g., temperature, pressure) that allow the only variables to be the state and type of substance.
- Use the small-particle model as evidence that supports the claim about the differences between the substances in terms of the distance between particles, the movement of particles and the distribution of particles.
- Use a description of direct observations of the differences in solids, liquids or gases in terms of the property as additional evidence to support the claim about the differences. For example, describe what happens when water is placed in a container versus what happens when a solid object is placed in the same container.
- Use the physical science principles of the speed and direction of particles, the relative movement of the particles, and the relationship between kinetic energy and temperature to justify how the evidence of the small-particle model supports the claim.

The difference between a claim and an explanation is described in one of the essential knowledge statements for science practices **Objective SP.4.1**.

Standards

1. Matter is composed of small particles called atoms that are in constant motion and that combine in various predictable ways.
2. The properties of matter and the changes that matter undergoes result from its atomic–molecular level structure. For any chemical or physical change, matter is conserved.
3. When any change occurs, energy is transferred and/or transformed, but it is never lost.

Chemistry

Organization and Structure of the Chemistry Standards for College Success

The chemistry standards are intended to outline the knowledge, skills and abilities that students need in order to be prepared for success in an introductory college-level chemistry course, or in an Advanced Placement (AP) Chemistry course. Core ideas, or "big ideas" — identified by the NSF-funded AP committee members as being central to an introductory college-level chemistry course — were the foundation of the creation of the chemistry standards. These ideas were distilled into the three chemistry standards.

The chemistry standards are organized around core ideas of the discipline. The three standards are not meant to represent an equal division of material and **concepts**,* and they are not meant to encompass *all* of the underlying concepts that may be included in a typical high school chemistry course. The committee has been deliberate in working backwards from the goal of a deep conceptual understanding of the structure of matter, the changes it undergoes, and the energy changes that accompany the changes in matter. Concepts that are not central to this theme may have been omitted. For example, the concepts (e.g., the structure of matter determines its properties, and an understanding of the energy changes that occur when matter undergoes change) that support the central themes of these standards are often developed in considerably more depth than in typical high school chemistry courses, and they are treated in a more conceptual manner. The connection between the macroscopic (real-world) level and the atomic–molecular level has been deliberately developed, and a real-world context for much of what is contained in the standards has been provided in a number of instances. Wherever possible, the relationship among the three levels of understanding chemistry has been emphasized. These levels are the macroscopic or observable level, the atomic–molecular or particulate level, and the symbolic representational level (which may include formulas and various kinds of structural drawings). Students' ability to translate among these three levels is crucial to a robust understanding of chemistry.

Each standard has three to six objectives that provide detailed descriptions of more specific chemistry core **principles** of which students should have knowledge. Similar to the enduring understandings that are the target concepts for the AP courses, the objectives are the focus of student mastery for college readiness and the key elements of the conceptual framework of the chemistry standards. An objective is often followed by a list of other objectives — within the discipline as well as from other disciplines — that are connected in some way to that objective. Both the standards and the objectives are preceded by key words and/or phrases that help articulate the content in a more concise manner. This is especially useful when a standard or an objective is referenced either by another discipline or during curriculum or instructional planning.

The objectives are, in turn, supported by a set of performance expectations (PEs) and a set of essential knowledge (EK) statements. The PEs describe what students should know, understand and be able to do in order to apply, as well as build and reason with, the essential knowledge that is necessary to understand the content outlined in the objective. The PEs illustrate how students engage in science practices to develop a better understanding of the objective. Students should be able to successfully engage in, *at the very least*, the performance expectations listed for each objective in order to be considered college ready. These performance expectations, along with the essential knowledge statements, can provide guidance in the development of assessments and curriculum materials.

* Boldfaced words and phrases are defined in the glossary.

In the chemistry standards, the emphasis on rote calculations has been minimized; instead, the PEs focus on the understanding that the molecular-level structure of a compound is reflected in its macroscopic properties and in the energy changes that accompany any change that matter undergoes. The goal of students' mastery of fewer topics in greater depth is reflected in the structure and conceptual knowledge that are demonstrated in the performance expectations and described in the essential knowledge statements.

The following performance expectation provides an example of the depth of the conceptual understanding that targets the subject of chemical and physical changes:

C-PE.2.2.9 Investigate why the dissolution of a salt (e.g., ammonium chloride, sodium acetate) in water is difficult to classify as either a chemical or physical change.

*[**BOUNDARY:** This PE addresses the fact that some processes are difficult to classify as either a chemical or physical change. One cannot assume that a salt dissolving in water is a simple physical change.]*

C-PE.2.2.9a Make a claim about the evidence required to differentiate between a chemical change and a physical change.

C-PE.2.2.9b Plan an investigation to gather data about the dissolution of a salt.

C-PE.2.2.9c Gather and record observations and measurements of the dissolution.

C-PE.2.2.9d Organize the data to present the results.

C-PE.2.2.9e Make a claim about whether the data provide evidence to identify the process of dissolution as a chemical or physical change.

With regard to this PE, students are not required to define or identify a chemical or physical change; students are asked to develop and carry out a procedure in which they examine a process that is actually very difficult to classify as either chemical or physical. The intent is not to have students probe in depth the hydrolysis of salts (which is not appropriate at this grade band), but to ask students to develop and execute a procedure to investigate the solution process, observe and record appropriate **data**, and make a **claim** based on the data and observations.

Immediately following the performance expectations, the EK statements are an articulation of the conceptual targets for student learning, providing a more detailed description of the broader knowledge delineated in the objective. These statements should be approached from a holistic perspective, and they should not be viewed as a list of discrete, unrelated **facts** for students to memorize. The EK statements also provide the language and appropriate terminology that should be incorporated into students' completion of the performance expectations.

It should be noted that both the performance expectations and the essential knowledge statements were written based specifically on the objective-level statements. There is not a corresponding relationship between the PEs and the EK statements; the PEs are a representative (but certainly not all inclusive) set of applications of the essential knowledge. Therefore, when interpreting the depth and scope of each PE, the EK statements should be considered.

The number of objectives, as well as the number of performance expectations and essential knowledge statements, varies considerably from standard to standard. For example, Standard C.2 contains the largest amount of material because structure–property relationships lie at the heart of chemistry. It should also be made clear that these objectives, PEs and EK statements are not intended to show a linear progression through the subject. Many of the topics and concepts in chemistry rely on more than one objective and on several PEs and EK statements, some of which may come from different standards. In addition, the number of PEs for a given objective does not indicate any level of importance, and it is assumed that some PEs may require a greater amount of instructional time than others.

Relationship Between Physical Science (6–8) and Chemistry (9–12)

The structure of the physical science standards for students in grades 6–8 is somewhat different than that of the chemistry standards for students in grades 9–12. Wherever possible, the appropriate learning progressions for major concepts in chemistry have been identified and used as a foundation for the understandings that students need to be successful in grades 9–12. The focus at the 6–8 grade band should be on what students can observe and measure. It is only when these observations and measurements have occurred that more complex ideas, such as a particulate level explanation, can be developed. For example, Objective PS.2.1 deals with what can be observed (students in grades 6–8 are expected to have the ability to measure basic properties such as mass, length, temperature and volume), and Objective PS.2.3 describes the use of the particulate nature of matter to explain the observations and measurements.

In general, the physical science EK statements are different from the chemistry EK statements; the chemistry EK statements were developed based on the assumption that students have already mastered the relevant material in grades 6–8. In some instances, the physical science EK statements overlap with the chemistry EK statements, but due to the complexity of the principle, it is expanded and used differently in the relevant PE for each discipline. In Standard C.3 and Standard PS.3, there are similar EK statements that appear within both physical science and chemistry objectives (e.g., "A closed system does not interact with its surroundings — matter and energy cannot get into or out of the system. Most systems of interest in our everyday lives are open systems — matter and energy can be transferred into or out of the system."). The physical science and chemistry PEs that are related to this EK statement reflect the increasing complexity of the content from the 6–8 grade band to the 9–12 grade band.

Standard C.1
Structure of Matter

Matter is composed of small **particles** called atoms that are in constant motion and that combine in various predictable ways.

Students understand that the existence of atoms can be used to explain the structure and behavior of matter. The current understanding of the nature of the atom is derived from experimental observations and is the underlying principle behind the organization of the periodic table, the understanding of periodicity, and the understanding of the bonds formed between elements.

Clarification: In statements where the assertion is made that matter is made of atoms, the term "atoms" refers to all of the forms that atoms can take when bonded or aggregated. Rather than repeat that matter may be made up of any of the following — atoms; ions; molecules in which atoms are bonded; crystalline lattices in which atoms or ions are bonded in three-dimensional arrays; or metals in which atomic nuclei and core electrons are surrounded by valence electrons — the statement has been simplified.

Objective C.1.1
Atomic Theories

Students understand the current **model** of atomic structure, how the model has changed over time, and how experimental **evidence** about atomic structure has led to changes in the atomic model.

> **Suggested Connections**
> *Within Chemistry:* Conservation of Matter (C.2.3)
>
> *Between Chemistry and Other Disciplines:* Nuclear Interactions and the Conservation of Mass–Energy (P.2.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Chemistry 1A, 1B, 1C, 1D

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.1.1.1 Describe how atomic models have changed over time as new experimental results have led to new **theories** about the structure of the atom. Description includes the experimental evidence that has led to changes in the atomic model, the construction of **representations**, the comparison and contrast of the models of atomic structure, and the identification of the factors that have remained consistent over the years and those that have changed.

*[**BOUNDARY:** Historical experiments are limited to models developed by Dalton, Thompson, Rutherford, Bohr and Schrödinger. Students should not be expected to memorize the names of scientists or the experimental details.]*

C-PE.1.1.2 Use data consisting of symbolic representations (e.g., $^{11}Na^{+}$) or numbers of subatomic particles for various atoms, isotopes or ions.

- **C-PE.1.1.2a** Make a claim, based on the number of protons, about which **species** are atoms of different elements, and identify the elements.
- **C-PE.1.1.2b** Make a claim, based on the number of protons and electrons, about which species are ions, and identify the ions.
- **C-PE.1.1.2c** Make a claim, based on the number of protons and neutrons, about which species are isotopes of the same element, and identify the element of which they are isotopes.
- **C-PE.1.1.2d** Explain, using the concept of isotopes, why atomic masses are not expressed as whole numbers.
- **C-PE.1.1.2e** Calculate atomic masses. Calculations are based on isotopic abundances.

C-PE.1.1.3 Explain, in terms of the mobility of electrons, how the charged nature of matter produces measurable and observable effects (e.g., static electricity, lightning) on the macroscopic scale.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Atomic theories have developed over time according to the available experimental evidence and the interpretation of this evidence. Theories of atomic structure have evolved from ideas of atoms as small, indestructible spheres to the current model, which indicates that an atom has a very small nucleus composed of protons and neutrons. The nucleus is surrounded by electrons that take up most of the space in an atom.
- Protons are positively charged particles that define the chemical identity of an element. Neutrons have no charge and have approximately the same mass as protons.
- The nucleus is surrounded by negatively charged electrons that have a relatively small mass compared to that of protons and neutrons. Electrons occupy most of the volume of an atom.
- The protons and electrons in a neutral atom are equal in number.
- An ion is a species in which the number of electrons is not equal to the number of protons. An anion has more electrons than protons, with a net negative charge; a cation has fewer electrons than protons, with a net positive charge.
- Based on the current atomic model, electrons can be considered as clouds of electron density, rather than as particles orbiting the nucleus.

Objective C.1.2
Electrons

Students understand that the **interactions** of electrons between and within atoms are the primary factors that determine the properties of matter.

> **Suggested Connections**
> *Within Chemistry:* Periodic Table (C.2.1)
>
> *Between Chemistry and Other Disciplines:* Electrical Interactions and Forces (P.1.5); Conservation of Linear Momentum (P.2.2); Energy and Fields (P.4.2); Electromagnetic Interactions and Fields (P.4.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Chemistry 1B, 1C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.1.2.1 Explain, using absorption and emission spectra, how this evidence supports the idea that electrons have discrete energy levels. Justification includes the use of models and visual representations, and a discussion of how emission and absorption spectra arise, why these spectra are unique to each element, and how these spectra are limited to discrete energy levels. Compare the spectra of elements to standard spectra in order to identify elements on Earth and in stars. Make a claim, using the spectra, that the same substances exist regardless of their location in the universe.

C-PE.1.2.2 Explain, based on the absorption of light, the relationship between the color of an object and the color of light that the object absorbs. Give examples of and explain differences in colors of light emitted and/or absorbed from a range of real-world examples (e.g., fireworks, textile dyes).

C-PE.1.2.3 Explain, based on repeating patterns of core and valence electrons, the organization of the periodic table. Represent, using the periodic table, the electron configurations of main group elements in periods 1–3. Represent, using noble gas notation, and in terms of core and valence electrons, electron configurations of main group elements in periods 1–3.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Only electrons in the highest energy state (valence electrons) are involved in bonding.
- It is not possible to predict exactly where electrons are located. Nevertheless, the exact energies of electrons can be measured, and regions where electrons are most likely located can be defined.
- Electrons in atoms have definite energy levels, with no values in between. When an electron moves from one energy level to another, it emits or absorbs a photon that has energy equal to the energy difference between the levels. The energy levels of electrons are different for each element. Consequently, each element has a unique emission or absorption spectrum.
- Both the emission and absorption spectra can be used to identify elements wherever they are located in the universe.
- Orbitals represent the probability of finding an electron in a region of space.

  *[**BOUNDARY:** Electrons exhibit characteristics of both particles and waves. This is a property of particles at the atomic–molecular level. This is beyond the scope of these standards.]*
- Electrons usually occupy the lowest available energy orbitals (ground state).
- Each orbital can describe the probability for a maximum of two electrons. Different types of orbitals are represented by lowercase letters (e.g., *s*, *p*, *d* and *f*). Each type of orbital has a different shape (e.g., *s* has a spherical shape and *p* has a dumbbell shape).

  *[**BOUNDARY:** Instruction should only focus on* s *and* p *orbitals.]*
- Higher-energy electron orbitals occupy space further from the nucleus. As a result, the size of atoms increases from the top to the bottom of a group on the periodic table.
- The electron configuration is a shorthand representation of the positions and energies of all the electrons in an atom.
- The electron configuration may be derived from an element's position on the periodic table.

Objective C.1.3
Bonding

Students understand that matter is composed of atoms of elements, most of which are bonded in different but predictable ways.

> **Suggested Connections**
> *Within Chemistry:* Periodic Table (C.2.1); Structure–Property Relationships (C.2.2); Chemical Energy (C.3.3)
>
> *Between Chemistry and Other Disciplines:* DNA to Trait (LS.5.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Chemistry 2C, 2D, 5C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.1.3.1 Describe, using graphic representations, the types of energy changes (e.g., potential energy **transforms** into kinetic energy during bond formation; change in potential energy for an exothermic or endothermic reaction) that may occur in a system of reacting molecules when a bond between atoms or ions is either broken or formed.

C-PE.1.3.2 Compare and contrast the following types of bonding: covalent, polar covalent and ionic. Discussion includes the nature of the attraction between bonded atoms, the placement of bonding electrons, the directionality of each bond, and the polarity of each bond.

PERFORMANCE EXPECTATIONS, *continued*

C-PE.1.3.3 Given a list of metal and nonmetal elements:

*[**BOUNDARY:** This PE should only address simple ionic compounds from main group elements. Metal and nonmetal elements from groups 1, 2 and 17, and the elements hydrogen, carbon, nitrogen and oxygen, should be provided to students. Students are not expected to memorize polyatomic ions and their charges, but when provided with a reference table of polyatomic ions and their charges, students should be able to predict formulas and names.]*

C-PE.1.3.3a Make a claim, using the periodic table, about the number of electrons (valence electrons) that are involved in any kind of bonding.

C-PE.1.3.3b Predict, using the identity of the elements and their locations in the periodic table, the type of bond that forms between any two atoms.

C-PE.1.3.3c Predict, based on the combination of a metal and a nonmetal, the formula of a compound, and name the compound. **Prediction** is based on the number, types and formulas of the component ions.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The atoms of many elements are more stable when they are bonded with other atoms.
- When two isolated atoms bond in the gas phase, energy is released to the surroundings, resulting in a lower energy system.
- Atoms can bond to form molecules, ionic lattices, network covalent structures or materials with metallic properties. Each of these types of structures has different, yet predictable, properties that depend on the identity of the elements and the types of bonds formed.
- The forces of attraction between the particles in molecules, ionic lattices, network covalent structures or materials with metallic properties are called chemical bonds.
- The bonds in most compounds fall on a continuum between the two extreme models of bonding: ionic and covalent.
- An ionic bond involves the attraction between two oppositely charged ions, typically a positively charged metal ion and a negatively charged nonmetal ion. An ion attracts oppositely charged ions from every direction, resulting in the formation of three-dimensional lattices.
- Covalent bonds typically involve at least two electrons shared between the bonding atoms. Nonmetal atoms usually combine by forming one or more covalent bonds between atoms. Covalent bonding can result in the formation of structures ranging from small molecules to large molar mass biopolymers and three-dimensional lattices (e.g., a diamond).
- A polar covalent bond forms between two atoms with different electronegativities; the magnitude of the polarity of the bond depends on the electronegativity difference and the distance between the atoms (bond length).
- Many acids and bases contain covalent bonds but may undergo reactions (e.g., reactions with water) that result in the production of an ionic species.
- When elements bond, they form compounds that are named in systematic ways.

Objective C.1.4
Representations of Matter

Students understand that atoms, molecules and ionic substances can be represented with a variety of models.

> **Suggested Connections**
> *Within Chemistry:* Structure–Property Relationships (C.2.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Chemistry 1D, 2A, 2C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.1.4.1 Translate among representations (including molecular formulas, Lewis structures, ball-and-stick models and **space-filling models**) of macroscopic, atomic–molecular and symbolic levels of matter. Compare and contrast the types of information that can be inferred from the different representations. Choose the most appropriate representation to illustrate a physical or chemical process. Justification includes a discussion of the type of information needed and how the representation best illustrates the information.

C-PE.1.4.2 Construct Lewis structures for simple molecules, showing all bonds and lone pairs of electrons for simple molecules. Using **regions of electron density**, predict **electron pair geometry** and the shape of the molecule from the arrangement of the atoms in space.

*[**BOUNDARY:** Students are expected to construct Lewis structures and valence shell electron pair repulsion (VSEPR) diagrams only for the following combinations of elements: hydrogen, carbon, nitrogen, oxygen, phosphorus, sulfur and the halogens.]*

C-PE.1.4.3 Predict, using the shape of a molecule and the polarity of bonds in a molecule, the type of intermolecular forces (IMFs) for a given compound.

*[**BOUNDARY:** Intermolecular forces include hydrogen bonding, dipole–dipole and London dispersion forces.]*

C-PE.1.4.4 Given the molecular formulas for two simple compounds with similar molar masses (e.g., ethane and methanol):

- **C-PE.1.4.4a** Construct two-dimensional models (Lewis structures).
- **C-PE.1.4.4b** Construct three-dimensional models (ball-and-stick models or computer models).
- **C-PE.1.4.4c** Predict, using the two-dimensional or three-dimensional models the types of intermolecular forces present in each of the compounds.
- **C-PE.1.4.4d** Explain, using the two-dimensional or three-dimensional models, the relative strength of the intermolecular forces.
- **C-PE.1.4.4e** Predict, using the two-dimensional or three-dimensional models, the relative physical properties (e.g., boiling point, solubility, vapor pressure).

C-PE.1.4.5 Given a simple chemical reaction (e.g., synthesis of water, decomposition of hydrogen peroxide, combustion of methane):

- **C-PE.1.4.5a** Write a balanced chemical reaction.
- **C-PE.1.4.5b** Translate from the molecular formulas to Lewis structures.
- **C-PE.1.4.5c** Translate from Lewis structures to three-dimensional models (ball-and-stick models or computer models).
- **C-PE.1.4.5d** Identify, using any of the models, which bonds are broken and which bonds are formed.
- **C-PE.1.4.5e** Make a claim, using the concept of atoms, about how these models support the conservation of matter.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Matter can be represented at three different levels: macroscopic, atomic–molecular and symbolic. The macroscopic level is observable in the real-world setting. The atomic–molecular level is often represented by visual representations, including animations. The symbolic level includes elemental symbols, chemical formulas and equations, and Lewis structures.
- The atomic–molecular level structure of matter determines both the macroscopic structure and the properties of the material.
- The atomic–molecular level structure of simple molecules can be represented symbolically in two or three dimensions as molecular formulas, structural formulas (Lewis structures), ball-and-stick models or space-filling models. Each of these symbolic representations can provide some unique information about the structure of the substance, as well as some information that is common to all the models.
- Different kinds of models or representations give different information about materials. For example, ball-and-stick models provide information about shape and bond angles; space-filling models give information about surface features.
- Symbolic representations allow for the visualization of atoms and molecules that are too small to see with conventional microscopes and for the prediction of the properties of these atoms and molecules.
- Two-dimensional representations (Lewis structures) can be drawn by using a set of simple rules.
- Lewis structures provide a foundation for predicting three-dimensional electron pair geometries and three-dimensional shapes of simple molecules.
- Intermolecular forces (IMFs) can be predicted based on the shape of the molecule and the polarities of the bonds.
- Different kinds of models are more appropriate for representing different chemical substances (e.g., ionic and covalent network species are best represented by models that incorporate elements of the lattice structure).

Objective C.1.5
States of Matter

Students understand that matter exists in different states, and that these states are determined by atomic–molecular level structure, attractions between particles, and the relative motions of particles.

> **Suggested Connections**
> *Within Chemistry:* Structure–Property Relationships (C.2.2); Energy Transfers and Transformations (C.3.2)
>
> *Between Chemistry and Other Disciplines:* Weather Processes (ES.1.4); Conservation of Linear Momentum (P.2.2); Heating and Cooling Interactions and Energy (P.3.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Chemistry 2A, 2B, 5D; AP Environmental Science 1B, 3C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.1.5.1 Translate among macroscopic (e.g., a beaker of water), symbolic [e.g., $H_2O(s)$], and atomic–molecular level representations of states. Describe, using representations, the relative arrangement of particles in solids, liquids and gases. Or conversely, identify the state of matter depicted in atomic–molecular level pictures or animations.

PERFORMANCE EXPECTATIONS, *continued*

C-PE.1.5.2 Explain why gases expand to fill a container of any size, while liquids flow and spread out to fill the bottom of a container and solids hold their own shape. Justification includes a discussion of particle motion and the attractions between the particles.

C-PE.1.5.3 Investigate the behavior of gases. Investigation is performed in terms of volume (V), pressure (P), temperature (T) and amount of gas (n) by using the ideal gas law both conceptually and mathematically.

- **C-PE.1.5.3a** Formulate a **scientific question** about the behavior of gases (e.g., the effect of changing temperature on the volume of a fixed amount of gas).
- **C-PE.1.5.3b** Plan an investigation to address the behavior of gases.
- **C-PE.1.5.3c** Gather and record observations and measurements.
- **C-PE.1.5.3d** Organize the data, and choose appropriate representation of the data to show the relationships among the variables.
- **C-PE.1.5.3e** Make a claim, using the analysis of the data, about the relationships among the variables.
- **C-PE.1.5.3f** Predict, using the relationships among variables (V, P, T, n), the effect on one variable when another variable is changed.
- **C-PE.1.5.3g** Explain, using visual representations, the observed relationships among the variables (V, P, T, n).

  *[**BOUNDARY:** Visual representation should focus on two variables with **conditions** that produce ideal behavior; phase diagrams are beyond the scope of these standards.]*

C-PE.1.5.4 Explain natural phenomena (e.g., cold air escaping from a tire or low atmospheric pressure on rainy days) in terms of the kinetic–molecular theory of gases.

C-PE.1.5.5 Construct atomic–molecular level representations of changes that occur when thermal energy is added to a pure substance. Explain, using these representations, why the continuous addition of thermal energy to a pure substance will generally result in a change of state (not a chemical reaction).

C-PE.1.5.6 Explain, in terms of molecular motion, why liquid water expands when it freezes, whereas most substances expand when heated (e.g., mercury in a thermometer). Provide examples of instances where the expansion of water upon freezing is important (e.g., ice floating on water acts as an insulator in ponds to keep temperature of the rest of the water above freezing).

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- There are four states of matter: solid, liquid, gas and plasma.
- The existence and behavior of matter in either the solid, liquid, gas or plasma state can be explained by the atomic–molecular theory (the idea that matter is composed of small particles).
- The behavior of a given quantity of gas can be described in terms of its pressure, volume and temperature.
- Each state of matter has a predictable behavior that depends on the chemical composition of the substance and the attractions between particles of that substance.
- In a solid, the kinetic energy of the particles making up the substance is not great enough to overcome the attractions holding them together. Although the particles vibrate in place, the distance between them does not increase.
- In a liquid, the kinetic energy of the particles making up the substance is sufficient to overcome the attractions, thereby allowing the particles to move relative to each other. Most of the particles, however, do not have enough kinetic energy to completely overcome the attractions and enter the gas state.
- In a gas, the particles have enough kinetic energy to overcome any attractions. Generally, the separation between gas particles is such that their interactions are minimal.

ESSENTIAL KNOWLEDGE, *continued*

- For a given substance, the temperature (and, therefore, the average kinetic energy) needed for a change of state to take place depends on the attractions between the particles in that substance. In other words, the temperature at which a change of state takes place depends on the amount of energy that is required to overcome the attractions between the particles.
- Vapor pressure occurs when the particles of solids and liquids have enough kinetic energy to enter the vapor (gas) state. Vapor pressure increases with temperature. Liquids boil when their vapor pressure reaches atmospheric pressure.
- When a substance changes state, the relative arrangement of the particles changes, as well as the distance between these particles. The atoms that make up the particles of the substance are *not* rearranged to form a new substance.
- When thermal energy is added to a solid, liquid or gas, most substances increase in volume because the particles have increased kinetic energy, causing a greater distance between the particles.
- For most substances, the distance between particles increases as they change from solid to liquid to gas, meaning that the density of a solid is usually greater than the density of a liquid. The density of a liquid is always greater than the density of a gas.
- Because solid water has an extensive network of hydrogen bonds that gives it an open structure, the density of solid water is less than that of liquid water. When water freezes, its volume expands.
- The kinetic–molecular theory is an explanation of the macroscopic properties (e.g., pressure, temperature, volume) of gases, using the idea of particle interactions and motions.

Objective C.1.6
Nuclear Chemistry

Students understand that changes occurring in the nucleus of an atom may alter the identity of an atom and often result in large changes in energy.

Suggested Connections
Within Chemistry: Conservation of Matter (C.2.3); Chemical Energy (C.3.3)

Between Chemistry and Other Disciplines: Relative and Absolute Dating (ES.3.1); Conservation of Charge, Mass and Energy (P.2.1); Nuclear Interactions and the Conservation of Mass–Energy (P.2.3)

Prepares students for the following AP Enduring Understandings: AP Chemistry 1E; AP Environmental Science 1A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.1.6.1 Compare and contrast chemical and nuclear reactions. Discussion includes the differences in energy changes and the idea that chemical reactions involve the rearrangement of atoms and their valence electrons, while nuclear reactions involve changes in the nucleus.

C-PE.1.6.2 Compare and contrast nuclear fusion and fission.
*[**BOUNDARY:** Balancing nuclear reactions is beyond the scope of these standards.]*

C-PE.1.6.3 Describe the formation of elements in stars by nuclear fusion of hydrogen and helium.

C-PE.1.6.4 Identify radioisotopes that are commonly used for medical and commercial purposes. Describe, based on the half-life of each radioisotope, the advantages and disadvantages of why certain radioisotopes are used for different purposes.

PERFORMANCE EXPECTATIONS, *continued*

C-PE.1.6.5 Construct representations, at the particle level and graphically, of the changes that occur in a given radioactive sample (e.g., 64 particles decaying over four half-lives).

C-PE.1.6.6 Construct a representation, based on information gathered from print and electronic resources, of the energy transformations and **transfers** occurring in a nuclear power plant.

C-PE.1.6.7 Describe, using information gathered from print and electronic resources, the advantages and disadvantages of nuclear power. Advantages and disadvantages should include the energy potential of fission and fusion, as well as the environmental impact of nuclear power (e.g., uranium mining, nuclear power plant safety and the issue of radioactive waste disposal).

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- All of the elements, except hydrogen and helium, originated from the nuclear fusion reactions of stars. This production of heavier elements from lighter elements by stellar fusion has never ceased and continues today.

- Chemical reactions involve electrons; nuclear reactions involve only changes in the nucleus. Neutrons have little effect on how an atom interacts with other atoms, yet the number of neutrons does affect the mass and stability of the nucleus.[12] Atoms with the same number of protons and a different number of neutrons are called isotopes.

- When an atom has an unstable nucleus, the unstable nucleus emits radiation (e.g., alpha, beta, gamma and positron). This process, called radioactive decay, increases the stability of the nucleus. Atoms with an unstable nucleus are often called radioisotopes.

- Half-life is a measure of the rate of radioactive decay, or the amount of time it takes for half of a radioactive sample to decay to its products. For any radioisotope, the half-life is constant and unique and can be used to determine the age of the material.

- Radioisotopes have several medical applications. The radiation emitted as a result of the unstable nucleus has high energy and can be detected. These characteristics allow radioisotopes to be used as tracers of biological processes and to kill biological materials (e.g., cancer cells).

- Fission, the splitting of a nucleus into small fragments, and fusion, the combining of two nuclei, are types of nuclear reactions.

- When a nuclear reaction occurs, the mass–energy interconversion is significant. Nuclear reactions, such as fission and fusion, are accompanied by large energy changes that are much greater than those that accompany chemical reactions.

- Nuclear reactions can be used as a controlled source of energy (e.g., a nuclear power plant).

12. American Association for the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford University Press, 1993), 80.

Standard C.2
Matter and Change

The properties of matter and the changes that matter undergoes result from its atomic–molecular level structure. For any chemical or physical change, matter is conserved.

Students understand that the properties of materials are determined by the elements present in the substance; the arrangement of the atoms, ions or molecules in the compound; and the forces between atoms, ions or molecules in the compound. Conversely, if the properties of a material are known, then predictions about the type of bonding and the type of intermolecular attractions present at the atomic–molecular level can be made.

Clarification: In chemical systems, mass–energy conservation is not considered.

Objective C.2.1
Periodic Table

Students understand that the periodic table is an organizational tool that can be used for the prediction and classification of the trends and properties of elements.

Suggested Connections
Within Chemistry: Electrons (C.1.2); Bonding (C.1.3)

Between Chemistry and Other Disciplines: Carbon Cycle (ES.4.2); Energy Transfer (LS.4.2); Nuclear Interactions and the Conservation of Mass–Energy (P.2.3)

Prepares students for the following AP Enduring Understandings: AP Chemistry 1C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.2.1.1 Predict, based on its position in the periodic table, the properties of a given main group element. Properties include appearance, electronegativity, type of bond formed, and ionic charge. Make a claim about the type (metal, nonmetal, metalloid) of the given element. Give examples of other elements that would have similar properties, and explain why they would have similar properties.

*[**BOUNDARY:** Elements are restricted to adjacent elements in the s-block and p-block only.]*

C-PE.2.1.2 Given a data table of atomic properties (e.g., atomic radius, ionization energy or electronegativity) for elements in a period and/or elements in a group:

*[**BOUNDARY:** Atomic properties do not include electron affinity and only address first ionization energy. It is not necessary to explain changes in size across a period.]*

- **C-PE.2.1.2a** Select the appropriate method of data representation.
- **C-PE.2.1.2b** Analyze data for trends of a property across a period and down a group.
- **C-PE.2.1.2c** Explain, using knowledge of atomic structure, the trend in that property across a period or down a group.
- **C-PE.2.1.2d** Predict, based on the previous explanation, the trend in that property for a different set of elements. Gather data from print and electronic resources, and confirm the prediction.

C-PE.2.1.3 Predict, using the periodic table, trends in properties for groups (i.e., families) of elements. Predicted trends should include atomic radius, electronegativity, ionic charge (if formed), type of bond formed with metal and/or nonmetal, and type of substance (metal, nonmetal, metalloid).

C-PE.2.1.4 Explain, in terms of attractions and repulsions between the electrons and the nucleus, why the radius of an atom changes when the atom becomes an ion.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The modern version of the periodic table is organized in order of increasing atomic number (number of protons).
- Elements were originally placed in the periodic table based on their repeating properties, which are a result of the number and type of valence electrons.
- Properties of an element can be predicted based on its placement in the periodic table. Groups of elements exhibit similar properties with predictable variations; rows of elements have predictable trends.
- Elements are often classified as metals, nonmetals and metalloids.
- There are a number of elements — such as nitrogen, oxygen, phosphorus, sulfur, hydrogen and carbon — that are important for living systems. Carbon, the most important of these elements, is central to the chemistry of biological systems because of its unique bonding characteristics. Carbon compounds are usually classified as organic compounds.
  *[**BOUNDARY:** Organic nomenclature is beyond the scope of these standards.]*
- Another way to use the periodic table is to consider the elements as arranged in "blocks" based on the elements' outermost electrons. The elements in these blocks (s-block, transition metals, p-block, lanthanides and actinides) in the modern periodic table also have similar properties of predictable variability.
  *[**BOUNDARY:** Only the s-block and the p-block should be discussed in detail.]*

Objective C.2.2
Structure–Property Relationships

Students understand the relationship between molecular-level structure and chemical and physical properties.

Suggested Connections
Within Chemistry: Bonding (C.1.3); Representations of Matter (C.1.4); States of Matter (C.1.5)

Between Chemistry and Other Disciplines: Humans and the Environment (ES.5.3); Cell Structure (LS.2.2); Nongenetic Information Transmission (LS.5.5)

Prepares students for the following AP Enduring Understandings: AP Chemistry 2A, 2B, 2C, 2D, 3B, 6C; AP Environmental Science 3B, 3C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.2.2.1 Make a claim, using a data table listing melting points and/or boiling points, about the degree of strength and the type of intermolecular forces between the particles of a substance (e.g., an ionic compound, a nonpolar molecular compound and a polar molecular compound). Justification includes a discussion of the molecular-level structure of the compound.

C-PE.2.2.2 Predict, in terms of the strength of the attractions between particles that must be broken as a substance changes state, the relative melting points, boiling points and vapor pressures for a range of types of substances (e.g., an ionic compound, a nonpolar molecular compound and a polar molecular compound).

C-PE.2.2.3 Explain, in terms of shape, polarity and intermolecular forces, the unique properties of water (e.g., high boiling point, high specific heat) and how these properties affect life on Earth. Explain, based on the structure and shape of water as well as on the intermolecular forces present in water, why liquid water expands when it freezes. Provide examples where this phenomenon is important (e.g., ice floats on water, acting as an insulator in ponds to keep the temperature of the rest of the water above freezing).

PERFORMANCE EXPECTATIONS, *continued*

C-PE.2.2.4 Explain, in terms of molecular structure and weak intermolecular forces, why volatile liquids (e.g., acetone, gasoline) and volatile solids (e.g., camphor, moth balls) can be detected by odor, while ionic solids (e.g., sodium chloride) or molecular solids with stronger intermolecular forces (e.g., sugar) are not detectable by odor.

C-PE.2.2.5 Investigate the solubility of a given set of substances in water.

*[**BOUNDARY:** Explanation should not include entropy changes for the water.]*

C-PE.2.2.5a Formulate a scientific question, based on the molecular-level structure of a substance, about the solubility of types of substances in water.

C-PE.2.2.5b Plan an investigation to address the variables involved in comparing solubility of types of substances.

C-PE.2.2.5c Gather and record observations and measurements of the relative solubility of given substances.

C-PE.2.2.5d Organize and present data to address the differences in solubility.

C-PE.2.2.5e Make a claim about the relative solubility of different types of substances in water.

C-PE.2.2.5f Explain results of the investigation. Explanation is based on the energies involved in breaking the interactions in the solute and the solvent, and in making new interactions between the solute and the solvent.

C-PE.2.2.6 Construct atomic–molecular level representations of the solution process for both ionic and molecular species. Describe, using these representations, the process of dissolving a solute in a solvent. Compare and contrast the solution of an ionic compound in water and the solution of a polar molecular compound (e.g., sucrose) in water. Predict, using molecular structure, the conductivities of the resulting solutions.

*[**BOUNDARY:** Students are expected to use only substances that are completely soluble and do not undergo further reaction.]*

C-PE.2.2.7 Choose a solvent that will dissolve a given solute. Justification of the chosen solvent is based on the types of intermolecular forces present in the solvent and solute. Give examples of solvents that could be used to remove stains or clean up spills of various types (e.g., using turpentine to remove grease; using water to remove sticky sugar residue), and explain why each of these solvents dissolves each spill or stain.

*[**BOUNDARY:** Explanation should not include a discussion of entropy.]*

C-PE.2.2.8 Investigate, from a set of given samples, the principles involved in carrying out ionic reactions in solution.

C-PE.2.2.8a Prepare, from given samples, a range of solutions of ionic compounds.

C-PE.2.2.8b Combine pairs of ionic solutions to determine which pairs form a precipitate. Identify some possible compounds that could be the precipitate.

C-PE.2.2.8c Predict, based on the results of the investigation, which ionic compounds are insoluble in water. Compare predictions to a reference table of solubility.

C-PE.2.2.8d Construct atomic–molecular level representations of reactions in solution, and use these representations to explain the processes that must occur when two ionic substances dissolve in water and react.

C-PE.2.2.9 Investigate why the dissolution of a salt (e.g., ammonium chloride, sodium acetate) in water is difficult to classify as either a chemical or physical change.

*[**BOUNDARY:** This PE addresses the fact that some processes are difficult to classify as either a chemical or physical change. One cannot assume that a salt dissolving in water is a simple physical change.]*

C-PE.2.2.9a Make a claim about the evidence required to differentiate between a chemical change and a physical change.

C-PE.2.2.9b Plan an investigation to gather data about the dissolution of a salt.

C-PE.2.2.9c Gather and record observations and measurements of the dissolution.

C-PE.2.2.9d Organize the data to present the results.

PERFORMANCE EXPECTATIONS, *continued*

C-PE.2.2.9e Make a claim about whether the data provide evidence to identify the process of dissolution as a chemical or physical change.

C-PE.2.2.10 Explain, using the structural features of molecules, why some compounds are considered acids and some are considered bases. Identify structural features of molecules that give rise to acidity, to strong basicity, and to weak nitrogenous bases.

C-PE.2.2.11 Investigate the relationship between pH and concentration of an acid.

*[**BOUNDARY:** This investigation is for a monoprotic strong acid.]*

C-PE.2.2.11a Formulate a scientific question about the effect of concentration on pH.

C-PE.2.2.11b Plan an investigation to address the variables involved when an acid is diluted.

C-PE.2.2.11c Gather and record observations and measurements of the pH and dilution of the acid.

C-PE.2.2.11d Organize and present data to show the relationship between the pH and concentration of the acid.

C-PE.2.2.11e Make a claim, using the results of the investigation, about the relationship between pH and concentration.

C-PE.2.2.11f Give examples of common substances that are acidic and common substances that are basic.

C-PE.2.2.12 Explain the differences in properties of familiar substances (e.g., sodium chloride, quartz, water, gasoline, copper). Justification includes a discussion of the molecular-level structures of the substances and the attractions between the particles in the substances.

*[**BOUNDARY:** Substances used should be familiar to students and should reflect a range of different types of bonding.]*

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The physical properties of materials are determined by the strength of the attractions (bonds or intermolecular forces) between particles.
- Compounds that have three-dimensional lattice networks of bonds, either ionic or covalent, have very high melting and boiling points because bonds must be broken in order to change state from solid to liquid to gas.
- The shape and polarity of the molecules of a substance determine the relative strength of its intermolecular forces (IMFs).
- There are several types of IMFs, including the following: London dispersion forces (present in all molecules), dipole–dipole (present in polar molecules) and hydrogen bonding (a special case of dipole–dipole).
- Molecular compounds generally have melting and boiling points that are dependent on their molar mass and IMFs.
- A solute will usually be most soluble in a solvent that has similar IMFs.
- Many substances dissolve in water (a polar solvent). Consequently, water is a very useful and familiar solvent.
- When a substance dissolves in water, it is sometimes difficult to determine whether the process is a physical or chemical change.

  *[**BOUNDARY:** Students are not required to determine whether dissolution is a physical or chemical process. They can participate in an investigation of a solution of a salt in order to understand that a clear distinction may not always be determined for certain processes.]*
- Many ionic compounds dissolve in water. In order for this to occur, the forces of attraction between the ions in the solid must be overcome by the ion–dipole interactions with the water.

ESSENTIAL KNOWLEDGE, *continued*

- The formation of a precipitate or a molecular compound, in a chemical reaction between ionic compounds in aqueous solution, often occurs because the new ionic or covalent bonds are stronger than the original ion–dipole interactions of the ions in solution.
- There are structural features of molecules that can give rise to specific kinds of reactivity (e.g., acidity often results when hydrogen is covalently bonded to an electronegative element).
- The acidity of an aqueous solution is often expressed as pH, where pH is related to the concentration of the hydronium ion.
- In very large molecules, a specific region may have predictable polarities and reactivities based on the structural features of that region.
- A common class of reactions (oxidation reactions) often involves the reaction of oxygen with carbon compounds.

  *[**BOUNDARY:** The common reaction classifications that are often used in high school chemistry courses often lead to misconceptions because they are not based on the actual chemistry, but on surface features that may be similar from one system to another (such as "exchanging partners"), even though the underlying chemistry is not the same. Therefore, these types of reaction classifications (e.g., single replacement, double replacement) are not addressed here.]*

Objective C.2.3
Conservation of Matter

Students understand that matter is conserved whenever any change occurs.

Suggested Connections

Within Chemistry: Atomic Theories (C.1.1); Nuclear Chemistry (C.1.6)

Between Chemistry and Other Disciplines: Water Cycle (ES.4.1); Carbon Cycle (ES.4.2); Cell Growth and Repair (LS.2.3); Ecosystem Stability (LS.3.3); Conservation of Charge, Mass and Energy (P.2.1)

Prepares students for the following AP Enduring Understandings: AP Chemistry 1A, 1E, 3A, 3C; AP Environmental Science 3A, 3C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.2.3.1 Construct a balanced symbolic representation, based on given reactants and products, of a chemical reaction. Construct a molecular-level representation of the chemical reaction, and explain, using the concept of atoms, why matter is conserved during any change.

C-PE.2.3.2 Translate, using the mole as a conversion factor, among symbolic, molecular-level and macroscopic-level representations. Explain, in terms of atoms, the conservation of mass at the atomic–molecular level and how this concept can be translated, using moles, to the macroscopic level.

C-PE.2.3.3 Use the mole concept to interconvert between amounts of reactants and products in chemical reactions at the macroscopic level for solids, liquids, gases and solutions.

- **C-PE.2.3.3a** Calculate the number of moles of a substance in a given mass.
- **C-PE.2.3.3b** Derive the empirical formula of a compound. Derivation is based on a given mass or percent by mass for each element in a compound.

CHEMISTRY

PERFORMANCE EXPECTATIONS, *continued*

C-PE.2.3.3c Explain, in terms of atoms and moles, why the ratio of the masses of each element in a compound is constant for a given compound.

C-PE.2.3.3d Predict, given the moles of one component of the reaction, the moles of the other components.

C-PE.2.3.3e Calculate, given the mass of one component of the reaction, the moles and masses of the other components, and show that matter is conserved at the macroscopic level.

C-PE.2.3.3f Explain, given moles of more than one reactant, why it is important to determine which reactant will limit the amount of product formed.

*[**BOUNDARY:** The focus of this PE should be conceptual and not quantitative.]*

C-PE.2.3.4 Design an experimental procedure to produce a salt from a simple precipitation reaction.

C-PE.2.3.4a Prepare, using molarity as the unit of concentration, solutions of appropriate concentrations.

C-PE.2.3.4b Calculate theoretical yield.

C-PE.2.3.4c Calculate experimental yield.

C-PE.2.3.4d Explain, using possible sources of error, why the experimental yield is not the same as the theoretical yield.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Atoms are central to the principle of the conservation of matter.
- When a change occurs, the total number of atoms within a closed system remains the same; therefore, the total mass of the system remains the same.
- The reference for atomic masses is carbon-12. One atomic mass unit (amu) equals 1/12 of the mass of a carbon-12 atom.
- Because the mass of an atom is very small, the mole is used to translate the mass of an atom to the macroscopic level. The mass of a mole of any substance is equal to its formula mass in grams.
- When a chemical change occurs, the numeric relationship between the reactants and products is determined at the atomic–molecular level. In order to translate this relationship from the atomic–molecular level to the macroscopic level, the mole and the formula mass in grams are used as a measure of the amount of substance.
- A mole is used as a counting unit, like a dozen.

  *[**BOUNDARY:** Students are not expected to memorize Avogadro's number or use it explicitly in calculations (e.g., calculate the number of oxygen atoms in 10 grams of carbon dioxide).]*
- A balanced chemical reaction represents the conservation of matter at both the atomic–molecular level and the macroscopic level by showing the relationship between the reactants and products.
- A stoichiometric calculation is a conversion from one amount (mass, mole, volume of gases, volume of solutions) of substance in any chemical change to another amount and can be made as long as the relationships among all of the reactants and all of the products at the molecular level are known.
- The standard unit of concentration is molarity (mol/L), which is a measure of the amount of a substance in solution.

Objective C.2.4
Chemical Equilibrium

Students understand that many reactions do not proceed completely from reactants to products; instead, reactions reach a state of dynamic equilibrium where the amounts of reactants and products appear constant.

Suggested Connections

Within Chemistry: Energy Transfers and Transformations (C.3.2)

Between Chemistry and Other Disciplines: Cell Structure (LS.2.2); Energy Transfer (LS.4.2)

Prepares students for the following AP Enduring Understandings: AP Chemistry 6A, 6B

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.2.4.1 Identify, given a table showing concentration versus time for a reaction, the time at which equilibrium is established. Explain, using the concept of dynamic equilibrium, what is happening in the reaction after equilibrium occurs.

C-PE.2.4.2 Provide, given an **energy diagram** for a reaction, a modified energy diagram for the same reaction that takes place with the addition of a catalyst. Explain, based on the modified energy diagram, why catalysts do not affect the position of equilibrium.

C-PE.2.4.3 Predict, using Le Chatelier's principle for a system at equilibrium, the effects of the following on a system: a change in the concentration of a product or a reactant, a transfer of thermal energy, a change in pressure or a change in temperature. Describe methods of improving reaction yields. Predict, based on the effect on a system of raising the temperature, whether the reaction is exothermic or endothermic.

*[**BOUNDARY:** Students are not expected to do calculations involving equilibrium constants.]*

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- All reactions are reversible, and many reactions do not proceed completely toward products. This does not mean that the reaction has stopped, but rather that the rate of the reverse reaction is equal to the rate of the forward reaction.
- Although some reactions appear to proceed only in one direction, the reverse reaction can occur; however, the occurrence of the reverse reaction is highly unlikely (e.g., combustion reactions).
- Reactions that appear to proceed only in one direction usually release a large amount of energy. An input of energy is required to make such a reaction go backwards.
- According to Le Chatelier's principle, if a chemical system at equilibrium is disturbed by a change in the conditions (e.g., temperature, pressure on gaseous equilibrium systems, concentration) of the system, then the equilibrium system will respond by moving to a new equilibrium state, reducing the effect of the change.
- An unfavorable reaction can be made to occur by removing products as they are formed. The removal of products forces the system to shift its equilibrium position.

Objective C.2.5
Chemical Kinetics

Students understand that for a chemical reaction to occur, reacting particles must collide in the appropriate orientation with enough energy to overcome the activation energy barrier.

> **Suggested Connections**
> *Within Chemistry:* Chemical Energy (C.3.3)
>
> *Between Chemistry and Other Disciplines:* Cell Structure (LS.2.2); Energy Transfer (LS.4.2); Nongenetic Information Transmission (LS.5.5); Conservation of Linear Momentum (P.2.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Chemistry 4A, 4B, 4D; AP Environmental Science 1C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.2.5.1 Predict, given an elementary reaction, the effect of changing concentrations of reactants or products on the rate of reaction. Give examples where changing concentration or pressure of reactants affects the rate of a reaction (e.g., increasing the amounts of emissions of nitrogen oxides from fossil fuels increases ozone production and acid rain production).

C-PE.2.5.2 Explain, using energy level diagrams, the role of activation energy in a reaction; why species must have a minimum amount of energy before they can react; and the role of changing the temperature or adding a catalyst in changing the rate of a reaction.

C-PE.2.5.3 Provide examples of reactions where an increase in temperature speeds up the rate of reaction (e.g., heating food hydrolyzes proteins and carbohydrates faster). Provide examples of systems where catalysts provide alternate pathways to increase the rate of a reaction (e.g., enzymes use intermolecular attractions to bind substrate molecules and hold the molecules in the correct orientation for reaction; catalytic converters absorb molecules of carbon monoxide onto the surface of the catalyst, weakening the bonds and thus making them more susceptible to reaction).

C-PE.2.5.4 Investigate the relationship between the solubility, temperature and the relative surface area of a solute.

- **C-PE.2.5.4a** Formulate a scientific question about the effects of temperature and relative surface area on solubility.
- **C-PE.2.5.4b** Plan an investigation, including a plan to control variables, to address the variables involved when a solid is dissolved.
- **C-PE.2.5.4c** Gather and record observations and measurements of the solubility as the temperature and relative surface area are changed.
- **C-PE.2.5.4e** Organize and present data to show the relationship between temperature, relative surface area and solubility.
- **C-PE.2.5.4f** Make a claim, using the results of the investigation, about the relationship between temperature, relative surface area and solubility.
- **C-PE.2.5.4g** Give real-world examples where temperature and relative surface area affect solubility.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- In order for reactions to occur, the reacting particles must collide in the appropriate orientation and with enough energy. Not all collisions are effective.
- Most reactions occur in solution or in the gas state because the reacting particles are free to move and can collide and interact with each other. Reactions among solids are not as prevalent because a reaction can only occur at the surface of a solid.

ESSENTIAL KNOWLEDGE, *continued*

- The rate of reaction can be defined as the change in the amount of products or reactants per unit of time.
- The rates at which reactions occur are affected by factors such as concentration, pressure, temperature and the addition of a catalyst.
- All stable species require the input of energy to initiate a reaction. The amount of energy required is called the activation energy barrier.
- When the concentrations/pressures of the reactants are increased, the probability of a molecular collision increases. Because a molecular collision may lead to a reaction, the rate of reaction increases as the probability of a molecular collision increases.
- When the kinetic energy of the reactants increases, indicated by a rise in temperature, the probability of a molecular collision increases. When molecules/atoms collide with increased energy, they are more likely to react.
- The process of dissolving a solute in a solvent may be considered a reaction, and the process is affected by many of the same factors (temperature, intermolecular forces and surface area) that affect reaction rates.
- The addition of a catalyst provides an alternate pathway for reactions to occur, usually with a lower activation energy barrier. More molecules therefore have enough energy to overcome the activation energy barrier, leading to an increased rate of reaction.
- One of the functions of an enzyme is to hold molecules in an orientation that can lead to a reaction.

Standard C.3
Energy and Change

When any change occurs, energy is transferred and/or transformed, but it is never lost.

Students understand that energy is conserved whenever a change takes place. Energy can be converted from one form to another, but can never be created or destroyed. As changes occur, energy tends to spread out so that less of it is available to be used. Based on this tendency, the direction of change for any system can be predicted.

Clarification: In chemical systems, mass–energy conservation is not considered.

Objective C.3.1
Conservation of Energy

Students understand that energy is conserved during any change — energy may be transformed into another type of energy, but it never disappears.

> **Suggested Connections**
> *Between Chemistry and Other Disciplines:* Energy Transfer (LS.4.2); Conservation of Charge, Mass and Energy (P.2.1); Contact Interactions and Energy (P.3.1); Heating and Cooling Interactions and Energy (P.3.5); Energy and Fields (P.4.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Chemistry 5B; AP Environmental Science 1B, 3A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.3.1.1 Investigate whether it is possible to construct a closed system.
*[**BOUNDARY:** Students should be able to describe a closed system and explain why they cannot construct a closed system in practice.]*

- **C-PE.3.1.1a** Formulate a scientific question about whether it is possible to construct a closed system.
- **C-PE.3.1.1b** Plan an investigation, and determine which data would provide evidence to address the scientific question.
- **C-PE.3.1.1c** Gather and record observations and measurements of the system being studied.
- **C-PE.3.1.1d** Make a claim, using the data, about whether the system is open or closed.
- **C-PE.3.1.1e** Identify potential sources of thermal energy loss in the investigation.

C-PE.3.1.2 Compare and contrast open and closed systems. Provide examples of systems in everyday life, and identify them as open or closed.

C-PE.3.1.3 Identify, given a change to a defined system and its surroundings, the direction of thermal energy transfer (heat) as either endothermic or exothermic. Identification should be based on the temperature change, or on other observable changes, to the system or to the surroundings. Conversely, predict the change to the temperature of the system and on the surroundings. Prediction is based on the given direction of thermal energy transfer (heat) (i.e., whether the change is endothermic or exothermic). Explain, using the conservation of energy, why thermal energy lost by a system is gained by the surroundings, or vice versa.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Mass–energy is always conserved for all defined systems, for all types of interactions, and at all scales.
- In chemical systems, the interconversion of mass and energy is negligible. Therefore, in chemical systems only energy changes need to be considered; mass–energy conversions need not be considered.
- The part of the universe that is being studied is called a system. A real or imaginary boundary separates the system from the rest of the universe, or the surroundings. By defining a system, any change the system undergoes can be tracked.
- A closed system does not interact with its surroundings — matter and energy cannot get into or out of the system. Most systems of interest in our everyday lives are open systems — matter and energy can be transferred into or out of the system.
- Energy may appear in different forms, such as potential energy or kinetic energy. In chemical systems, the stored energy is called chemical energy and the energy of motion (translational, rotational or vibrational) is called thermal energy.
- The total energy of a chemical system is impossible to measure. When a chemical system reacts, its energy change can be measured by observing the effect of that change on a property of a substance within the system (e.g., the temperature of water is easily measured and can be related to changes in energy).
- If energy moves from a system to its surroundings, the temperature of the surroundings will increase. This is often described as an exothermic process. If energy moves from the surroundings to a system, then the temperature of the surroundings will decrease. This is often described as an endothermic reaction. Temperature changes in large surroundings may not be detectable.

Objective C.3.2
Energy Transfers and Transformations

Students understand that when any change occurs, energy is transferred or transformed; some energy (in the form of thermal energy) always spreads out, making it more difficult to effect further change.

Suggested Connections

Within Chemistry: States of Matter (C.1.5); Chemical Equilibrium (C.2.4)

Between Chemistry and Other Disciplines: Energy Transfer (ES.1.2); Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Energy Transfer (LS.4.2); Conservation of Linear Momentum (P.2.2); Heating and Cooling Interactions and Energy (P.3.5)

Prepares students for the following AP Enduring Understandings: AP Chemistry 5A, 5E; AP Environmental Science 1A, 1B, 1C, 2A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.3.2.1 Investigate the relationship between temperature and thermal energy.

C-PE.3.2.1a Formulate a scientific question about the relationship between temperature and thermal energy.

C-PE.3.2.1b Plan an investigation, and determine which data would provide evidence to address the scientific question.

C-PE.3.2.1c Gather and record data about the change in temperature as thermal energy is added to or removed from a system.

PERFORMANCE EXPECTATIONS, *continued*

C-PE.3.2.1d Choose appropriate representation of data.

C-PE.3.2.1e Calculate the thermal energy change.

C-PE.3.2.1f Explain, in terms of molecular motion, the relationship between the change in temperature and the change in thermal energy.

C-PE.3.2.1g Predict, in terms of changes in speed, vibrations and rotations, what happens to particles at the molecular level when the temperature is increased or decreased.

C-PE.3.2.1h Make a claim, in terms of possible numbers of arrangements of particles, about what happens to the entropy of a system when the temperature is increased or decreased.

C-PE.3.2.2 Predict, given a data table with specific heat values, how the addition of the same amount of thermal energy to a given amount of different substances affects the temperature of these substances. Justification is expressed in terms of molecular structure.

C-PE.3.2.3 Identify on a graph showing temperature versus time where change of state occurs. Explain, in terms of molecular motion and the attraction between particles, why the temperature of a system does not change during a change of state even as thermal energy is being added to the system.

C-PE.3.2.4 Explain why the temperature of the skin decreases when sweat evaporates from the skin. Provide additional examples from everyday life in which a change of state affects the temperature of the surroundings (e.g., when snow melts, the temperature of the surroundings decreases).

C-PE.3.2.5 Explain, in terms of molecular structure, why some materials are good thermal insulators and some are not. Provide examples of situations in which thermal insulation is important. Explain, in terms of the molecular structure of water, the role of water in regulating Earth's average temperature.

C-PE.3.2.6 Explain, on the atomic–molecular scale, why the temperature of water exposed to sunlight is greater than the temperature of an equal amount of water that is not exposed to sunlight. Explanation is based on the idea of photons.

C-PE.3.2.7 Investigate the thermal energy transfer (heat) that takes place when a hot object is placed in a known mass of water.
*[**BOUNDARY:** Entropy should be discussed conceptually rather than quantitatively.]*

C-PE.3.2.7a Predict the direction of thermal energy transfer (heat), and estimate the final temperature.

C-PE.3.2.7b Calculate the expected final temperature.

C-PE.3.2.7c Measure the final temperature.

C-PE.3.2.7d Explain, in terms of energy dissipation and entropy changes, the direction of thermal energy transfer (heat).

C-PE.3.2.7e Give examples of thermal energy transfers (heat) that occur in everyday life (e.g., in electrical appliances, in food chains), and explain, in terms of energy dissipation and entropy changes, why energy is lost and 100 percent efficiency is not possible.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Thermal energy is the energy associated with the movement (translational, rotational and vibrational) of all particles in a system. Although thermal energy cannot be directly measured, the effects of changes in the thermal energy of the system can be observed and calculated.
  *[**BOUNDARY:** In the "real world," thermal energy and heat are often used synonymously; however, in the physical sciences the term "heat" is reserved for the transfer of thermal energy (e.g., from a hot object to a cold object). For the purposes of this standards document, and in order to avoid misunderstandings, the terms "thermal energy" and "thermal energy transfer" are used.]*

ESSENTIAL KNOWLEDGE, *continued*

- At the atomic–molecular scale, thermal energy is associated with the kinetic energy of molecules. As the thermal energy increases, the molecules move (translate, rotate and vibrate) faster.
- The thermal energy of an object depends on its mass, temperature and chemical composition.
- Temperature is a measure of the average kinetic energy of all particles in a substance. Temperature is independent of the amount of matter present, while thermal energy is dependent on the amount of matter present.
- At the atomic–molecular scale, electromagnetic radiation (photons) is absorbed by molecules. Some of this radiation can be transformed into kinetic energy (molecules vibrate and move faster) that appears as thermal energy and causes a rise in temperature.
- Thermal energy transfer (heat) occurs from a warm object to a cooler object.
- When energy is transferred (e.g., from the exothermic reaction system to the surroundings), some of the energy (in the form of thermal energy) always becomes less available to bring about change. Consequently, the amount of useful energy decreases over time, even though the total energy is constant.
- Entropy is a measure of the number of possible arrangements of atoms, molecules or energy in a system — the more possible arrangements, the more entropy the system has. Any thermodynamically favored process is accompanied by an increase in the total entropy (i.e., the entropy of the universe) and in the dispersion of energy.

  *[**BOUNDARY:** While entropy is commonly discussed in terms of randomness or disorder, this can lead to significant misconceptions — including the idea that systems cannot spontaneously become more organized. On the contrary, increases in entropy often drive the organization of systems (e.g., protein folding and micelle formation).]*

Objective C.3.3
Chemical Energy

Students understand that energy changes associated with chemical reactions are a result of the rearrangement of atoms in a chemical system.

Suggested Connections
Within Chemistry: Bonding (C.1.3); Nuclear Chemistry (C.1.6); Periodic Table (C.2.1); Chemical Kinetics (C.2.5)

Between Chemistry and Other Disciplines: Energy Transfer (LS.4.2)

Prepares students for the following AP Enduring Understandings: AP Chemistry 3C, 4B, 5C, 5D

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

C-PE.3.3.1 Investigate energy changes for a simple acid–base reaction.

*[**BOUNDARY:** The acid–base reaction is the system; the water in the calorimeter is the surroundings. Students should measure the temperature of the surroundings.]*

C-PE.3.3.1a Formulate a scientific question about the energy changes in an acid–base reaction.

C-PE.3.3.1b Determine which variables (temperature, concentration, mass or volume) are involved in measuring the energy changes in a reaction.

C-PE.3.3.1c Gather and record observations and measurements of the reaction.

C-PE.3.3.1d Calculate, using appropriate data, thermal energy changes, and choose an appropriate method to present data.

PERFORMANCE EXPECTATIONS, *continued*

C-PE.3.3.1e Make a claim, using data and calculations from the investigation, about the direction and magnitude of the energy changes.

C-PE.3.3.1f Describe, in terms of bond breaking and bond formation, the sources of the energy changes in the system.

C-PE.3.3.2 Predict, using a table of bond energies, whether a reaction will be exothermic or endothermic. Prediction is made by identifying bonds that are broken and those that are formed during the reaction.

*[**BOUNDARY:** Reactions should be limited to those in which only one bond breaks and one bond forms.]*

C-PE.3.3.3 Construct an energy diagram to represent the energy changes that take place when a bond is either broken or formed, and identify whether the process is endothermic or exothermic. Construct an energy diagram to represent the energy changes that occur during a reaction, and identify whether the reaction is endothermic or exothermic.

C-PE.3.3.4 Explain, using the concept of bond energies, why energy is produced during all reactions that result in the formation of carbon dioxide and water from the combination of organic molecules with oxygen. Explain, using real-world examples (e.g., metabolism of glucose, gasoline combustion), why reactions of organic molecules with oxygen are examples of the same principle (oxidation).

C-PE.3.3.5 Provide examples of chemical reactions (e.g., the reaction between hydrogen and oxygen; metabolism) that are common sources of energy.

C-PE.3.3.6 Explain, using the concept of bond energies, why molecules that have weak bonds (e.g., ATP [adenosine triphosphate]) are less stable and tend to react to produce more stable compounds.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Chemical energy is the potential energy associated with chemical systems. The amount of chemical energy in a system changes when the chemicals are allowed to react. The energy transferred when a chemical system undergoes a reaction often appears as thermal energy.
- Energy is always required to break chemical bonds, and energy is always produced when a bond is formed.
- A chemical reaction can be considered a system. The reaction is a result of breaking bonds and/or overcoming IMFs in reactants, and of forming new bonds and/or IMFs in products.
- In general, energy is transferred out of a system (exothermic) when the products have stronger bonds than those in the reactants. Energy is transferred into the system (endothermic) when the products have weaker bonds than those in the reactants.

Unpacking the Performance Expectations: Chemistry

Why "unpack" a performance expectation?

- The science practices standards appear to be separate from the discipline-specific standards, but they are intended to be integrated with disciplinary content knowledge.
- Unpacking a performance expectation establishes clear, specific targets of learning.
- Unpacking a performance expectation illustrates that any one performance expectation may involve multiple science practices.
- The unpacking is intended to provide a model for interpreting the science practices for a specific discipline.

How should an unpacked performance expectation be used?

- The sample unpacked performance expectation provided should be used as a model so that teachers can unpack all of the performance expectations within the discipline-specific standards.
- All of the unpacked performance expectations can be used for guidance in developing instructional strategies and curricula that offer opportunities for students to develop a robust understanding of the science practices and disciplinary content knowledge.
- All of the unpacked performance expectations can be used to develop curricula, instruction and assessments that are aligned with each other.
- Unpacking all of the performance expectations within a specific discipline enables teachers and curriculum supervisors to delineate the multiple science practices and content knowledge that are facilitated, and ultimately to link or map the performance expectations to existing curricula or to use the performance expectations as a basis for the establishment of curricular structure.
- All of the unpacked performance expectations allow decisions about instruction and curriculum design to be made in a more principled way.

SAMPLE UNPACKED PERFORMANCE EXPECTATION

Construct atomic–molecular level representations of the solution process for both ionic and molecular species. Describe, using these representations, the process of dissolving a solute in a solvent. Compare and contrast the solution of an ionic compound in water and the solution of a polar molecular compound (e.g., sucrose) in water. Predict, using molecular structure, the conductivities of the resulting solutions.

*[**BOUNDARY:** Students are expected to use only substances that are completely soluble and do not undergo further reaction.]*

This is **C-PE.2.2.6**. It can be completed together in one context, or developed over time throughout multiple experiences.

This is part of science practices **Objective SP.4.2**.

Unpacking the construction of a representation in the performance expectation:

- Select an ionic substance and a molecular substance to be used as representatives of the different species.
- Describe the phenomenon to be modeled (i.e., the solution process for both ionic and molecular species at the atomic–molecular level).
- Identify the purpose of constructing the representation (i.e., to describe the solution process), and identify the key components (e.g., the production of charged or uncharged particles when the substance dissolves) that must be present in the representation to achieve this purpose.
- Articulate how the representation best fits the purpose of describing the process of dissolving a solute in a solvent.
- Describe the limits of the representation's ability to accurately depict the solution process.
- Collaborate with fellow students to evaluate and revise the representation as necessary.

Unpacking the description using the representation in the performance expectation:

This is part of science practices **Objective SP.4.2**.

- Use appropriate terminology and language for ionic and molecular species and for the solution processes in the representation.

- Identify parts of the solution process that are not present in the representation due to the limitations of the representation.

- Describe the key components of the representation (e.g., arrangement of particles, movement of particles) as they appear at different times during the dissolving process.

Unpacking the comparisons and contrasts in the performance expectation:

- Select an ionic substance (e.g., sodium chloride) to be dissolved in water, and describe a solution of that ionic compound in water.

- Select a polar molecular substance (e.g., sucrose) to be dissolved in water, and describe a solution of that polar molecular compound in water.

- Identify the similarities between the two solutions (e.g., both dissolve in water).

- Identify the differences between the two solutions (e.g., arrangement of ions and molecules, dissociation in solution).

Unpacking the prediction in the performance expectation:

This is part of science practices **Objective SP.1.2**.

- Identify the appropriate property of the solutions that involves the conductivity of the resulting ionic and polar solutions.

- Identify a method for testing the conductivity of the solutions to ensure that the prediction is testable.

- Predict the conductivity of the ionic and polar molecular solutions.

Unpacking the justification of the prediction in the performance expectation:

The **justification** is a critical component of this performance expectation. It helps the teacher understand students' **reasoning** and their use of scientific principles to make the prediction.

- Connect the conductivity prediction of the ionic solution to the molecular structure of the compound and its dissociation in water.

- Connect the conductivity prediction of the polar molecular solution to the molecular structure of the compound and its dissociation in water.

- Support the prediction by describing the mechanism for how electric charge is moved through the solution.

Standards

1. Changes in the natural and designed world are caused by interactions. Interactions of an object with other objects can be described by forces that can cause a change in motion of one or both interacting objects.
2. The interaction of an object with other objects is governed by conservation principles such as the conservation of mass, energy, mass–energy (nuclear interactions), electric charge and linear momentum.
3. Interactions of an object with other objects can be described and explained by using the concept of the transfer of energy from one object to another, both within a defined system and across the boundary of the system. Energy transfers across the boundary of a system can change the energy within the system.
4. Attractive and repulsive interactions at a distance (e.g., gravitational, magnetic, electrical and electromagnetic) can be described by using the concept of fields.

Physics

Organization and Structure of the Physics Standards for College Success

The physics standards are intended to outline the knowledge, skills and abilities that students need in order to be prepared for success in an introductory college-level physics course. Since the AP Physics courses are designed to be students' first courses in physics, the 9–12 physics standards are not an exclusive pathway toward AP Physics. The physical science standards (grades 6–8) are preparation for high school (grades 9–12) physics and for other science courses. Core ideas, or "big ideas" — identified by the NSF-funded AP committee members as being central to an introductory college-level physics course — were the foundation of the creation of the physics standards.

The physics standards are organized around four core ideas of the discipline: **Interactions**,* Motion and Forces; Interactions and Conservation **Principles**; Interactions and Energy; and Interactions and Fields. While there are four standards, they are not meant to represent an equal division of material and **concepts**. Each standard has two to five objectives that provide detailed descriptions of more specific physics core principles of which students should have knowledge. Similar to the enduring understandings that are the target concepts for the AP courses, the objectives are the focus of student mastery for college readiness and the key elements of the conceptual framework of the physics standards. (See Appendix D for the AP Physics Enduring Understandings.) An objective is often followed by a list of other objectives — within the discipline as well as from other disciplines — that are connected in some way to that objective. Both the standards and the objectives are preceded by key words and/or phrases that help articulate the content in a more concise manner. This is especially helpful when a standard or an objective is referenced either by another discipline or during curriculum or instructional planning.

The objectives are, in turn, supported by a set of performance expectations (PEs) and a set of essential knowledge (EK) statements. The PEs describe what students should know, understand and be able to do in order to apply, as well as build and reason with, the essential knowledge that is necessary to understand the content outlined in the objective. The PEs illustrate how students engage in science practices to develop a better understanding of the objective. Students should be able to successfully engage in, *at the very least*, the performance expectations listed for each objective in order to be considered college ready. These performance expectations, along with the essential knowledge statements, can provide guidance in the development of assessments and curriculum materials. The EK statements are an articulation of the conceptual targets for student learning, providing a more detailed description of the broader knowledge delineated in the objective. These statements should be approached from a holistic perspective, and they should not be viewed as a list of discrete, unrelated **facts** for students to memorize. The EK statements also provide the language and appropriate terminology that should be incorporated into students' completion of the performance expectations.

It should be noted that both the performance expectations and the essential knowledge statements were written based specifically on the objective-level statements. There is not a corresponding relationship between the PEs and the EK statements; the PEs are a representative (but certainly not all inclusive) set of applications of the essential knowledge. Therefore, when interpreting the depth and scope of each PE, the EK statements should be considered.

* Boldfaced words and phrases are defined in the glossary.

The number of objectives, as well as the number of performance expectations and essential knowledge statements, varies considerably from standard to standard. For example, Standard P.4 contains the smallest amount of material because the field concept applies only to at-a-distance attractive or repulsive interactions. It should also be made clear that these objectives, PEs and EK statements are not intended to show a linear progression through the subject. Many of the topics and concepts in physics rely on more than one objective and on several PEs and EK statements, some of which may come from different standards. In addition, the number of PEs for a given objective does not indicate any level of importance, and it is assumed that some PEs may require a greater amount of instructional time than others.

The physical science standards (grades 6–8) and the physics standards (grades 9–12) reflect current research about student learning by identifying and building on previous knowledge in a cumulative manner and by requiring higher levels of abstract thinking from middle school to high school. Following each physics objective is a brief clarification of the concepts introduced in the physical science objective(s) as indicated in parentheses at the end of the description, and a description of how the concepts are built upon and expanded in high school physics. It should be noted, however, that a complete understanding of the physics standards requires reading the corresponding physical science standards.

Breadth of Coverage Versus Depth of Understanding

Two current issues within science education are the large number of concepts taught in each science discipline and the repetition of the same discipline content in middle school and high school science courses. Both of these practices leave little time in a school year for developing students' depth of understanding of key concepts and core principles within each science discipline. The physical science and physics standards are designed to help address these issues. In order to provide adequate time for instructors to teach fewer concepts in depth at each grade band, the Physics Standards Advisory Committee decided to restrict the breadth of coverage and prevent unnecessary redundancy of basic ideas in middle school and high school. For example, the physical science and physics standards for motion and forces are limited primarily to straight-line motion and horizontal and vertical forces. (The exception is forces and circular motion, which were included because of their importance for astronomy topics in the earth sciences.) Projectile motion and two-dimensional forces are excluded from the standards. These decisions narrow the breadth of information and leave time for students to develop a depth of understanding of the basic physics ideas within the motion and forces standard as well as in the other physics standards. Limitations to breadth of coverage are indicated in boundary statements that appear after an objective. More specific boundaries occasionally appear after a performance expectation or essential knowledge statement.

The physical science and physics standards for motion and forces also illustrate the prevention of unnecessary repetition of basic ideas. An example of an idea introduced in middle school that is reused but not re-taught in high school is the defining of a system of interest by identifying the objects within a system, the boundary between the system, and the objects in the surroundings of the system.

Finally, breadth of coverage is restricted in the physics standards by limiting the number of equations students are required to understand and use. Less emphasis is placed on plug-and-chug calculations, and fewer equations are introduced than in many traditional physics courses. No other equations are required to meet the goal of depth of conceptual knowledge and science practices skills for college readiness. It should be noted that the symbols in the equations do not have to be the same as those shown.

Definition of Rigor

The standards represent the shift in the College Board's view of rigor, from requiring that students know all of the facts, vocabulary and specific examples related to various topics, to ensuring students' understanding and application of core principles for the discipline and the integration of this knowledge with the skills essential for practicing science. Students are expected to understand the core principles of physics, not only as abstract scientific generalizations but also in terms of how the ideas are related to a wide range of different phenomena. For example, there is only one conservation principle that is applied to mass, charge, energy, mass–energy (nuclear reactions) and linear momentum. Similarly, there is only one conservation of energy principle, and other principles (e.g., work–energy theorem, conservation of mechanical energy, first law of thermodynamics) are all special cases. The conservation of energy principle is applied to many different phenomena involving contact, gravitational, magnetic, electrical, electromagnetic, electrical circuit, mechanical wave and radiant energy interactions.

To emphasize conceptual understanding rather than the memorization of terminology, before a discipline-specific term is introduced, a broader term, phrase or statement is used that summarizes the meaning of the discipline-specific term, which appears in parentheses after the broader term. This applies primarily to everyday terms that have a very different meaning from the physics definition. Examples include mechanical energy **transfer** (work), thermal energy transfer (heat) and vector sum of all forces (net force). The question of when or if the term in parentheses is taught along with the idea is left up to the discretion of each individual instructor.

Goal of Conceptual Understanding

To address the College Board's goal of conceptual understanding, the Physics Standards Advisory Committee took into account the large number of research studies in physics education and cognitive psychology that address how students learn physics concepts and problem-solving skills, and that address students' pervasive **conceptual difficulties**. The committee decided that it would be a disservice to students, as well as inconsistent with the new AP Physics courses, to ignore this extensive research literature. The research literature guided the committee in writing the performance expectations and the essential knowledge statements.

Only appropriate curricula and instruction can address students' pervasive conceptual difficulties and their difficulties learning the problem-solving skills found in the extensive research literature. Conceptual understanding cannot be achieved without developing problem-solving skills. One skill emphasized in the standards is using and translating between different **representations** of concepts and principles, including verbal and written descriptions, **data** tables, graphs, diagrams, and mathematical representations. Other problem-solving skills include recognizing and using the conditions of applicability of concepts and principles in different **problems**, using the defining characteristics of different types of interactions, and recognizing and using simplifying assumptions (e.g., negligible air resistance) for different problems. Further elaboration on these problem-solving skills is found within the physics standards.

Standard P.1
Interactions, Motion and Forces

Changes in the natural and designed world are caused by interactions. Interactions of an object with other objects can be described by forces that can cause a change in motion of one or both interacting objects.

In physical science (grades 6–8), students learn that interaction is a statement of causality in science: Two objects (which can be a defined quantity of a solid, liquid or gas) interact when they act on or influence each other to cause some effect. The **evidence** of the interaction is usually the effect — an observed change in one or both objects or systems. Interactions are classified by type (contact, gravitational, magnetic, electrical, mechanical wave and electric circuit), based on their defining characteristics, in order to find consistent patterns in the multitude of observed changes. Using the concept of forces is one way to describe and explain how two objects can act on or influence each other: During some interactions, two objects exert forces on each other, which can cause a change in motion of one or both objects. Most events or processes involve multiple interactions that occur simultaneously. The vector sum of all the forces (net force) acting on an object causes the object to speed up, slow down and/or change direction of motion (Newton's second law). In grades 9–12, students build on and extend their knowledge of the patterns of motion of objects to include the concepts of linear **displacement**, velocity, instantaneous velocity and acceleration. Defining characteristics of different types of interactions can be represented mathematically with empirical approximations (e.g., $F_k = \mu_k N$ for **kinetic friction**) or **force laws** (e.g., Newton's universal law of gravitation, Coulomb's law). The acceleration of an object is directly proportional to the vector sum of all the forces (net force) acting on an object and inversely proportional to the object's mass ($\vec{a} = \vec{F}_{net}/m$). Students in grades 9–12 also develop problem-solving skills, including recognizing and using the conditions of applicability of concepts and principles, and making simplifying assumptions for different problems.

Clarification: The objectives for this standard are limited to linear and uniform circular motion and to horizontal and/or vertical forces (with the exception of forces and circular motion) in order to meet the goal of depth of understanding while allowing time for students to learn the content described in the other standards. The objectives in this standard provide a strong foundation for extending the content and skills to projectile motion and two-dimensional forces in introductory college physics courses.

Objective P.1.1
Patterns of Constant and Changing Linear Motion

Students understand that the constant and changing linear motion of an object is characterized by the vector quantities of displacement, velocity and acceleration.

Clarification: In grades 6–8, students begin to develop fluency with different **models** for describing, explaining and predicting different patterns of straight-line motion of objects: verbal and/or written descriptions, graphs of distance versus time, one-dimensional **motion diagrams**, and mathematical representations of constant and **average speed** (see Objective PS.1.1). In grades 9–12, students continue to develop fluency with different models used to solve problems concerning the straight-line motion of objects, including an introduction to simple, one-dimensional vector representations of displacement, velocity, instantaneous velocity and constant acceleration. The change in these quantities is determined by **vector subtraction**.

> **Suggested Connections**
> *Within Physics:* Conservation of Linear Momentum (P.2.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Physics 3A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

*[**BOUNDARY:** Motion is limited to objects moving in straight lines horizontally, up an incline, and/or down an incline. Since motion is linear, the sign determines the direction for all vector quantities.]*

P-PE.1.1.1 Represent and calculate the distance traveled by an object, as well as the displacement, the speed and the velocity of an object for different problems. Representations include data tables, distance versus time graphs, position versus time graphs, motion diagrams and their mathematical representations. Interpret the meaning of the sign (+ or −) of the displacement and velocity.

*[**BOUNDARY:** Problems should include situations in which the distance traveled is not the same as the displacement, and objects move from higher to lower positions.]*

PERFORMANCE EXPECTATIONS, *continued*

P-PE.1.1.2 Investigate, and make a **claim** about, the straight-line motion of an object in different laboratory situations. Representations include data tables, position versus time graphs, instantaneous velocity versus time graphs, motion diagrams and their mathematical representations. When appropriate, calculate the constant velocity, average velocity or constant acceleration of the object. Interpret the meaning of the sign of the constant velocity, average velocity or constant acceleration. Interpret the meaning of the average velocity.

P-PE.1.1.3 Explain what is "constant" when an object is moving with a constant velocity and how an object with a negative constant velocity is moving. Justify the explanation by constructing sketches of motion diagrams and using the shape of position and instantaneous velocity versus time graphs.

P-PE.1.1.4 Explain what is "constant" when an object is moving with a constant acceleration, the two ways in which an object that has a positive constant acceleration can be moving (speeding up in the positive direction or slowing down in the negative direction), and the two ways in which an object that has a negative constant acceleration can be moving (slowing down in the positive direction or speeding up in the negative direction). Justify the explanations by constructing sketches of motion diagrams and using the shape of instantaneous velocity versus time graphs.

P-PE.1.1.5 Compare and contrast the following: distance traveled and displacement; speed and velocity; constant velocity and instantaneous velocity; constant velocity and average velocity; and velocity and acceleration.

P-PE.1.1.6 Translate between different representations of the motion of objects: verbal and/or written descriptions, motion diagrams, data tables, graphical representations (position versus time graphs and instantaneous velocity versus time graphs) and mathematical representations.

P-PE.1.1.7 Predict algebraically a displacement, an initial or final time (clock reading), or a time interval for different problems involving objects that are moving with either a constant velocity or a constant acceleration. Justify the **prediction** by constructing a motion diagram and using mathematical representations.

P-PE.1.1.8 Predict algebraically a displacement, an initial or final time (clock reading), or an initial or final instantaneous velocity in different problems. Justify the prediction by constructing motion diagrams and using the mathematical representations for constant velocity, constant acceleration, and/or the relationship between average velocity and initial and final instantaneous velocities for constant acceleration.

*[**BOUNDARY:** Students should not be given problems that require them to solve a quadratic equation.]*

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The displacement, or change in position, of an object can be calculated by subtracting the initial position from the final position, where initial and final positions can have positive and negative values ($\Delta x = x_f - x_i$). Displacement is not always equal to the distance traveled.

- An object that travels the same displacement in each successive unit time interval has constant velocity. Constant velocity is a vector quantity and can be represented by and calculated from a position versus time graph, a motion diagram or the mathematical representation for average velocity. The sign ($+$ or $-$) of the constant velocity indicates the direction of the velocity vector, which is the direction of motion.

- An average velocity over any interval is the constant velocity an object would travel to achieve the same change in position in the same time interval, even when the object's velocity is changing. Average velocity can be mathematically represented by $\overline{v} = (x_f - x_i)/(t_f - t_i)$. For straight-line motion, average velocity can be represented by and calculated from the mathematical representation, a curved position versus time graph and a motion diagram.

- The velocity of an object in straight-line motion changes continuously, from instant to instant, while it is speeding up or slowing down and/or changing direction. The velocity of an object at any instant (clock reading) is called its instantaneous velocity. The object may not have this velocity over any time interval or travel any distance with this velocity. Instead, the instantaneous velocity is the constant velocity at which an object would continue to move if its motion stopped changing at that instant.

ESSENTIAL KNOWLEDGE, *continued*

- When the change in an object's instantaneous velocity is the same in each successive unit time interval, the object has constant acceleration. For straight-line motion, constant acceleration can be represented by and calculated from a linear instantaneous velocity versus time graph, a motion diagram and the mathematical representation [$a = (v_f - v_i)/(t_f - t_i)$]. The sign ($+$ or $-$) of the constant acceleration indicates the direction of the change-of-velocity vector. A negative sign does not necessarily mean that the object is traveling in the negative direction or that it is slowing down.

  *[**BOUNDARY:** The term "deceleration" should be avoided because students tend to associate a negative sign of acceleration only with slowing down.]*

- When the acceleration is constant, the magnitude of the average velocity during a time interval is one-half of the sum of the initial and final instantaneous velocities [$\bar{v} = (v_f + v_i)/2$].

Objective P.1.2
Forces and Changes of Motion

Students understand that the acceleration of an object is proportional to the vector sum of all the forces (net force) on the object and inversely proportional to the object's mass ($\vec{a} = \vec{F}_{net}/m$). When two interacting objects push or pull on each other, the force on one object is equal in magnitude but opposite in direction to the force on the other object.

*[**BOUNDARY:** This is not a stand-alone objective — it is linked to Objectives P.1.3 (Contact Interactions and Forces), P.1.4 (Gravitational Interactions and Forces) and P.1.5 (Electric Charge Interactions and Forces), which provide the specific types of interaction forces that are helpful in understanding and applying Newton's laws. Motion is limited to inertial frames of reference, so Newton's first law is a special case of Newton's second law. Excluded is the distinction between gravitational and inertial mass.]*

Clarification: In grades 6–8, students begin to develop fluency with one-dimensional **force diagrams** and relate the vector sum of all the forces (net force) on an object to changes in straight-line motion (speeding up, slowing down and/or changing direction) of an object (see Objective PS.1.2). In grades 9–12, students continue to develop fluency with force diagrams in more complex situations, relate the linear acceleration of an object with the vector sum of all the forces (net force) on the object and with the mass of the object, and apply Newton's third law.

> **Suggested Connections**
> *Within Physics:* Conservation of Linear Momentum (P.2.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Physics 3A, 3B, 4A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

*[**BOUNDARY:** Problem types are the same as for grades 6–8 (see Objective PS.1.2), but involve more complex situations, including situations involving linear motion in two parts (e.g., object accelerates and then moves with a constant velocity), situations involving the linear motion of two objects, and situations involving Newton's third law (e.g., objects at rest, a person who is walking or a moving car).]*

P-PE.1.2.1 Analyze force diagrams to determine if they accurately represent different situations involving multiple contact, gravitational and/or electrical interactions. When appropriate, determine the one-dimensional vector sum of all the forces (net force), and interpret the meaning of the vector sum of all the forces (net force).

P-PE.1.2.2 Analyze different problems involving at least two different types of interactions (contact, gravitational, magnetic and/or electrical) and an identified object of interest.

P-PE.1.2.2a Identify the types of objects interacting with the object of interest, and observe the motion of each object.

P-PE.1.2.2b Make a claim about the types of interactions. Justification is based on the evidence and the defining characteristics of the different types of interactions.

P-PE.1.2.2c Represent the forces acting on the object of interest by drawing a force diagram showing both the vertical and horizontal forces. When appropriate, use **vector addition** to determine the relative size and direction of the sum of all the forces (net force), and interpret the meaning of the net force.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.1.2.2d Explain the observed motion of the object of interest. Justification is based on Newton's second law.

P-PE.1.2.3 Identify the interaction (third-law) pair of any force in different problems. Compare the size and direction of the interaction pair of forces. Construct force diagrams that show all interaction (third-law) pairs.

P-PE.1.2.4 Predict algebraically a force, the linear acceleration, the initial or final velocity, or the initial or final time (clock readings) in different problems. Justify the prediction by constructing one-dimensional motion and force diagrams and by using the mathematical representations of average velocity and constant acceleration, the defining characteristics of different types of interaction forces, and Newton's second and third laws of motion.

P-PE.1.2.5 Investigate and explain why an object moving at a constant speed in a circle is accelerating. Justify the explanation by constructing a motion diagram and by using knowledge of acceleration and Newton's second law.

*[**BOUNDARY:** Students are only required to explore two-dimensional vector subtraction in this one case; they are not required to become proficient.]*

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The force on a 1 kg mass that causes an acceleration of 1 m/s^2 is one newton (N), where a newton is defined as kg m/s^2. Since many events consist of a sequence of interactions, the force diagram for an object/system of interest can be different for different time intervals.

- The linear acceleration of an object is directly proportional to the vector sum of all the forces (net force) acting on the object and inversely proportional to the object's mass ($\vec{a} = \vec{F}_{net}/m$). The vector sum of all the forces (net force) is not a real force caused by an interaction with another object. The vector sum of all the forces (net force) is the single force that could replace the original multiple forces and cause the same acceleration of the object.

- A special case of Newton's second law occurs when the vector sum of all the forces (net force) on an object is zero. In this case, there is no acceleration and the object remains at rest or maintains a constant speed and a constant direction of motion.

- When two interacting objects push or pull on each other, the force on one object is equal in magnitude but opposite in direction to the force on the other object (Newton's third law of motion for an interaction pair).

- An object moves in a circle when the vector sum of all the forces (net force) is constant in magnitude, always directed at right angles to the direction of motion and always directed toward the same point in space, the center of the circle. The speed of the object does not change: The acceleration causes the continual change in the direction of the change-in-velocity vector.

Objective P.1.3
Contact Interactions and Forces

Students understand that some types of contact interactions have force laws that are empirical approximations. Some contact interactions have no force laws because the value of the force depends on other forces from different simultaneous interactions. These interactions can cause a change in motion of one or both interacting objects.

*[**BOUNDARY:** The situations are limited to horizontal or vertical motion and forces in more complex problems than those that are covered in grades 6–8. Such complications as dimpled surfaces (e.g., golf balls, baseballs) are not considered.]*

<u>Clarification</u>: In grades 6–8, students are introduced to the qualitative defining characteristics of applied, elastic (e.g., spring), kinetic friction and **drag** contact interactions (see Objective PS.1.3), as well as to the small-particle model of substances (see Objective PS.2.2). In grades 9–12, contact interactions are expanded to include the defining characteristics of additional types of interactions and the empirical force laws for the elastic, kinetic friction and **static friction** interactions. Students also explore simplifying assumptions for solving problems involving contact interactions.

Suggested Connections
Within Physics: Conservation of Charge, Mass and Energy (P.2.1); Conservation of Linear Momentum (P.2.2); Contact Interactions and Energy (P.3.1)

Prepares students for the following AP Enduring Understandings: AP Physics 3C

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.1.3.1 Investigate, and make a claim about, the variables (e.g., materials of the surfaces; an object's surface area; velocity of an object; mass or weight of an object) that could affect the kinetic frictional force on an object. Justification is based on the evidence and Newton's laws.

P-PE.1.3.2 Measure and mathematically represent the elastic constant of a linearly elastic object (e.g., a spring, a steel wire, a bungee cord). Measurements and representations are based on data tables, graphs and the empirical force law for **elastic materials**.

P-PE.1.3.3 Analyze different problems involving contact interactions and forces to determine whether any simplifying assumptions are needed to solve each problem. Justification is based on the defining characteristics of different types of contact interactions and on the simplifying assumptions for contact interactions.

P-PE.1.3.4 Identify a pair of surfaces and explain why it is best in different situations (e.g., different soled shoes for various surfaces). Justify by using a table of kinetic and static friction coefficients.

P-PE.1.3.5 Analyze problems involving the different types of contact interactions and an identified object of interest.

- **P-PE.1.3.5a** Identify the types of objects interacting with the object of interest, and observe the changes in motion of each object.
- **P-PE.1.3.5b** Make a claim about the types of contact interactions. Justification is based on the evidence and the defining characteristics of each type of interaction.
- **P-PE.1.3.5c** Represent the forces on the object of interest by drawing a force diagram showing both the vertical and horizontal forces.
- **P-PE.1.3.5d** Explain the observed motion of the object of interest. Justification is based on Newton's second law.

P-PE.1.3.6 Give examples of everyday phenomena and/or technological devices that involve contact interactions, and identify interacting objects (such as an energy source [motor]–moving blades of a helicopter interacting with the surrounding air).

P-PE.1.3.7 Analyze different problems involving contact interactions to determine whether any simplifying assumptions are needed to solve each problem. Justification is based on the defining characteristics of different types of contact interactions and on knowledge of simplifying assumptions.

P-PE.1.3.8 Predict what happens to the kinetic frictional force in different situations involving a change in the pair of sliding surfaces. Justify the prediction by using a table of kinetic friction coefficients.

P-PE.1.3.9 Explain why the kinetic frictional force and the static frictional force are different for a given surface. Justify the explanation by using knowledge of friction interactions and the small-particle model of the forces between the **particles** of different substances.

P-PE.1.3.10 Explain why the drag force is larger in liquids than in the air. Justify the explanation by using the small-particle model (see Objective PS.2.3).

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The three defining characteristics of a specific type of interaction are: (1) the **conditions** necessary for the interaction to occur (e.g., two objects must be touching; one object must be charged; one object must be a solid and the other a fluid); (2) the evidence of the interaction — usually the observed changes; and (3) the variables (e.g., force law, equation for a form of energy) that influence the magnitude and direction of the interaction.

- The types of interactions of the object/system of interest with its surroundings and the force laws for each type of interaction must be identified in order to use Newton's laws to quantitatively explain and predict the motion of an object or system.

- There are empirical force laws for some types of contact interactions.

  - The force of kinetic friction always acts in the opposite direction of the object's velocity. The magnitude of the kinetic friction depends on the types of materials that make up the two surfaces sliding past each other and the magnitude of the compression (normal) force acting on the object. This can be mathematically represented by $F_k = \mu_k N$.

  - When an external force is applied parallel to two surfaces that are in contact, a force opposes the external force and keeps the objects from moving relative to each other. This interaction force is called static friction, which is mathematically represented by an inequality: $F_S \leq \mu_S N$. The magnitude of the static friction depends on the types of materials that make up the two surfaces sliding past each other and the magnitude of the compression (normal) force acting on the object.

  - Elastic materials stretch or compress in proportion to the load they support. The mathematical model (Hooke's Law) for the force that a linearly elastic object exerts on another object is $F_{elastic} = k\Delta x$, where Δx is the displacement of the object from its relaxed position. The direction of the elastic force is always toward the relaxed position of the elastic object. The constant of proportionality is the same for compression and extension, and depends on the "stiffness" of the elastic object.

- There are no force laws for some types of contact interactions because the complexity of the interactions does not allow the magnitude of the forces to be easily represented.

  - A contact interaction occurs when the surfaces of two solid objects are pressed together because of other interactions on one or both objects (e.g., a solid sitting on or sliding along a table; a magnet attached to a refrigerator). This is sometimes called a compression interaction. A compression (normal) force applied to an object is always a push directed at right angles from the surface of the other interacting object.

  - A contact interaction occurs when a cord (e.g., rope, wire, rod) pulls on another object or system and the cord is not slack. This is sometimes called a tension interaction. A tension force on an object always points in the direction the cord is pulling.

- In static friction and drag interactions, one of the interacting systems can be an energy source with a moving part (e.g., energy source [motor]–moving blades of a helicopter; a person's moving foot). When the interacting system with an energy source pushes on another object or system (e.g., the air or the ground), the other object pushes back on the system with equal and opposite force (Newton's third law), which can cause a change in motion of the system.

- Simplifying assumptions are often needed to gain a basic understanding of a situation or to solve a problem (e.g., for contact interactions, "massless" ropes, "frictionless" sliding surfaces, maximum static friction and negligible air resistance).

- At the atomic scale, the interaction between the particles (atoms or molecules) of different substances is an electric charge interaction. At this scale, there are no "contact" forces. The strength of the attractive forces between the particles of different substances is different for different pairs of substances, depending on the electron configurations of the atoms or molecules of the two substances (see Objective PS.2.3).

Objective P.1.4
Gravitational Interactions and Forces

Students understand that the gravitational force on an object is proportional to the product of the two interacting masses and inversely proportional to the square of the distance between the centers of the masses (Newton's law of universal gravitation). When an object's distance from Earth's surface is small compared to Earth's radius, then all objects fall with approximately the same acceleration (ignoring the effect of air resistance).

*[**BOUNDARY:** Situations are limited to vertical motion and circular motion; projectile motion is excluded.]*

Clarification: In grades 6–8, students are introduced to the qualitative defining characteristics of the gravitational interaction. Students in this grade band also distinguish between weight and mass (see Objective PS.1.4). In grades 9–12, students are introduced to the inverse squared law for gravity, but they are not expected to understand the origin of this relationship.

> **Suggested Connections**
> *Within Physics:* Conservation of Linear Momentum (P.2.2); Forces and Fields (P.4.1)
>
> *Between Physics and Other Disciplines:* Energy Transfer (ES.1.2); Planetary Evolution (ES.2.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Physics 2B, 3C, 3G; AP Environmental Science 1B

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.1.4.1 Explain why all objects near Earth's surface fall with approximately the same acceleration, despite having different masses and weights. Justify by using the universal law of gravitation and Newton's second law.

P-PE.1.4.2 Analyze different problems to determine whether a constant gravitational acceleration can be assumed. Justify the analysis by using the universal law of gravitation. When appropriate, calculate a gravitational force.

P-PE.1.4.3 Explain why the spring scale reading for someone standing on a scale in an accelerating elevator is different from the spring scale reading when the elevator is at rest or moving with a constant speed. Justify the explanation by constructing force diagrams of the person and the scale for the different situations (moving up or down with increasing or decreasing velocities) and by using Newton's laws.

P-PE.1.4.4 Predict algebraically how a change in distance (e.g., triple the distance) between two objects with mass and/or a change in mass (e.g., one-fourth of the mass) of one or both interacting objects changes the gravitational force on an object. Justification is based on the universal law of gravitation.

P-PE.1.4.5 Predict algebraically the position between two objects at which the vector sum of the gravitational forces (net force) on an object is zero (e.g., Earth–Moon system, planet–Sun system). Justification is based on the universal law of gravitation and Newton's second law.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Gravitational, magnetic, electrical and electromagnetic interactions occur continually when objects are not touching, and they do not require an intervening material (medium). They are called interactions at a distance, or long-range interactions.

- The force law for gravitational interaction, called Newton's universal law of gravitation, states that the strength of the gravitational force is proportional to the product of the two masses and inversely proportional to the square of the distance between the centers of the masses [$F_G = (G\, m_1 m_2)r^2$]. The proportionality constant is called a universal constant because it does not depend on any other properties (e.g., chemical composition) of the objects or whether the object is charged or is a magnet.

ESSENTIAL KNOWLEDGE, *continued*

- When an object's distance from Earth's surface is small compared to Earth's radius, then a simplifying assumption is that the gravitational force on an object depends only on the mass of the object. In this case, objects fall with approximately the same acceleration: 9.8 m/sec/sec.

Objective P.1.5
Electrical Interactions and Forces

Students understand that electrical interactions occur between mutually attracting or repelling charged objects, which can cause a change in motion of one or both objects. The attraction between a charged object and a neutral object is caused by the separation of charges in neutral objects.

*[**BOUNDARY:** This content can be addressed in the same way as it is for students in grades 6–8, but can include more complicated situations and materials. Two- and three-dimensional forces and motion are excluded.]*

Clarification: In grades 6–8, students are introduced to the qualitative defining characteristics of magnetic and electric charge interactions, including the attraction between charged and neutral objects, and the variables that affect the magnitude of the forces between two charged objects (see Objective PS.1.5). In grades 9–12, students are introduced to Coulomb's law for point charges (students are not expected to understand the origin of the $1/r^2$ relationship), and to the atomic-level explanation for the attraction between charged and neutral objects. Students also explore the conditions necessary for the application of Coulomb's law to solve a problem.

Suggested Connections

Within Physics: Conservation of Linear Momentum (P.2.2); Nuclear Interactions and the Conservation of Mass–Energy (P.2.3); Electric Current Interactions and Energy (P.3.2); Forces and Fields (P.4.1)

Between Physics and Other Disciplines: Electrons (C.1.2)

Prepares students for the following AP Enduring Understandings: AP Physics 1A, 1B, 2A, 2C, 2D, 3C, 5C; AP Biology 2C; AP Chemistry 1A, 1B, 2C, 5D

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.1.5.1 Calculate, using the conservation of charge law, the charge on an object in simple problems.

P-PE.1.5.2 Investigate, and make a claim about, the mathematical relationship between the electrical force, the amount of charge of each interacting object, and the distance separating the two charged objects. Justification is based on the evidence and Newton's laws.

P-PE.1.5.3 Investigate and explain the differences between charging electrical conductors and insulators by contact and **charging by induction**. Justification is based on the evidence, on knowledge of Newton's second law, and on the defining characteristics of an electrical interaction (see Objective PS.1.5).

P-PE.1.5.4 Explain why, when a metal is charged, the charges "spread out" on the surface of the conductor and quickly stop moving. Justify the explanation by constructing diagrams and by using Coulomb's law, Newton's second law and the atomic model of charges in neutral conductors.

P-PE.1.5.5 Predict, using a series of diagrams, how a conductor is charged by contact and by induction in different problems. Justification is based on Coulomb's law, Newton's second law, the conservation of charge law, and the atomic model of charges in neutral conductors.

P-PE.1.5.6 Explain why there is an attraction between a charged object and a neutral insulator or conductor. Justify the explanation by constructing force diagrams and by using Coulomb's law, Newton's laws of motion, and the atomic model of charges in neutral conductors or insulators.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.1.5.7 Analyze different problems to determine whether Coulomb's law can be used to solve each problem. Justification is based on the conditions necessary for the application of Coulomb's law. If appropriate, calculate the force on an object, the amount of charge on an object or the separation of two charged objects.

P-PE.1.5.8 Predict algebraically the change in the electrical force on a point charge in different problems where the distance between the interacting point charges changes (e.g., one-fourth of the original distance) and/or where the magnitude of the charge of one or both point charges changes (e.g., triple the original charge). Justification is based on Coulomb's law.

P-PE.1.5.9 Predict algebraically the position in which a point charge must be placed in a line of two or three other point charges, where the vector sum of the electrical forces (net force) on the point charge is zero. Justification is based on Coulomb's law and Newton's laws of motion.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- At the atomic scale, charge is a property of subatomic particles (e.g., electrons or protons) and is quantized — that is, there is an elementary unit of observable charge that is the charge of the electron.
- Two charged objects, which are small compared to the distance between them, can be modeled as point charges. The forces between point charges are proportional to the product of the charges and inversely proportional to the square of the distance between the point charges [$F_e = (k_e\, q_1\, q_2)/r^2$]. This force law is known as Coulomb's law.
- For ordinary-size objects, Coulomb's law is difficult to apply. The charged objects must be approximately modeled as point charges and be far apart compared to their size. For the electrical force to be comparable in magnitude to other forces in the problem, the objects must have a small mass (e.g., small pieces of paper or foil) and be close together (e.g., a few inches apart).
- All neutral materials contain equal amounts of positive and negative charge. For all methods of charging neutral objects (e.g., rubbing together two neutral materials; charging by contact and by induction; using a van de Graff machine or a battery), one object/system ends up with a surplus of positive charge and the other object/system ends up with the same surplus amount of negative charge. These and other experiments support the conservation of charge law: $\Delta q_{system} = q_{in} - q_{out}$.
- Based on the atomic model, most materials have the same number of electrons and protons; therefore, the materials are electrically neutral. Charged objects can be modeled as having an unequal amount of protons and electrons. When an electrical conductor is charged, the charge "spreads out" over the surface. When an electrical insulator is charged, the excess or deficit of electrons on the surface is localized to a small area of the insulator.
- The second type of electrical interaction occurs between charged and neutral objects. The atomic **theory** of materials explains why charged objects and neutral objects exert an electrical force on each other.
  - When a charged object is near a neutral metal conductor, the free electrons in the metal are attracted toward or repelled away from the external charge. As a result, one side of the conductor has an excess of electrons, and the opposite side has an electron deficit. This separation of charges on a neutral conductor causes an attractive net force on the neutral conductor.
  - When a charged object is near a neutral insulator, the electron cloud of each insulator atom shifts position slightly so it is no longer centered on the nucleus. The separation of charge is very small, much less than the diameter of the atom. The polarized atoms point approximately toward the external charge. The sum of all the Coulomb forces on each molecule results in an attractive force on the whole insulator.

Standard P.2
Interactions and Conservation Principles

The interaction of an object with other objects is governed by conservation principles such as the conservation of mass, energy, mass–energy (nuclear interactions), electric charge and linear momentum.

All interactions are governed by conservation principles. A quantity is "conserved" when the total quantity does not change as the universe evolves. Therefore, in an open system, any change in a conserved quantity represents a transfer of the quantity into or out of the system. There are a limited number of quantities that are conserved. Electric charge and linear momentum are always conserved. Mass and energy are conserved separately at the macroscopic scale (no mass is converted to energy). At the scale of the nucleus, the nuclear forces that hold the protons and neutrons together are much stronger than the electrical forces that hold the electrons and nucleus together in the atom. Consequently, much larger amounts of energy can be transferred out of a system during nuclear interactions than can be transferred during chemical interactions that only involve the outermost electrons of an atom or a molecule. At the nuclear scale, a more general principle is the conservation of mass–energy, which includes nuclear interactions in which mass is converted to energy.

Objective P.2.1
Conservation of Charge, Mass and Energy

Students understand that charge is always conserved. Mass and energy are conserved separately for all types of interactions (except for interactions at the subatomic scale) and for all defined systems (open and closed). There is no measurable change in the mass of a system when energy is transferred across the boundary of the system.

*[**BOUNDARY:** This is not a stand-alone objective — the specific types of energy and energy transfers needed to apply the conservation of energy principle are provided in Objective P.4.2 and in each objective of Standard P.3. Nuclear and subatomic particle interactions are excluded from the types of interactions for which energy is conserved.]*

Clarification: The physics standards use the conservation principle as a central idea to organize and understand the interactions between and among objects and systems. For students in grades 6–8, the conservation of mass principle is addressed (see Objective PS.3.1). For students in grades 9–12, both conservation of charge and conservation of energy are addressed (when no mass is converted to energy). The more general principle of the conservation of mass–energy is introduced in Objective P.2.3.

> **Suggested Connections**
> *Within Physics:* Contact Interactions and Energy (P.3.1); Electric Current Interactions and Energy (P.3.2); Mechanical Wave Interactions and Energy (P.3.3); Radiant Energy Interactions (P.3.4); Heating and Cooling Interactions and Energy (P.3.5); Energy and Fields (P.4.2)
>
> *Between Physics and Other Disciplines:* Nuclear Chemistry (C.1.6); Conservation of Matter (C.2.3); Conservation of Energy (C.3.1)
>
> *Prepares students for the following AP Enduring Understandings:* AP Physics 1C, 4C, 5A, 5B, 5F, 7B; AP Environmental Science 1A; AP Biology 2A; AP Chemistry 1E, 5B

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.2.1.1 Analyze different problems involving multiple interactions (e.g., contact, electric circuit, mechanical wave, radiant energy and/or thermal).

- **P-PE.2.1.1a** Select an object/system and a time interval to solve the problem. Identify the interactions of the defined system with other systems. Identification is based on the defining characteristics of interactions and on information from the problem.
- **P-PE.2.1.1b** Determine and represent, with an **energy diagram**, the type and direction of energy transfers across the system boundary, as well as energy changes within the system.

PERFORMANCE EXPECTATIONS, ***continued***

P-PE.2.1.1c Make claims about which terms in the conservation of energy equation are applicable, are zero or not applicable, or are too small to be measurable. Justify the claims based on knowledge of methods of energy storage and methods of energy transfer.

P-PE.2.1.1d Write the conservation of energy equation for the problem.

P-PE.2.1.1e Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation under different conditions for the problem. Justification is based on the terms in the conservation of energy equation.

P-PE.2.1.2 Describe, using words and energy diagrams, the energy changes within a system and the transfer of energy into and out of a system, for different defined systems or time intervals of the same event.

P-PE.2.1.3 Explain why an energy description of an event for a given system can differ for different time intervals, and why an energy description of an event for a given time interval can differ for different systems of interest.

P-PE.2.1.4 Describe the same event in terms of energy transfers and energy **transformations**. Description is based on energy diagrams and the conservation of energy principle.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The mathematical form of the conservation of energy principle is the same as for the conservation of mass principle: total energy change within system (ΔE_{system}) is equal to the total energy transfer into or out of system ($E_{in} - E_{out}$):

$$\Delta E_{system} = E_{in} - E_{out}.$$

- For all types of interactions covered in this standards document (except nuclear interactions), mass and energy are always conserved separately.

- The energy terms in the conservation of energy principle depend on the defined system and the defined time interval. For any event or process, the terms in the conservation of energy equation will be different for different defined systems or time intervals.

- Many events and processes involve multiple interactions occurring simultaneously and/or chains of interactions. When the details of the multiple transfers of energy are unknown or not of interest in a problem, the term "transformation" can be used (i.e., the initial form of energy is "transformed" into the final form of energy within the defined closed system). For radiant energy transfers into or out of a system, this description is often extended to include the transformation of radiant energy (electromagnetic waves or photons) into the final form(s) of energy within the system (e.g., chemical energy or thermal energy).

- Charge is always conserved for all types of interactions (including nuclear interactions). The total change of charge within a system is equal to the total charge transferred into or out of the system. This can be mathematically represented by:

$$\Delta Q_{system} = Q_{in} - Q_{out}.$$

Objective P.2.2
Conservation of Linear Momentum

Students understand that the linear momentum of an object/system is the product of its mass multiplied by its velocity, and that interactions across the boundary of the system can transfer momentum into or out of the system. Linear momentum is always conserved for all defined systems (open and closed) and all types of interactions.

*[**BOUNDARY:** Problems are limited to motion in one dimension.]*

Clarification: Conservation of linear momentum is a fundamental principle of physics. This objective provides a strong foundation for extending the content and skills to two- and three-dimensional linear momentum and angular momentum in an introductory college physics course. This objective can be introduced prior to, or after, the introduction of Newton's laws (see Objective P.1.2). A full discussion of collisions also requires conservation of energy, but collisions can be approached from the point of view of conservation of momentum, and energy can be discussed at a later time.

Suggested Connections
Within Physics: Forces and Changes of Motion (P.1.2)

Between Physics and Other Disciplines: Electrons (C.1.2); States of Matter (C.1.5); Chemical Kinetics (C.2.5); Energy Transfers and Transformations (C.3.2)

Prepares students for the following AP Enduring Understandings: AP Physics 3D, 4B, 5A, 5D, 6A, 7A, 7B; AP Chemistry 4B

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.2.2.1 Investigate the conservation of linear momentum (one-dimensional) for different situations involving open and closed systems and for different types of interactions (e.g., an automobile collision, a bat hitting a baseball).

- **P-PE.2.2.1a** Predict and justify the transfer of momentum into or out of a defined system during the interaction.
- **P-PE.2.2.1b** Determine and justify the data needed to test the prediction.
- **P-PE.2.2.1c** Record and organize data.
- **P-PE.2.2.1d** Analyze and represent the data on a (one-dimensional) momentum diagram.
- **P-PE.2.2.1e** Make claims about the transfer of momentum into or out of the system. Claims are based on gathered data that can be used as evidence and on the conservation of momentum principle.

P-PE.2.2.2 Predict qualitatively the change in direction of motion of two interacting objects in different problems. Justification is based on the initial conditions and on the relationship between the momenta of the two objects in a closed system.

P-PE.2.2.3 Explain when the external friction interaction may be ignored when using the conservation of linear momentum principle.

P-PE.2.2.4 Explain, using the conservation of linear momentum principle, how a process or design achieves a desired effect (e.g., reducing damage or injury, or maximizing a force).

P-PE.2.2.5 Design or adapt a process to achieve a desired effect of increasing or decreasing the force applied to an object by using the conservation of linear momentum principle.

P-PE.2.2.6 Investigate, and make a claim about, the changes in kinetic energy and momentum for a defined system of two objects in different problems involving inelastic collisions. Identify possible methods of energy transfer or transformation within the system to account for the "lost" kinetic energy, and construct energy and momentum diagrams. Justification is based on the conservation of energy and on the conservation of linear momentum.

*[**BOUNDARY:** Students are not expected to do calculations or use the coefficient of restitution.]*

P-PE.2.2.7 Explain and justify how conservation of linear momentum can be used in the investigation of traffic accidents to determine the initial motions of the objects based on measurements of the final motions.

P-PE.2.2.8 Calculate, using the conservation of linear momentum principle, the final velocity in a two-object system for different problems involving **totally inelastic collisions**.

P-PE.2.2.9 Predict algebraically the average force, initial or final velocity, mass, or time interval in multistep word problems. Prediction is made by using the conservation of linear momentum principle.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.2.2.10 Predict algebraically the initial or final velocities or masses of each interacting object in different problems where external forces can be neglected and where the approximation that no energy is dissipated can be made. Justify the prediction by constructing (one-dimensional) momentum diagrams and by using the conservation of linear momentum principle.

P-PE.2.2.11 Predict algebraically the relative size of the accelerations of two interacting objects in different problems by drawing a (one-dimensional) momentum diagram and by using the mathematical representation for the relationship between the momenta of the two objects in a closed system.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- All moving objects can be described by a quantity of motion called linear momentum. Momentum ($\vec{p}$) for objects with mass is a vector quantity that depends on the mass of the object (increases with increasing mass) and on the velocity of the object (increases with increasing velocity), and is in the direction in which the object is moving $\vec{p} = m\vec{v}$. There is no standard unit of momentum; the units are those of the product of mass and velocity, kg m/s.

- The conservation of linear momentum principle states that the total (net) momentum change within a system is equal to the total momentum transfer into or out of the system. This can be mathematically represented by:

$$\Delta\vec{p}_{system} = \vec{p}_{in} - \vec{p}_{out}.$$

- Linear momentum is always conserved for all types of interactions and for both open and closed systems. For any system, impulse — the total momentum transfer into or out of the system — is equal to the change in momentum for the system. This transfer is the result of interaction(s) with other systems outside the system and can be mathematically represented by:

$$\Delta\vec{p}_{system} = \vec{p}_f - \vec{p}_i = \vec{F}_{ave}\,\Delta t\,,$$

  where $\vec{F}_{ave}$ is the vector sum of the external forces (net force).

- Any combination of force and time could be used to produce the transfer of momentum (impulse) necessary for a given change of momentum of an object: The smaller the force, the longer the time interval over which the force acts; the larger the force, the shorter the time interval.

- In a system where the interactions across the system boundary may be neglected because they are insignificant compared to the interactions within the system, or because the time interval is very short, the momentum of the system is constant.

- Newton's second and third laws of motion are a direct result of the conservation of momentum principle applied to cases of constant mass:

  *[**BOUNDARY:** For inertial frames of reference, Newton's first law of motion is a special case of Newton's second law of motion. The distinction between gravitational and inertial mass is not necessary for preparing students for college success.]*

  - The vector sum of the external forces (net force) acting on an object causes the object's momentum to change: The average force multiplied by the time interval is equal to the momentum change ($m\Delta\vec{v}$):

$$\vec{F}_{net} = \vec{F}_{ave} = \frac{m\Delta\vec{v}}{\Delta t} = m\vec{a}\,.$$

  - If there are no external forces acting on an object, the object's momentum (and therefore its motion) cannot change.

  - Interaction forces between two objects cannot change the total momentum of the objects, since these forces would exist even if the system were isolated. Consequently, when two objects interact, the force on one object is equal in magnitude but opposite in direction to the force on the other object. This is the origin of Newton's third law.

Objective P.2.3
Nuclear Interactions and the Conservation of Mass–Energy

Students understand that much larger amounts of energy can be transferred out of a system during nuclear interactions than during chemical interactions. Nuclear interactions can result in a change in the number of protons, thus changing the identity of the element.

Clarification: In grades 6–8, students are introduced to the small-particle model of matter, chemical interactions and the periodic table (see Objectives PS.2.2, PS.2.3, PS.3.1 and PS.3.2). In grades 9–12, this knowledge is extended to include atomic structure (i.e., protons, neutrons and electrons) and nuclear interactions, which serve as an introduction to the conservation of mass–energy.

Suggested Connections
Within Physics: Electrical Interactions and Forces (P.1.5)

Between Physics and Other Disciplines: Relative and Absolute Dating (ES.3.1); Atomic Theories (C.1.1); Nuclear Chemistry (C.1.6); Periodic Table (C.2.1)

Prepares students for the following AP Enduring Understandings: AP Physics 1A, 3G; AP Chemistry 1A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.2.3.1 Compare and contrast the masses, charges and locations of the protons, neutrons and electrons in an atom.

P-PE.2.3.2 Explain why the nuclear interaction among the protons and neutrons in the nucleus of an atom does not play a role in everyday phenomena. Justify the explanation by using knowledge of electrical and nuclear forces.

P-PE.2.3.3 Contrast nuclear fusion with nuclear fission, in terms of what happens to the nuclei. Contrast includes visual representations of the two processes.

P-PE.2.3.4 Predict the new element that is formed during the radioactive decay (alpha or beta) of a given isotope. Justify the prediction by using the periodic table and knowledge of radioactive decay.

P-PE.2.3.5 Explain why it is possible to get more energy out of fission and fusion reactions than out of chemical reactions involving the same amount of material. Justification is based on knowledge of mass–energy equivalence.

P-PE.2.3.6 Calculate the energy required to fuse two atoms in a fusion reaction and the energy released in a fission reaction, using the mass–energy equivalence principle and knowledge of fusion and fission reactions. Calculations are based on the atomic masses of the original particle(s) and the masses of the particle(s) that interacted to produce them.

P-PE.2.3.7 Explain and justify why it can be appropriate to solve some problems by using the conservation of mass principle or the conservation of energy principle, rather than the conservation of mass–energy principle.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- An atom consists of three subatomic particles called protons, neutrons and electrons. Positively charged protons and neutrally charged neutrons are found in the nucleus and have similar mass. The number of protons defines the chemical identity of an element. The nucleus is surrounded by negatively charged electrons that have significantly less mass than protons and neutrons, and the region of electrons takes up most of the space in an atom.

- The nuclear interaction between protons and neutrons is a non-electrical, attractive interaction at a distance that binds them to form a stable nucleus. The attractive nuclear force is much stronger than the repulsive electrical force between the protons for particle distances less than 10^{-15} meters, but the nuclear force becomes extremely weak for greater distances. Consequently, neutrons have little effect on how an atom interacts with other atoms, yet the number of neutrons does affect the mass and stability of the nucleus.[13]

13. American Association for the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford University Press, 1993), 80.

ESSENTIAL KNOWLEDGE, *continued*

- Atoms with the same number of protons and a different number of neutrons are called isotopes. Most elements have more than one stable isotope. When an atom has an unstable nucleus, the unstable nucleus emits very fast-moving particles (e.g., alpha, beta or positron). This process, called radioactive decay, results in nuclei of a different element being formed from the old one. Sometimes the emission of radiant energy (e.g., gamma rays) is part of this process. Atoms with an unstable nucleus are often called radioisotopes.

- Radioisotopes have several medical applications. The particles and radiant energy emitted as a result of the unstable nucleus have high energy and can be detected. These characteristics allow radioisotopes to be used as tracers of biological processes and to kill biological materials (e.g., cancer cells).

- Half-life is a measure of the rate of radioactive decay, or the amount of time it takes for half of a radioactive sample to decay to its products. For any radioisotope, the half-life is constant and unique and can be used to determine the age of the material.

- Nuclear fusion reactions occur when two smaller nuclei combine to produce one larger nucleus. The process of fusion is the source of energy for stars. Elements heavier than hydrogen continue to be created as a result of fusion reactions in the centers of stars. In the fusion process, the mass of the product is less than the mass of the reactants. The missing mass appears as energy. These energy changes are much greater than those that accompany chemical reactions.

- Nuclear fission reactions occur when a large nucleus splits to produce two smaller nuclei. In many fission reactions, energetic neutrons are also released, which can be absorbed by nearby nuclei, causing them to undergo fission. In the fission process, the mass of the product is less than the mass of the original nucleus. The missing mass appears as energy. These energy changes are much greater than those that accompany chemical reactions.

- As predicted by Albert Einstein in his special theory of relativity, during nuclear interactions, the transfer of energy out of a system is directly proportional to the change in mass of the system. The mass–energy equivalence principle is $\Delta E = \Delta mc^2$, where c is the speed of light in a vacuum. A very small amount of mass is converted to a large amount of energy.

- The more general conservation principle is a combination of the conservation of mass principle and the conservation of energy principle: Mass–energy is always conserved for all types of interactions at all scales, including nuclear interactions and other types of interactions among subatomic particles.

Standard P.3
Interactions and Energy

Interactions of an object with other objects can be described and explained by using the concept of the transfer of energy from one object to another, both within a defined system and across the boundary of the system. Energy transfers across the boundary of a system can change the energy within the system.

Students understand that scientists can describe, explain and predict an event involving different types of interactions (excluding nuclear interactions) by using the concept of energy transfer and the conservation of energy principle. During an interaction between two objects/ systems, energy is transferred from one object/system (acting as the energy source) to the other object/system (acting as the energy receiver). The energy of the source decreases and the energy of the receiver usually increases. When energy is transferred across the boundary of a system, the energy within the system changes. When the amounts of energy are measured, energy is always conserved for both open and closed systems.

Clarification: In this standard, there is only one fundamental conservation of energy equation, and all other energy equations are special cases (e.g., work–energy theorem, conservation of mechanical energy, the first law of thermodynamics).[14] In the objectives of this standard, the conservation of energy equation is applied to many different topics (contact, electric current, mechanical wave, radiant energy [light], and heating and cooling interactions).

Objective P.3.1
Contact Interactions and Energy

Students understand that a mechanical energy transfer (work) across the boundary of a system can change the kinetic energy, the stored elastic energy and other types of energy within the system.

*[**BOUNDARY:** Motion and forces are limited to horizontal one dimension.]*

Clarification: In grades 6–8, students begin to develop fluency in qualitatively describing contact interactions in terms of a mechanical energy transfer (work) from one object, which acts as the energy source, to the other interacting object, which acts as the energy receiver (see Objective PS.4.1). In grades 9–12, students extend their knowledge to include mathematical representations of mechanical energy transfer (work), elastic energy and kinetic energy, and they begin to develop the skill of determining the terms in the conservation of energy equation that apply to different problems. Situations involving gravitational interactions are in Objective P.4.2.

> **Suggested Connections**
> *Within Physics:* Contact Interactions and Forces (P.1.3); Conservation of Charge, Mass and Energy (P.2.1)
>
> *Between Physics and Other Disciplines:* Tectonism (ES.1.3); Climate (ES.2.4); Energy Transfer (LS.4.2); Conservation of Energy (C.3.1)
>
> *Prepares students for the following AP Enduring Understandings:* AP Physics 3E, 4C, 6A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.3.1.1 Translate between different representations (e.g., verbal and/or written descriptions, energy diagrams and the conservation of energy equation) of energy transfers and changes within a system for different problems involving mechanical interactions.

P-PE.3.1.2 Investigate and analyze problems involving different types of contact interactions between two objects, with the two objects identified as the defined system.

P-PE.3.1.2a Predict which terms in the conservation of energy equation will be applicable, not applicable or too small to be measurable for a given problem. Prediction is based on the defining characteristics of the different types of contact interactions.

14. A similar approach is described in a series of articles by J. W. Jewett Jr. (2008a, 2008b, 2008c, 2008d).

PERFORMANCE EXPECTATIONS, *continued*

P-PE.3.1.2b Measure appropriate quantities (e.g., force, mass, distance, elastic constant) needed to confirm or refute the prediction.

P-PE.3.1.2c Analyze and represent data, including calculations and diagrammatic representations of changes in energy within the system and transfers of energy into or out of the system.

P-PE.3.1.2d Make a claim about which terms in the conservation of energy equation are not applicable or too small to be measurable. Justification is based on the evidence.

P-PE.3.1.2e Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation under different conditions for the problem. Justification is based on the terms in the conservation of energy equation.

P-PE.3.1.3 Predict qualitatively the relative energy transfers and energy changes in a system for different problems involving mechanical energy transfers (work) and for different systems of interest. Justify the prediction by using energy diagrams and the conservation of energy equation.

P-PE.3.1.4 Explain and predict algebraically how changing a variable (e.g., the magnitude of a force or the distance over which a force acts) changes the amount of mechanical energy transfer (work) in different problems involving contact interactions. Justification is based on the definition of mechanical energy transfer (work).

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Mechanical energy transfer (work) is mathematically represented by $W = F\Delta x$, where F is the vector sum of the external forces (net force) in the direction of motion. When an external force causes a transfer of energy into the system, then $W = W_{in}$ ("work done on the system"). When the external force causes a transfer of energy out of the system, then $W = W_{out}$ ("work done by the system"). Mechanical energy transfers (work) within and across the boundaries of a system can result in changes in the kinetic, elastic, chemical or thermal energy of the interacting objects.

- If the only transfers of energy into or out of a system are mechanical interactions, then the conservation of energy principle is:

$$\Delta E_{system} = E_{in} - E_{out}$$
$$\Delta E_{kinetic} + \Delta E_{elastic} + \Delta E_{grav} + \Delta E_{other} = W_{in} - W_{out}\,,$$

  where ΔE_{other} includes other forms of energy (such as thermal energy). Depending on the situation, one or more of the energy transfers across the system boundary could be applicable, not applicable or too small of an effect to be measurable.

- The empirical approximation for the change in the stored elastic energy of an object made of elastic material (such as a spring) is $\Delta E_{elastic} = 1/2\ k\ \Delta x^2$, where Δx is the distance the elastic object is compressed or stretched from its relaxed length.

- Kinetic energy is the energy of motion and can be mathematically represented by $E_{kinetic} = 1/2\ m\ v^2$, where v is the magnitude of the instantaneous velocity of the object.

Objective P.3.2
Electric Current Interactions and Energy

Students understand that during electric circuit interactions, electrical energy is transferred from the source of electric current to the electric device, or devices, in the circuit. In most electric circuit interactions, energy is also transferred to the surroundings.

Clarification: In grades 6–8, students are introduced to qualitative ideas about series and parallel circuits, electric current as a flow of charge, and the idea that the charges that flow are in conductors all the time (see Objective PS.4.2). In grades 9–12, students extend their knowledge to include mathematical representations of current, resistance, potential difference and power, and they continue to develop the skill of determining the terms in the conservation of energy equation that apply to different circuit problems.

Suggested Connections
Within Physics: Gravitational Interactions and Forces (P.1.4); Conservation of Charge, Mass and Energy (P.2.1)

Prepares students for the following AP Enduring Understandings: AP Physics 1B, 4E, 5B, 5C; AP Chemistry 5B

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.3.2.1 Compare the speeds of electrons at different points in a circuit that is made up of sections of metal wire of different diameters by using a conceptual model of electric current.

P-PE.3.2.2 Explain how a simple device (e.g., incandescent light bulb, fuse) works. Justification is based on a model of electric current through conductors.

P-PE.3.2.3 Investigate the relationship between current and potential difference (measured in volts and sometimes referred to as voltage) for different circuit devices (e.g., light bulb, commercial resistor).

- **P-PE.3.2.3a** Ask and refine a **scientific question** about the relationship between potential difference and current for a circuit device.
- **P-PE.3.2.3b** Measure and record the voltage for different values of the current.
- **P-PE.3.2.3c** Analyze and represent the data on a potential difference versus current graph.
- **P-PE.3.2.3d** Make a claim about the relationship between potential difference and current for the device. Justification is based on the evidence.
- **P-PE.3.2.3e** Discuss the meaning of the slope for linear potential difference versus current graphs.

P-PE.3.2.4 Analyze problems involving electric circuit interactions.

- **P-PE.3.2.4a** Select an object/system and a time interval in order to solve the problem.
- **P-PE.3.2.4b** Identify the transfers of energy into and out of the system, and the changes in energy within the system.
- **P-PE.3.2.4c** Write the conservation of energy equation for the problem.
- **P-PE.3.2.4d** Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation under different conditions for the problem. Justification is based on the terms in the conservation of energy equation.

P-PE.3.2.5 Calculate the current in various segments or branches of an electrical circuit from a description or schematic diagram of the circuit.

P-PE.3.2.6 Predict the value of the current through a circuit or the potential difference across an element of a circuit in different problems. Prediction is based on knowledge of conservation of energy and charge.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The electric current is the amount of charge that flows past a specific point each second ($I = q/\Delta t$). The measurement unit of current, the ampere (A), is equal to one coulomb of charge per second (C/s).
- The atomic model of metal conductors has a lattice of positively charged metal ions that are more or less fixed within a conductor, permeated by a "sea" of mobile, negatively charged electrons. Using this model, one can demonstrate that electrons in metals typically "move" a few centimeters per hour, even during high currents. By convention, current is defined as the amount of positive charge that flows past a specific point each second.

ESSENTIAL KNOWLEDGE, *continued*

- The potential difference, or voltage (ΔV), across a battery is the potential energy difference (ΔE) per unit charge q that is caused by the chemical reaction in the battery that separates charges on the positive and negative ends of the battery ($\Delta V_{battery} = \Delta E/q$). Potential difference is a property of the battery and does not depend on the devices in the circuit.

- The electric potential difference across a resistor is the product of the current and the resistance.

- Electrical charge is conserved. In a closed system such as a circuit, the current flowing into a branch point junction must equal the total current flowing out of the junction (junction rule).

- For a system consisting of resistive devices in series, the conservation of energy equation is:

$$\Delta E_{system} = E_{in} = E_{out}$$

$$\Delta E_{system} = 0,\ E_{in} = q\Delta V_{battery},\ \text{and}\ E_{out} = q\Delta V_1 + q\Delta V_2 + q\Delta V_3 + \ldots$$

$$\text{so} \quad q\Delta V_1 + q\Delta V_2 + q\Delta V_3 + \ldots = q\Delta V_{battery}.$$

For circuits, it is often more useful to calculate the energy changes and energy transfers per unit time. Energy change or transfer per unit time is called power (P):

$$P = \frac{\Delta E}{\Delta t} = \frac{q\Delta E}{\Delta t} = I\Delta V$$

$$\text{so} \quad \frac{q\Delta V_1}{\Delta t} + \frac{q\Delta V_2}{\Delta t} + \frac{q\Delta V_3}{\Delta t} \ldots = \frac{q\Delta V_{battery}}{\Delta t}$$

$$I\Delta V_1 + I\Delta V_2 + I\Delta V_3 + \ldots = I\Delta V_{battery} = P_{battery}.$$

The unit of power is the watt (W).

Objective P.3.3
Mechanical Wave Interactions and Energy

Students understand that during mechanical wave interactions, mechanical energy is transferred through a material without a transfer of matter; different objects or materials can cause the path of the wave to change; and waves pass through each other, causing interference patterns.

*[**BOUNDARY:** The wavelet model of wave propagation and interactions is excluded.]*

Clarification: For students in grades 6–8, the mechanical wave properties that are addressed are those that are most easily observed by using simple physical systems such as a string, a slinky or a rope. These properties are **frequency**, **wavelength**, **amplitude** and wave speed. Students describe and represent mechanical wave interactions with energy diagrams (see Objective PS.4.3). Students in grades 9–12 expand their knowledge to include reflection, diffraction and the superposition principle, and they continue to develop the skill of determining the terms in the conservation of energy equation that apply to different problems.

Suggested Connections
Prepares students for the following AP Enduring Understandings: AP Physics 5B, 6A, 6B, 6C, 6D

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.3.3.1 Recognize, for waves in one-, two- and three-dimensional materials, examples of reflection, refraction, diffraction and interference.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.3.3.2 Investigate, and make a claim about, the variables that affect the interaction of mechanical waves with different boundaries. Analyze and represent observations with a drawing and, when appropriate, with a **ray diagram**.

*[**BOUNDARY:** Solid boundaries and variables should include solid objects of different sizes, the interface between two materials, a solid boundary with a single slit of different sizes, a solid boundary with two slits of different sizes, and different distances between the slits.]*

P-PE.3.3.3 Explain, using words and diagrams, an example of interference (e.g., standing waves, **two-source interference patterns**). Justification is based on the principle of the superposition of waves.

P-PE.3.3.4 Predict, using words and diagrams, what happens to a mechanical wave interference pattern in different problems when two slits in a barrier are moved closer together or farther apart, or when the wavelength changes. Justify the prediction based on the observed interference pattern and areas of constructive and destructive interference.

P-PE.3.3.5 Describe the evidence that supports the idea that sound is a wave phenomenon.

P-PE.3.3.6 Explain and predict, using words and diagrams, what happens to the observed frequency of a wave (increases, stays the same, decreases) in different problems when the observer and the wave source are moving toward each other or moving away from each other. Justify the explanation and prediction based on knowledge of the Doppler effect.

P-PE.3.3.7 Investigate and analyze energy transfers and energy changes in different problems involving a mechanical wave interaction at a barrier or boundary with another material.

- **P-PE.3.3.7a** Select an object/system and a time interval in order to solve the problem.
- **P-PE.3.3.7b** Identify the incident and reflected mechanical wave energy, and determine what happens to the energy that passes into the material.
- **P-PE.3.3.7c** Write the conservation of energy equation for the problem.
- **P-PE.3.3.7d** Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation if the conditions for the problem changed. Justification is based on the terms in the conservation of energy equation.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- When energy in a mechanical wave ($E_{incident}$) reaches a barrier or boundary to another material, a portion of its energy is reflected at the boundary ($E_{reflected}$), and a portion of the energy passes through the boundary into the material ($E_{transmitted}$). For a system consisting of two materials and incident, reflected, and transmitted waves, the conservation of energy principle can be mathematically represented by:

$$\Delta E_{system} = E_{in} - E_{out}$$
$$E_{incident} - E_{reflected} - E_{transmitted} = E_{dissipated},$$

  where $E_{dissipated}$ is the energy "dissipated," or transferred, out of the system due to the interaction of the system with surrounding objects, assuming no other transfers of energy have taken place. When the dissipated energy is so small that it can be neglected, then:

$$E_{incident} - E_{reflected} = E_{transmitted}.$$

- When the wave material (medium) is two-dimensional (e.g., surface water waves, surface seismic waves) or three-dimensional (e.g., sound), then the interaction between a wave and another object or interface causes the path of the wave to change (bend or change direction). The change in the path of the wave can be represented with ray diagrams.
  - ◆ Mechanical waves can bounce off of solid barriers. This interaction is called reflection. The law of reflection states that the angle at which a wave approaches the barrier (angle of incidence) equals the angle at which the wave reflects off the barrier (angle of reflection).

ESSENTIAL KNOWLEDGE, *continued*

- ◆ When a mechanical wave travels from one material (medium) into another material, its direction changes. This interaction is called refraction. Since the speed of a wave depends on the material through which the wave travels, both the speed and the wavelength of the refracted wave change.
- ◆ Mechanical waves bend around small obstacles or openings. This interaction is called diffraction. The amount of diffraction increases with increasing wavelength. When the wavelength is smaller than the obstacle or opening, no noticeable diffraction occurs.

- When two waves traveling in the same elastic material meet, they pass through each other. When the waves pass through each other, the displacements caused by the two waves add algebraically. This phenomenon is called the superposition of waves.
  - ◆ When the two displacements are in the same direction (same sign), the total displacement of the material is larger than the displacement of either wave (constructive interference).
  - ◆ When the two displacements are in opposite directions (opposite signs), the total displacement of the material is less than the displacement of the largest amplitude wave (destructive interference).
- When an observer and a mechanical wave source move toward each other, the observed frequency is higher; when they move away from each other, the observed frequency is lower. This phenomenon is called the Doppler effect.

Objective P.3.4
Radiant Energy Interactions

Students understand that during radiant energy interactions, energy can be transferred over a distance without a material (medium), and that there are two models that illustrate how this happens. There is a continuous range of radiant energies that includes visible light. Some objects produce their own visible light, while others reflect light from their surroundings.

Clarification: In grades 6–8, students are introduced to thermal radiation as one mechanism for a thermal energy transfer (heat) (see Objective PS.4.5). In grades 9–12, students extend their knowledge to include the full spectrum of radiant energy transfers. They explore how people perceive objects with different colors, the difference between mechanical wave energy transfer and radiant energy transfer, and the two models of radiant energy transfer (wave-like and particle-like transfer).

> **Suggested Connections**
> *Prepares students for the following AP Enduring Understandings:* AP Physics 1D, 6A, 6B, 6C, 6E, 6F, 6G, 7C; AP Environmental Science 1A, 1C; AP Biology 2A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.3.4.1 Investigate, and make a claim about, light energy interactions with different types of objects, including opaque objects with smooth, shiny or rough surfaces; transparent objects with different shapes (rectangular, converging lens, diverging lens); barriers with two slits; and diffraction gratings. Analyze and represent the observations by drawing an energy diagram and/or a light ray diagram. Justification is based on the observed evidence.

P-PE.3.4.2 Compare and contrast mechanical wave interactions and light energy interactions.

P-PE.3.4.3 Explain, using words and a light-ray diagram (source, object, eye–brain system), why a person can or cannot see an object in different problems. Justification is based on knowledge of light sources, reflection and diffuse reflection.

P-PE.3.4.4 Explain, using words and a light-ray diagram (light source, object, eye–brain system), why an object appears to be a specific color. Justify the explanation by using knowledge of the interaction of white light with the pigments in objects.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.3.4.5 Describe the evidence supporting the idea that a prism or diffraction grating does not create the colors of light, but spreads the colors.

P-PE.3.4.6 Compare and contrast the different bands of the electromagnetic spectrum of radiant energy, in terms of energy, frequency and wavelength. Give examples of devices or phenomena for each band of the spectrum.

P-PE.3.4.7 Analyze problems involving radiant energy interactions at the interface between two materials.

- **P-PE.3.4.7a** Select an object/system and a time interval in order to solve the problem.
- **P-PE.3.4.7b** Identify the incident and reflected light energy, and determine what happens to the energy that passes into the material. Determination is based on the problem.
- **P-PE.3.4.7c** Write the conservation of energy equation for the problem.
- **P-PE.3.4.7d** Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation under different conditions for the problem. Justification is based on the terms in the conservation of energy equation.

P-PE.3.4.8 Explain or justify how life has evolved in response to where the solar spectrum peaks.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Radiant energy transfer occurs when radiant energy from an object acting as the energy source (e.g., radio transmitter, the Sun) travels to an object acting as the energy receiver some distance away. Radiant energy transfer does not require a material (medium) between the source and the energy receiver. For most everyday systems of interest, the surroundings of the system are also energy receivers.

- When light energy from a source ($E_{incident}$) reaches a boundary between materials with different optical properties (such as air to water), a portion of the energy is reflected at the boundary ($E_{reflected}$), and a portion of the energy passes through the boundary into the material ($E_{material}$). At such a boundary, the conservation of energy principle can be mathematically represented by:

$$\Delta E_{system} = E_{in} - E_{out}$$
$$E_{incident} - E_{reflected} - E_{material} = 0$$
$$E_{incident} - E_{reflected} = E_{material} .$$

- The amount of energy that is absorbed into the material depends primarily on the properties of the object. For example, the visible light energy that is absorbed into opaque objects (e.g., paper, a chair, an apple) usually results in an increase in the object's thermal energy. Transparent materials transmit most of the energy through the material.

- Light sources (e.g., the Sun, a light bulb) radiate energy continually from each point on the source in all directions.
  - ◆ When light energy interacts with an opaque object, some of the light reflects off each point of the object in all directions (diffuse reflection).
  - ◆ Humans can only perceive visible light energy — either from a source or that which is reflected off objects — when the light interacts with the eye–brain system. Light interactions can be represented by ray diagrams.

- Light energy from the Sun or a light bulb filament is a mixture of all the colors of light (visible light spectrum). The different colors correspond to different energies: from red (lowest energy) to orange, yellow, green, blue and violet (highest energy).

- When white light hits an object, the pigments in the object reflect one or more colors (radiant energies) in all directions and absorb the other colors (radiant energies).

- There are two models of how radiant energy travels through space at the speed of light.

ESSENTIAL KNOWLEDGE, *continued*

- ◆ One model is that the radiation travels in discrete packets of energy continuously emitted from an object in all directions. This particle-like model is called the photon model of light energy transfer.
- ◆ A second model is that radiant energy travels like a mechanical wave disturbance that spreads out in all directions from a source. This wave-like model is called the electromagnetic wave model of light energy transfer.
- ◆ Strong scientific evidence supports both the particle-like model and the wave-like model. Depending on the problem scientists are trying to solve, they either use the particle-like model or the wave-like model of radiant energy transfer.

- The history of the particle-like and wave-like models of light energy transfer illustrates the role of evidence in the development of alternative models. In the 18th century, both the particle-like model and the wave-like model for light energy transfer had been proposed. However, scientists tended to favor the particle-like model because it seemed to explain the properties of light better than the wave-like model did. In the 19th century, new evidence strongly supported the wave-like model for light, which became the commonly accepted model. In the 20th century, additional evidence led to a resurrection of the particle-like model because it could explain phenomena that the wave-like model could not. Today, scientists recognize either model as being appropriate for predicting the results of radiant energy interactions, depending on the circumstances.
- Despite the fact that there is no observable wave or material through which a wave can travel, a frequency (and wavelength) for radiant energy can be calculated from its wave-like, two-slit interference pattern. The continuous range of radiant energies is organized into the electromagnetic spectrum, which is determined by the frequency or wavelength (the greater the frequency, the greater the radiant energy). This spectrum is further divided into seven bands: radio (lowest energy band), microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays (highest energy band).

Objective P.3.5
Heating and Cooling Interactions and Energy

Students understand that during heating and cooling interactions, there is a thermal energy transfer (heat) across the boundary of a system, affecting the temperature or the state of matter of the system. These interactions depend on the properties of the materials and on how far the system is from equilibrium.

*[**BOUNDARY:** Examples of change of state are limited to simple cases of melting, freezing or boiling (e.g., melting ice, freezing water and boiling water).]*

Clarification: In grades 6–8, students are introduced to thermal energy and the different mechanisms of thermal energy transfer (heat) (see Objective PS.4.5). Students in grades 9–12 extend their knowledge of thermal conductivity and thermal energy, and they continue to develop the skill of determining the terms in the conservation of energy equation that apply to different problems.

Suggested Connections
Within Physics: Conservation of Charge, Mass and Energy (P.2.1)

Between Physics and Other Disciplines: Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Climate (ES.2.4); States of Matter (C.1.5); Conservation of Energy (C.3.1); Energy Transfers and Transformations (C.3.2)

Prepares students for the following AP Enduring Understandings: AP Physics 3E, 4C, 6A

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.3.5.1 Investigate, and make a claim about, the relationship between a variable (e.g., temperature, mass of a system, type of material) and the change in the thermal energy of a system for the special case of no change of state and no transfer of mechanical energy across the boundary of the system. Justification is based on the evidence and the conservation of energy principle. Write a mathematical representation of the relationship between the change in thermal energy and the change in the temperature and the mass of the system.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.3.5.2 Rank in order, based on a data table or experimental results, the thermal conductivity of different materials.

P-PE.3.5.3 Construct explanations of everyday problems involving heating and cooling, including why two objects next to each other in a room feel like they are at different temperatures; why clothes made of wool or fur keep people warm; why a hot object that is left in a room cools down to room temperature; why a solid object that is left out in the hot summer Sun all day does not keep increasing in temperature until it melts; and why two objects or systems, when heated or cooled by the same method for the same time interval, can have different final temperatures. Justifications are based on knowledge of thermal conductivities, thermal radiation and absorption, and thermal equilibrium.

P-PE.3.5.4 Rank in order, based on a data table or experimental results, the thermal radiant energy reflection of different materials.

P-PE.3.5.5 Explain the experimental results observed in a situation where the variable is the thermal absorption or radiation of the objects being observed.

P-PE.3.5.6 Explain qualitatively why the temperature remains constant while an object melts, freezes, condenses or boils, even though there is a continual thermal energy transfer (heat) across the system boundary.

P-PE.3.5.7 Analyze problems involving thermal energy transfers (heat) and/or mechanical energy transfers (work) and changes in the thermal energy of a system.

P-PE.3.5.7a Select an object/system and a time interval in order to solve the problem.

P-PE.3.5.7b Determine and represent, with an energy diagram, the direction of thermal or mechanical energy transfers across the system boundary and the thermal energy changes within the system.

P-PE.3.5.7c Make claims about which terms in the conservation of energy equation are applicable, not applicable or are too small to be measurable. Justifications are based on knowledge of methods of thermal energy transfer (heat).

P-PE.3.5.7d Write the conservation of energy equation for the problem.

P-PE.3.5.7e Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation under different conditions for the problem. Justification is based on the terms in the conservation of energy equation.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The thermal energy of a system in a given state depends on the temperature of the system (the higher the temperature of a system, the greater its thermal energy) and the mass of the system (the larger the mass of a system, the greater its thermal energy at a given temperature), and is different for different substances with the same mass and temperature.

- The small-particle model of thermal energy explains why the temperature of a substance remains constant during a change of state, despite the fact that thermal energy is continually transferred into or out of the substance.

  - *Small-Particle Model of Melting.* As a solid is heated, the average speed of the vibrating molecules increases. At the melting temperature, the average speed of these vibrating molecules is large enough so that some of the faster-moving molecules start to break free from their fixed positions and move around. As heating continues, more molecules break free from their fixed positions until all the molecules are moving around in the liquid state with the same average speed, and hence the same temperature, as they had just before melting began. For energy to be conserved, the thermal energy of the liquid must be higher than the thermal energy of the solid at the melting temperature.

  - *Small-Particle Model of Boiling.* As a liquid is heated, the average speed of the molecules increases. At the boiling temperature, molecules that are close together are sometimes moving so fast that the attractive forces can no longer hold them together. The molecules fly apart into a bubble of vapor. The bubbles rise to the surface and pop open, releasing the vapor into the air. All of the thermal energy transfer (heat) during boiling results in breaking the molecules free from their loose connections until all the molecules are moving randomly around in the gas state with the same average speed, and hence the same temperature, as they had just before boiling began. For energy to be conserved, the thermal energy of the gas must be higher than the thermal energy of the liquid at the vaporization temperature.

ESSENTIAL KNOWLEDGE, *continued*

- Thermal conductivity depends on the rate of thermal energy transfer (heat) from one end of the material to the other end (for a constant temperature difference and shape). Thermal conductivities of materials can be ranked in order on a continuous scale from good thermal insulators (thermal energy transfer [heat] is relatively slow) to good thermal conductors (thermal energy transfer [heat] is relatively fast).

- The rate at which thermal radiation is absorbed or emitted by a system depends on the system's surface properties (e.g., color, texture, exposed area) and its temperature. Thus, in a given amount of time, black, rough surfaces absorb more thermal energy than smooth, white surfaces (all other variables being equal).

- At a constant temperature, and in any time interval, the amount of thermal radiation emitted by an object to its surroundings is equal to the amount of thermal radiation absorbed by the object from its surroundings in that same time interval. This process is called thermal equilibrium.

- The conservation of energy law for situations in which the only transfers of energy into and/or out of a system are thermal energy transfers (heat) and/or mechanical energy transfers (work), and the only change of energy within a system is an increase or decrease of thermal energy, is known as the first law of thermodynamics. This process is mathematically represented by:

$$\Delta E_{system} = E_{in} - E_{out}$$
$$\Delta E_{thermal} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}),$$

  where Q is the thermal energy transfer (heat). Depending on the situation, one or more of the energy transfers across the system boundary could be applicable, not applicable or too small of an effect to be measurable.

Standard P.4
Interactions and Fields

Attractive and repulsive interactions at a distance (e.g., gravitational, magnetic, electrical and electromagnetic) can be described by using the concept of fields.

Students understand that one way scientists describe, explain and predict how forces act over a distance without contact is by using the concept of a field. A field is created by an object that serves as a source, extends through space and exerts a force on other objects. A gravitational field is produced by an object with mass, and the gravitational field exerts a force on other objects with mass. An electric field is created by an electrically charged object, and the electric field exerts a force on other electrically charged objects. A magnetic field is produced by moving electrical charges (i.e., electric current), and the magnetic field exerts a force on other moving electrical charges. Atoms have magnetic fields due to the motion of electrically charged particles in the atoms. In most materials these atomic magnetic fields are randomly oriented and cancel each other out, but in some materials the atomic magnetic fields are aligned so that the material produces a macroscopic magnetic field. Fields can be used to model the forces and stored (potential) energies in gravitational, electrical and magnetic interactions. Electric and magnetic fields can also interact without the presence of electrical charge or current. This interaction is an electromagnetic interaction.

Objective P.4.1
Forces and Fields

Students understand that a field model is used to visualize at-a-distance interactions, and that these fields are the agents of the interaction.
*[**BOUNDARY:** Only field diagrams are used; field line diagrams are excluded.]*

Clarification: Students in grades 6–8 are not introduced to fields, but they are introduced to gravitational, magnetic and electric charge interactions and forces (see Objectives PS.1.4 and PS.1.5). In grades 9–12, the concept of a field is introduced in order to explain interactions at a distance. The field concept also allows for the conservation of energy to be applied to numerous systems. Students relate the source of the field with the field itself, along with qualitative descriptions of the direction of the field. They are also introduced to the mathematical representation of a field.

> **Suggested Connections**
> *Within Physics:* Gravitational Interactions and Forces (P.1.4); Electrical Interactions and Forces (P.1.5); Electric Current Interactions and Energy (P.3.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Physics 2A, 2B

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.4.1.1 Explain how mutually attracting or repelling objects interact at a distance without touching. Justify the explanation based on knowledge of the field model.

P-PE.4.1.2 Draw a magnetic field diagram for a magnet, using a compass (or many compasses). Analyze two magnetic field diagrams to determine which magnet has the strongest magnetic field. Predict the differences that would be observed if compasses were placed at different locations around each magnet.

P-PE.4.1.3 Draw a gravitational field diagram for a planet or moon. Identify correct and incorrect gravitational field diagrams for a planet or moon. Analyze two gravitational field diagrams to determine which of two planets has the strongest gravitational field. Predict the differences that would be observed if unit masses (1 kg) were hung from spring scales placed at different locations around the planet.

P-PE.4.1.4 Calculate the weights of an object on the surfaces of different planets or moons by using a table showing the gravitational field strength (gravitational force per unit of mass, g) at the surfaces of the planets and moons.

P-PE.4.1.5 Calculate the electric forces on a point charge at different locations, given the magnitude of the electric field at these locations.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.4.1.6 Analyze an electric field diagram for a collection of two or three point charges in a line (with the same charge magnitudes) to determine whether the diagram accurately represents the problem. Explain why the diagram is correct or incorrect. Justification is based on knowledge of field diagrams and electric fields.

P-PE.4.1.7 Draw a sketch of the electric field diagram for two point charges, given each charge type, relative charge magnitudes and the distance between the two charges.

P-PE.4.1.8 Recognize the electric field diagrams for a dipole, a large sheet of charges (uniform surface charge density) and two large capacitor plates.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Magnetic, electrical, gravitational and electromagnetic interactions occur continually when objects are not touching, and they do not require a material (medium) between the two interacting objects. These types of interactions are called at-a-distance interactions.
- The field model represents spheres of influence called fields that surround objects. When an object with the appropriate property is placed in the field of another object, the field exerts a force on it (e.g., a magnet influencing a compass needle). The stronger the field, the larger the magnitude of the force exerted by the field on objects placed in the field.
- The direction of the magnetic field at any point in space is the equilibrium direction of the north end of a compass placed at that point. The gravitational field strength at any point in space around a planet can be measured by hanging a unit mass on a stationary spring scale. The direction of the gravitational field is the direction of a plumb line, toward the center of the object causing the field. Magnetic and gravitational fields can be represented by field diagrams obtained by plotting field arrows at a series of locations.
- The field of a particular source (such as Earth) depends only on the properties of the source and the position of an object relative to the source, not on any properties of objects placed in the field (such as a ball). The field of an object is always there, even if the object is not interacting with anything else. Mathematically, a field must be represented by a set of specific values at every position in space.
- The strength of an object's (i.e., the source's) gravitational field at a certain location is given by the gravitational force per unit of mass experienced by another object placed at that location. The field direction is toward the center of the source: $\vec{g} = \vec{F}_g/m$. If the gravitational field at a certain position is known, then the gravitational force exerted by the source of that field on any object at that position can be calculated by multiplying the gravitational field and the mass of the object.
- The strength of the electrical field of a charged object at a certain location is given by the electric force per unit of charge experienced by another charged object placed at that location. The direction of the electric field at a certain location is parallel to the direction of the electrical force on a positively charged object at that location: $\vec{E} = \vec{F}_e/q$. The electric field caused by a collection of charges is equal to the vector sum of the electric fields caused by the individual charges (superposition of charge).

Objective P.4.2
Energy and Fields

Students understand that the energy stored in a system of two mutually attracting or repelling objects can be modeled as energy stored in the fields of the two objects.

Clarification: In grades 6–8, students are introduced to mechanical energy transfers (work) and elastic energy (see Objective PS.4.4). In grades 9–12, the use of the conservation of energy as one of the key organizing principles of physics requires the introduction of the notion of a field because energy can be transferred to and from a field. Potential energy concepts are applied to fields in order to provide a complete description of easily observable systems.

Suggested Connections

Within Physics: Gravitational Interactions and Forces (P.1.4); Electrical Interactions and Forces (P.1.5); Contact Interactions and Energy (P.3.1)

Between Physics and Other Disciplines: Electrons (C.1.2); Conservation of Energy (C.3.1)

Prepares students for the following AP Enduring Understandings: AP Physics 2A, 2B, 5B

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.4.2.1 Explain why energy must be stored in the fields of attracting or repelling objects and not in the objects themselves.

P-PE.4.2.2 Describe the similarities between the model for energy stored in gravitational fields and the model for energy stored in magnetic fields.

P-PE.4.2.3 Compare by ranking the amount of gravitational potential energy stored in an Earth–object system for different positions of the object relative to Earth's surface.

P-PE.4.2.4 Calculate the change in gravitational potential energy of the Earth–object system for different objects at different locations above Earth's surface by using different reference points.

P-PE.4.2.5 Identify, for different problems, when the correct system has been selected for describing gravitational or electric potential (field) energies. Justification is based on the field model of potential energy.

P-PE.4.2.6 Translate between representations (e.g., energy diagrams and the conservation of energy equation) of energy transfers and energy changes in a defined system for problems involving lifting or falling objects or the separation of charged objects.

P-PE.4.2.7 Analyze problems involving lifting or falling objects near Earth's surface, with the system defined as Earth and the object.

- **P-PE.4.2.7a** Determine and represent, with an energy diagram, the energy changes within the system and the transfers of energy within and across the boundaries of the system.
- **P-PE.4.2.7b** Make claims about which terms in the conservation of energy equation are applicable, not applicable or too small to be measurable. Justification is based on the conditions in the problem and knowledge of mechanical energy transfers (work) and gravitational potential energy.
- **P-PE.4.2.7c** Write the conservation of energy equation for the Earth–object system.
- **P-PE.4.2.7d** Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation under different conditions for the problem. Justification is based on the terms in the conservation of energy equation.
- **P-PE.4.2.7e** Define the system as the object. Make and justify claims about which terms in the conservation of energy equation are applicable, not applicable or too small to be measurable.
- **P-PE.4.2.7f** Write the conservation of energy equation for the object.

P-PE.4.2.8 Analyze problems involving different methods of separating charges, with the system defined as the two interacting objects (e.g., a rubber rod rubbed with fur, then separated).

- **P-PE.4.2.8a** Determine and represent, with an energy diagram, the energy changes within the system and the transfers of energy within and across the boundaries of the system.
- **P-PE.4.2.8b** Make claims about which terms in the conservation of energy equation are applicable, not applicable or too small to be measurable. Justification is based on the conditions in the problem and knowledge of mechanical energy transfers (work) and electric potential energy.
- **P-PE.4.2.8c** Write the conservation of energy equation for the defined system.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.4.2.8d Predict what would happen to a given energy term (increase, stay the same, decrease) in the conservation of energy equation under different conditions for the problem. Justification is based on the terms in the conservation of energy equation.

P-PE.4.2.8e Define the system as one of the interacting objects. Make and justify claims about which terms in the conservation of energy equation are applicable, not applicable or too small to be measurable.

P-PE.4.2.8f Write the conservation of energy equation for the defined object.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- When two mutually repelling or attracting objects interact, both objects' kinetic energies change, but since there are no other observable changes in the objects, neither is acting as the energy source or receiver. Instead, the energy is stored in or extracted from the field around the system.

- The energy stored in the field around two mutually attracting or repelling objects is called potential energy (e.g., gravitational potential energy, electric potential energy). A single object does not have potential energy. Only the system consisting of two or more attracting or repelling objects can have potential energy.

- During a magnetic interaction, magnetic energy can be modeled as being stored in the magnetic field around the system (magnet–magnet or magnet–magnetic object). A change in the separation of the magnets is evidence that the magnetic field energy around the system has changed.

    - When two magnetically repelling objects are moved close to one another, energy is stored in the field; when these objects are moved apart, energy is extracted from the field (similar to compressing and releasing a spring).

    - When two objects attract one another magnetically, energy is stored in the field by moving the objects apart, and energy is extracted from the field by allowing them to move closer (similar to stretching and releasing a spring).

- Gravitational fields only produce attraction. Gravitational energy can be modeled as being stored in the gravitational field of an Earth–object system. A change in the separation between the objects is evidence that the gravitational field energy of the system has changed.

    - When two attracting masses are moved farther apart, energy is stored in the field.

    - When two attracting masses are moved closer together, energy is extracted from the field.

- For an object close to Earth's surface (where gravitational field strength, g, is constant), mechanical energy must be transferred into the Earth–object system (W_{in}) to lift an object at a constant velocity a distance (Δy) above a zero reference point. So for energy to be conserved, the gravitational potential energy stored in the field (ΔPE_{grav}) must increase. As the object is lifted it pushes on the air, so mechanical energy is transferred out of the Earth–object system (W_{out}):

  $$\Delta E_{system} = E_{in} - E_{out}$$
  $$\Delta PE_{grav} = W_{in} - W_{out}$$
  $$\Delta PE_{grav} = m\,g\,\Delta y - W_{out}\,.$$

  For objects that are not lifted too far or too fast through the atmosphere, the mechanical energy transfer (work) due to the air is very small and can be neglected.

ESSENTIAL KNOWLEDGE, *continued*

- For falling objects close to Earth's surface and a system defined as Earth and the object, the only mechanical energy transfer (work) is out of the system to the air that is pushed by the falling object. The kinetic energy of the object increases and the gravitational potential (field) energy of the Earth–object system decreases:

$$\Delta E_{system} = E_{in} - E_{out}$$
$$\Delta E_{kinetic} - \Delta PE_{grav} = - W_{out} .$$

  When the mechanical energy transfer (work) to the air is so small it can be neglected, then:

$$\Delta E_{kinetic} + \Delta PE_{grav} = 0 .$$

- Whenever charge is transferred from an object to another object (e.g., separating strips of tape, rubbing objects against each other, using batteries, using a van de Graff generator), a mechanical energy transfer (W_{in}) is required to separate the positive and negative charges, just like energy is required to stretch a spring:

$$\Delta E_{system} = E_{in} - E_{out}$$
$$\Delta PE_{electric} + \Delta E_{other} = W_{in} ,$$

  where ΔE_{other} refers to other energy changes within the system (e.g., stored chemical energy of battery, thermal energy from friction).

- Whenever mechanical energy is transferred to a system of charged objects and there is no change in kinetic energy and no energy is transferred out of the system, the electric potential energy stored in the system must increase for energy to be conserved. The change in electric potential energy per unit charge is called the potential difference:

$$\Delta E_{system} = E_{in} - E_{out}$$
$$\Delta PE_{electric} = W_{in}$$
$$\Delta V = \Delta PE_{electric}/q .$$

Objective P.4.3
Electromagnetic Interactions and Fields

Students understand that an electromagnetic interaction occurs when a flow of charged particles creates a magnetic field around the moving particles, or when a changing magnetic field creates an electric field.

Clarification: In grades 6–8, students are not introduced to electromagnetic forces and fields. In grades 9–12, students develop a fairly extensive understanding of electromagnetism and fields at a qualitative level.

Suggested Connections
Within Physics: Forces and Changes of Motion (P.1.2); Electrical Interactions and Forces (P.1.5); Electric Current Interactions and Energy (P.3.2); Radiant Energy Interactions (P.3.4)

Between Physics and Other Disciplines: Electrons (C.1.2)

Prepares students for the following AP Enduring Understandings: AP Physics 2A, 2D

PERFORMANCE EXPECTATIONS

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

P-PE.4.3.1 Investigate, and make a claim about, the connection between electrical and magnetic interactions. Justification is based on the observed evidence and knowledge of electrical and magnetic interactions.

PERFORMANCE EXPECTATIONS, *continued*

P-PE.4.3.2 Identify, in different problems, whether or not there would be an electromagnetic interaction between a given wire in a circuit and a nearby magnet.

P-PE.4.3.3 Investigate, and make a claim about, the variables that affect the magnitude of the electromagnetic force on a current-carrying wire in a magnetic field. Justification is based on the evidence and Newton's second law of motion.

P-PE.4.3.4 Distinguish between examples where there is relative motion between a magnet and a closed-loop wire or coil, and examples where the magnet and the wire or coil are both in motion, but not in motion relative to each other.

P-PE.4.3.5 Investigate, and make a claim about, the variables that affect the magnitude of the induced electric current created by a changing magnetic field. Justification is based on the evidence and Faraday's law of induction.

P-PE.4.3.6 Explain, given a wire near a changing magnetic field, why an electric current in a loop of wire that is not connected to a battery could be detected.

P-PE.4.3.7 Explain the role of magnets and coils of wires in the functioning of microphones, speakers, generators and/or motors. Justification is based on the defining characteristics of electromagnetic interactions.

P-PE.4.3.8 Predict whether or not there will be a force on a current-carrying wire in a magnetic field for different situations. Justification is based on the defining characteristics of electromagnetic interactions.

P-PE.4.3.9 Predict whether or not there will be an electromagnetic force on two current-carrying wires in different situations. Justification is based on the defining characteristics of electromagnetic interactions.

P-PE.4.3.10 Explain qualitatively why radiant energy creates electric currents in conductors. Justification is based on the defining characteristics of electromagnetic interactions.

P-PE.4.3.11 Predict whether there will be more cosmic rays at the equator or at the poles of Earth. Justification is based on the defining characteristics of electromagnetic interactions.

ESSENTIAL KNOWLEDGE

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Electric current and magnetic interactions are closely related, even though they appear to be distinct from each other. The interaction between electricity and magnetism is referred to as an electromagnetic interaction. A basic component of technology is the use of electromagnetic interactions to convert mechanical energy into electrical energy and vice versa.

- A flow of charged particles (including an electric current in a wire) creates a magnetic field around the moving particles or the current-carrying wire. The evidence of the interaction is a change in motion of a nearby magnet or a change of flow of charged particles.

- A moving charged particle interacts with a magnetic field. The magnetic force that acts on a moving charged particle in a magnetic field is perpendicular to both the magnetic field and to the direction of motion of the charged particle. The magnitude of the magnetic force depends on the speed of the moving particle, the magnitude of the charge of the particle, the strength of the magnetic field, and the angle between the velocity and the magnetic field. There is no magnetic force on a particle moving parallel to the magnetic field. Earth's magnetic field shields Earth from high-energy charged particles (known as cosmic rays) by deflecting them away from Earth.

- Moving charged particles in magnetic fields typically follow spiral trajectories. Moving charged particles can also be trapped in the magnetic field of an object such as Earth. The Van Allen radiation belts are regions of high-energy particles trapped in Earth's magnetic field.

ESSENTIAL KNOWLEDGE, *continued*

- A changing magnetic field creates an electric field (while the magnetic field is changing). If a closed conducting path such as a wire occupies the space where the magnetic field is changing, the electric field may cause the flow of a changing electric current (evidence of the interaction). This is known as Faraday's law of induction. A changing magnetic field can be created through a closed-loop wire when a magnet and the loop move relative to each other. The magnitude of the induced electric current depends on the strength of the magnetic field, the speed and direction of the relative motion, and the configuration of the wire.

- A changing electric field creates a magnetic field, and a changing magnetic field creates an electric field. Thus, one model of radiant energy is an electromagnetic wave in which a pattern of changing electric and magnetic fields propagates at the speed of light.

Unpacking the Performance Expectations: Physics

Why "unpack" a performance expectation?

- The science practices standards appear to be separate from the discipline-specific standards, but they are intended to be integrated with disciplinary content knowledge.
- Unpacking a performance expectation establishes clear, specific targets of learning.
- Unpacking a performance expectation illustrates that any one performance expectation may involve multiple science practices.
- The unpacking is intended to provide a model for interpreting the science practices for a specific discipline.

How should an unpacked performance expectation be used?

- The sample unpacked performance expectation provided should be used as a model so that teachers can unpack all of the performance expectations within the discipline-specific standards.
- All of the unpacked performance expectations can be used for guidance in developing instructional strategies and curricula that offer opportunities for students to develop a robust understanding of the science practices and disciplinary content knowledge.
- All of the unpacked performance expectations can be used to develop curricula, instruction and assessment that are aligned with each other.
- Unpacking all of the performance expectations within a specific discipline enables teachers and curriculum supervisors to delineate the multiple science practices and content knowledge that are facilitated, and ultimately to link or map the performance expectations to existing curricula or to use the performance expectations as a basis for the establishment of curricular structure.
- All of the unpacked performance expectations allow decisions about instruction and curriculum design to be made in a more principled way.

SAMPLE UNPACKED PERFORMANCE EXPECTATION

Explain and justify how conservation of linear momentum can be used in the investigation of traffic accidents to determine the initial motions of the objects based on measurements of the final motions.

This is **P-PE.2.2.7**.

Unpacking the explanation in the performance expectation:

This is part of science practices **Objective SP.4.1**.

- Make the claim that traffic accidents can be investigated by using the conservation of linear momentum principle.
- Identify the conditions (e.g., the time interval in which the objects are in contact [collision] is short; friction across the boundary is much smaller than interaction between the vehicles; no mass is lost from the system) associated with the traffic accident investigation.
- Identify variables (i.e., initial and final motion) that can be investigated. Variables must be observable and measurable so that data can be collected.
- Use measurements of initial and final velocity and mass as evidence to support the claim in terms of the conservation of momentum.
- Construct a justification, based on knowledge of conservation of momentum and on the conditions associated with the traffic accident, that connects the measurements of the change in motion of the objects to the claim.
- To further support the explanation, articulate why the use of forces alone is not the most appropriate approach to investigating traffic accidents to determine initial and final motion (e.g., forces are difficult to measure).

This is part of science practices **Objective SP.4.3**.

Appendix A: AP Environmental Science Enduring Understandings

The following appendix represents the enduring understandings that will increasingly be the focus and the end goals of the AP Environmental Science course.

Enduring Understanding 1A

The energy available for processes on Earth is derived largely from the Sun, with a small contribution from geothermal sources.

The principal sources of energy on Earth are solar radiation produced by the fusion of hydrogen atoms into helium atoms within the Sun, and geothermal energy originating from radioactive decay within the Earth's interior. Inputs of energy to the Earth are balanced by losses of energy to space mostly as heat, allowing Earth's temperatures to remain relatively constant. Geothermal energy supplies a fraction of a percentage of the total energy input to the Earth's surface. In all cases, energy inputs to the Earth's surface are spatially variable, with the specific energy source driving natural processes that are dependent on location and process. The intensity of solar radiation varies spatially as a function of latitude. Solar energy inputs to the Earth vary over short time periods due to Earth's rotation orbit and fluctuations of sunspot activity, and over time these inputs vary due to variations in the Earth's tilt and orbital eccentricity. Geothermal energy makes a substantial contribution to the total available energy in regions of active volcanism where heat rises from the Earth's interior.

Enduring Understanding 1B

Energy transformations drive the movement of water and air on global and local scales.

Solar energy heats the Earth unevenly, producing temperature gradients that cause stratification of the atmosphere and ocean. Solar energy also produces winds and currents at the local scale and global convective circulation in the oceans and atmosphere. Heat causes evaporation of water and induces plants to release water by transpiration. Heat energy is transferred from the Earth's surface to the atmosphere by evapotranspiration and condensation of water, forming clouds and precipitation. Gravitational forces drive the surface and subsurface flow of water and its infiltration as groundwater, dependent on soil properties and saturation, and aquifer systems. In the subsurface, the local effects of geothermal energy can produce hot springs, geysers and hydrothermal vents, whereas gravitational interactions among the Sun, Moon and Earth produce tides in the ocean and control the variations in their timing and magnitude.

Enduring Understanding 1C

Primary production requires biologically accessible energy inputs, which vary over time and space.

Solar radiation is the ultimate source of energy for almost all organisms, as the energy captured in primary production is sequentially transferred, albeit inefficiently, between trophic levels within ecosystems. Geographical, especially latitudinal, variations in the availability of solar energy affect terrestrial primary production, leading to higher production rates in the tropics. In aquatic systems, photosynthesis is limited to the euphotic zone and affected by other factors that restrict the depth of penetration of solar energy. Components of Earth's atmosphere interact with solar electromagnetic radiation by absorbing portions of the spectrum; this strips out higher-energy x-rays and UV rays, and allows Earth's surface to be habitable. In contrast, chemoautotrophs are primary producers that derive energy from chemical substrates such as sulfides, and thereby can support ecosystems in the absence of sunlight.

Enduring Understanding 2A

Climate is influenced by interactions of multiple physical, chemical and biological factors, including human actions.

Climate is influenced by many factors, including solar inputs, air and water circulation, and gases and particulates in the atmosphere. Evidence of past changes in climate suggests that natural variations in climate occur over time. In addition to this natural change, the impact of humans on climate through the release of greenhouse gases is increasingly apparent. Greater understanding of climate dynamics is needed in order to predict the extent to which human actions will affect climate in the future.

Enduring Understanding 2B

Ecosystems emerge from biotic and abiotic interactions among Earth's atmosphere, hydrosphere, lithosphere and cryosphere.

Earth appears to be unique among planets in the solar system in its ability to sustain living systems, which are prevalent in terrestrial and aquatic environments. Ecosystems are dynamic communities of plants, animals, microorganisms and their abiotic environment that interact as a functional unit. The assemblage of organisms and environmental conditions in a particular region characterizes the type of terrestrial biome or aquatic life zone in that area. Ecosystems adapt to changing conditions in their environment over short and long time scales.

Enduring Understanding 2C

Earth's landscapes emerge from the interactions among the atmosphere, hydrosphere, lithosphere, biosphere, cryosphere and human activity.

Earth's surface has changed over time, both in surface landforms, which affect local climates, and in continent–ocean distribution, which affects global climates. Processes controlled by climate and plate tectonics shape landforms. Geomorphic processes controlled by climate, including weathering and erosion, sculpt Earth's surface through both chemical and physical processes; these processes disintegrate mountains while promoting constructive, depositional processes elsewhere. Over a very long period of time, a mixture of weathering products and organic material produces soil that supports plant growth and human habitation.

Geomorphic processes controlled by tectonics, including volcanic activity and uplift, also shape landforms. Plate tectonics is a unifying theory that explains the distribution of continents, landforms, climate and other environmental phenomena. For example, mountain ranges and volcanism usually occur near plate boundaries due to the forces created by the relative motions of plates. Volcanic activity adds materials to Earth's surface, and subduction moves material to the mantle. These processes may modify a region's topography and extent, and also may add materials that support primary production and dependent ecosystems.

Enduring Understanding 3A

Biogeochemical cycles are representations of the transport, transformation and storage of elements on a local, regional or global scale.

Much of the complex behavior of the Earth system can be envisaged as cycles involving physical, chemical and biological processes that transfer components among various storage locations over time. The inputs and outputs connecting such reservoirs, the changes in the physical state or chemical characteristics of the components, and the time scale of these processes can all be recognized and quantified. Biogeochemical cycles, such as the water cycle and carbon cycle, are driven and sustained by solar and/or geothermal energy, which is transferred, utilized and lost as an integral aspect of the cycles.

Enduring Understanding 3B

Living things are composed of, and hence require, the elements and compounds that make up their biological components.

All life requires water and specific chemicals for its existence and survival, albeit in varying amounts and in different forms among organisms. The fundamental building blocks for all organisms are organic molecules composed of carbon, hydrogen and oxygen, and supplemented by other elements, especially nitrogen, phosphorus and sulfur. The structural characteristics and bonding possibilities of organic compounds — such as carbohydrates, lipids, proteins and nucleic acids — that are assembled from these constituents facilitate fundamental life processes, including energy transfer, molecular replication and biosynthesis, and construction of cell membranes. Some chemicals, however, interfere with such biochemical processes and can produce toxic effects when present above tolerance levels. Ongoing removal of micronutrients in agricultural soils requires an awareness of their importance in biological systems.

Enduring Understanding 3C

The major biogeochemical cycles of elements and compounds (water, carbon, nitrogen, sulfur and phosphorus) are composed of specific processes that occur over varying intervals of space and time based on their chemical and physical properties.

Biogeochemical cycles involve the flux of components between major physical reservoirs. Cycles vary in terms of the nature and speciation of the chemicals involved, the processes that control component transfer and transformations, the rates of the processes and residence times of components in different reservoirs, and the characteristics of the reservoirs themselves. Phase changes between different forms of water are the principal processes of the hydrologic cycle that connect the global reservoirs, which are dominated by the oceans. Biological reactions interconvert inorganic and organic forms of carbon, while their interaction with geological processes result in long-term burial of carbon within rocks. Thus, the concentrations of two greenhouse gases, carbon dioxide and methane, in the atmosphere can be affected by geologic and anthropogenic influences, causing climate change. Nitrogen is both critical for life and a limiting factor in some ecosystems; the nitrogen cycle involves processes of biological utilization and cycling of elemental nitrogen, ammonia, nitrate and organic nitrogen as major forms of this element. The movement of phosphate between mineral and organic phases — governed by its solubility and coupled to its role in critical metabolic processes — drives the phosphorus cycle and its transfer between geological and biological reservoirs. The major reservoir of sulfur as both sulfides and sulfates (its most reduced and oxidized forms, respectively) is sedimentary rocks, followed by the oceans. Sulfur gases generated by volcanoes and the burning of fossil fuels are soluble and cycle rapidly through the atmosphere, accumulating in soils over the short term and ultimately as sulfate in the oceans that can be transformed to sulfides by microbial activity in marine sediments.

Enduring Understanding 4A

Ecosystems supply humans with a multitude of resources and processes that are collectively known as *ecosystem services*.

Many people, especially those in developed countries or urban areas, no longer recognize their connection to the ecosystems that help support them. Wide varieties of ecosystem services and natural capital provide numerous benefits, making human economic activity possible. Perhaps the most easily recognized are provisioning services, which provide resources such as food and energy. Regulating services, such as climate moderation and nutrient cycling, help prevent extreme changes to environmental systems. Supporting services include air and water purification and crop pollination. Preserving and cultural services include such aspects as genetic diversity, recreational opportunities and even spiritual inspiration. Most ecosystem services are dependent on healthy, functioning ecosystems if they are to be sustainable.

Enduring Understanding 4B

Ecosystem services have value.

People sometimes consider a local natural area or broader ecosystem to be "priceless" and hence refuse to put a dollar value on it. However, amid the conflicting interests of modern economic systems, the value of such ecosystems may then in practice be considered to be zero in economic analyses and public policy decisions. A newer approach used by a growing number of environmental scientists, ecologists and economists has been to try to assign dollar values, not to the ecosystem itself but to the services it provides. This can be determined by estimating the cost of providing the same service through human activity. In many cases, the value of these services is found to be very high, and thus maintenance of the functioning ecosystem becomes a high priority.

Enduring Understanding 4C

The value of ecosystem services is integral to decision-making processes.

Decisions that affect the environment are not based on scientific analysis alone, but must also incorporate social and economic considerations. The benefits, costs and risks of decisions may not be evenly shared among all parties. In many cases, economically disadvantaged and/or minority groups have disproportionately suffered from these decisions, leading to concerns of *environmental justice*. Local, national and international laws, treaties and regulations have helped to manage environmental impacts. There are many examples of damaged ecosystems that have been successfully restored.

Enduring Understanding 4D

Sustainability is a guiding principle by which systems and resources are used in ways that they can be maintained at an acceptable level indefinitely.

Unregulated publicly owned resources that are freely accessible to all for individual use — such as traditional community grazing lands (the original "commons"), fisheries and clean water — tend to be overexploited, leading to system collapse; this phenomenon is known as the "tragedy of the commons." Sustainable natural and human systems have identifiable characteristics, and these can be analyzed to support sustainable development, which is a major goal of environmental economics. A variety of tools, such as risk/benefit analysis and life cycle assessment, are being used or developed to evaluate the overall environmental impacts of products and activities in order to move toward creating sustainable societies.

Enduring Understanding 5A

Human societies require Earth's resources; the amounts required are a function of human population size, growth and affluence.

The survival of human societies is dependent on Earth's resources. Overall, there are positive correlations between population, natural resource consumption and environmental degradation, although environmental policies and technology influence these relationships. This can be applied to the regional, national and global scales. While urbanization may involve or provide a number of economic, social and environmental benefits, the global population demographic trend of increased urbanization that has been seen as more countries prepare to further industrialize may be associated with negative environmental and human health consequences. Major factors influencing population growth include education, economic status, opportunities for women, public policy, conflict, disease, climate and resource availability. Combined with other considerations, such as access to clean drinking water/sanitation, availability of food/proper nutrition, and access to prenatal and other medical care, these factors are typically used in making models and predictions as to how populations might change over time.

Enduring Understanding 5B

Humans engineer systems in order to (1) maximize outcomes to meet societal needs, (2) moderate system extremes, and (3) control or change interactions. Engineered systems, as all systems, have many interactions with the rest of the environment.

Human systems, such as agricultural systems, water diversion networks, energy-related systems, and the footprint occupied by urban and other human settlements themselves, are dependent on natural systems. The operation of these human systems generally results in altered natural systems. While human systems may be sustainably managed, and detrimental environmental impacts to habitats, the atmosphere and water supplies may be minimized, unsustainable management approaches typically result in greater alterations of the natural systems that support them. These landscape alterations may substantially affect adjacent and downstream/downwind ecosystems, human settlements and Earth systems. Some technologies, such as air and water pollution control systems, have been very successful in reducing some harmful environmental effects.

Enduring Understanding 5C

Human activities, including use of resources, have physical, chemical and biological consequences for watersheds and aquatic systems.

Human activities, such as the overuse of groundwater resources and activities that involve the production and release of point or nonpoint pollution, have physical, chemical and biological consequences for the aquatic environment. Point and nonpoint source discharges containing sewage, pesticides, nutrients, animal waste, industrial wastes, sediments and/or pathogens may have substantial impacts on wetlands, streams, lakes, estuaries and coastal waters. In addition, these waters and even the open ocean may be harmed by the intentional and accidental dumping of wastes and spills of oil and other chemical wastes.

Enduring Understanding 5D

Human activities have physical, chemical and biological consequences for the atmosphere.

Air pollutants of concern, such as the six criteria pollutants (SO_x, NO_x, Pb, CO, particulate matter and O_3) and hydrocarbons/VOCs, have various sources and identifiable ecological and human health effects. Air pollutants may originate from mobile (e.g., cars) or stationary (e.g., smokestacks) sources, or be formed in the atmosphere (e.g., tropospheric ozone and photochemical smog) from precursors. Persistent air pollutants are transported throughout the world by way of convection cells and wind currents, and their distribution is strongly influenced by surface topography. Halogenated hydrocarbons are very stable near the Earth's surface, where solar UV radiation levels are low, but when transported to the stratosphere, where solar UV radiation is more intense, they undergo photochemical reactions that reduce stratospheric ozone levels. Federal regulations (e.g., the Clean Air Act), international agreements (e.g., the Montreal Protocol), improved technology (e.g., catalytic converter, wet scrubber, electrostatic precipitator, baghouse) and implementation of effective international policies — combined with changes in personal behavior — can reduce levels of air pollutants.

Enduring Understanding 5E

Human activities have physical, chemical and biological consequences for ecosystems; the magnitude of the impact depends in part on the sensitivity of the system to perturbation.

Ecosystems are sensitive to the impacts of human activities. Illustrative examples related to air pollution include the effects of climate change on all ecosystems, acid deposition (resulting from the burning of fossil fuels) on forests and lakes, and increased UV radiation (resulting from stratospheric ozone depletion) exposure to animals and plants. Examples related to biodiversity loss involve habitat destruction, invasion by exotic species, and commercial overfishing; examples relating to food web alteration can result from pollutant persistence, bioaccumulation and biomagnification. All of the above may cause irreversible damage to the environment.

Appendix B: AP Biology Enduring Understandings

The following appendix represents the enduring understandings that will increasingly be the focus and the end goals of the AP Biology course.

Enduring Understanding 1A

Change in the genetic makeup of a population over time is evolution.

Natural selection is the major driving mechanism of evolution because the essential features of the mechanism contribute to the change in the genetic makeup of a population over time. Darwin's theory of natural selection states that inheritable variations occur in individuals in a population. Due to competition for resources that are often limited, individuals with more favorable variations or phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations. Fitness, the number of surviving offspring left to the next generation, is a measure of evolutionary success. Individuals do not evolve; rather, populations do. Because the environment is always changing, there is no "perfect" genome, and a diverse gene pool is important for the long-term survival of a species.

Genetic variations within a population contribute to a diverse gene pool. Changes in genetic information may be silent (with no observable phenotypic effects) or result in a new phenotype, which can be positive, negative or neutral. The interaction of the environment and the phenotype determines the fitness of the phenotype. Thus, the environment does not direct the changes in DNA; rather, it acts upon phenotypes that occur through random changes in DNA. These changes can involve alterations in DNA sequences, changes in gene combination, and the formation of new gene combinations.

Although natural selection is usually the major mechanism for evolution, genetic variation in populations can occur through other processes, including mutation, genetic drift, sexual selection and artificial selection. Inbreeding, small population size, nonrandom mating, the absence of migration, and lack of net mutations can lead to loss of genetic diversity. Human-directed processes can also result in new genes and combinations of alleles that confer new phenotypes.

Biological evolution driven by natural selection is supported by evidence from many scientific disciplines, including geology and physical science. In addition, biochemical, morphological and genetic information from existing and extinct organisms supports natural selection. Phylogenetic trees serve as dynamic models that show common ancestry, while geographical distribution and the fossil record link past and present organisms.

Enduring Understanding 1B

Organisms are linked by lines of descent from common ancestry.

Organisms share many conserved core elements and features that evolved and are widely distributed among organisms today. These processes provide evidence that all organisms (archaea, bacteria and eukaryotes, both extant and extinct) are linked by lines of descent from common ancestry. Elements that are conserved across all three domains of life are DNA and RNA as carriers of genetic information, a universal genetic code and many metabolic pathways. The existence of these properties in organisms today implies that they were present in a universal ancestor and that present life evolved from a universal ancestor. Phylogenetic trees are used to graphically model evolutionary history and can represent both acquired traits and those lost during evolution. In eukaryotes, conserved core processes provide evidence for evolution. These elements and features include the presence of a cytoskeleton, a nucleus, membrane-bound organelles, linear chromosomes and endomembrane systems. Due to evolutionary descent from a common ancestor, eukaryotic genetic material is not usually transferred laterally from one organism to another. However, in bacteria variation results from lateral transfer of genetic information. In eukaryotes, lateral genetic transfer occurs between organelles such as chloroplasts, mitochondria and nuclei.

Enduring Understanding 1C

Life continues to evolve within a changing environment.

Speciation and extinction have occurred throughout Earth's history, and life continues to evolve within a changing environment. However, the rates of speciation and extinction vary. Speciation can be slow and gradual or, as described by punctuated equilibrium, it can occur in "bursts" followed by relatively quiet periods. At times of ecological stress, extinction rates can be rapid, and mass extinctions are often followed by adaptive radiation, the rapid evolution of species when new habitats open. Scientific evidence — including emergent diseases, chemical resistance and genomic data — supports the idea that evolution occurs for all organisms and that evolution explains the diversity of life on the planet.

A species can be defined as a group of individuals capable of interbreeding and exchanging genetic information to produce viable, fertile offspring. New species arise when two populations diverge from a common ancestor and become reproductively isolated. Although speciation can occur by different processes, reproductive isolation must be maintained for a species to remain distinct. Evidence that speciation has occurred include the fossil record and genomic data.

Enduring Understanding 1D

The origin of living systems is explained by natural processes.

The process of evolution explains the diversity and unity of life. The question of the origin of life is one of the unsolved mysteries of biology. Experimental procedures have generated complex molecules and simple cell-like structures through a sequence of stages. In the "organic soup" model, the primitive atmosphere contained inorganic precursors from which organic molecules could have been synthesized through natural chemical reactions catalyzed by the input of energy. In turn, these molecules served as monomers or building blocks for the formation of more complex molecules, including amino acids and nucleotides. Other models build upon the finding of amino acids in meteorites and the possibility of primitive life being introduced by naturally occurring objects from space, while other models suggest that primitive life developed on biogenic surfaces that served as templates and catalysts for assembly of macromolecules.

Under laboratory conditions, complex polymers and self-replicating molecules can spontaneously assemble, including nucleic acids; it remains an open question whether the first genetic and self-replicating material was DNA or RNA. Certain RNAs, in addition to encoding information, have the ability to carry out enzyme-like catalytic functions. Natural selection at the molecular level has been observed in RNA populations in the laboratory. Among a diverse population of RNA molecules, the molecule(s) that contains sequences best suited to a selective environment replicates most efficiently and frequently.

Enduring Understanding 2A

Growth, reproduction and maintaining the organization of living systems require energy and matter.

Living systems require energy to maintain order, grow and reproduce. In accordance with the laws of thermodynamics, to offset entropy, energy input must exceed the energy that is lost from and used by an organism to maintain order. Organisms use various energy-related strategies to survive; strategies include different metabolic rates, physiological changes and variations in reproductive and offspring-raising practices. Not only can energy deficiencies be detrimental to individual organisms, but changes in energy availability can also affect population size and cause disruptions at the ecosystem level.

Organisms have evolved several means to capture, use and store energy. Cells can capture energy through photosynthesis, chemosynthesis, cellular respiration and fermentation. Autotrophs capture energy from the environment, including energy present in sunlight and chemical sources, whereas heterotrophs harvest energy from carbon compounds produced by other organisms. Through a series of coordinated reaction pathways, photosynthesis traps free energy in sunlight that, in turn, is used to produce carbohydrates from carbon dioxide. Cellular respiration and fermentation capture free energy available from sugars and from interconnected, multistep pathways (such as glycolysis, the Krebs cycle and the electron transport chain) to produce the most common energy carrier, ATP. The energy stored in ATP can be used to drive metabolic pathways vital to cell processes. The processes of photosynthesis and cellular respiration are interdependent in their reactants and products.

Organisms must exchange matter with the environment to grow, reproduce and maintain organization. The surface-to-volume ratios affect a biological system's ability to obtain resources and eliminate waste products. Water and macronutrients are essential for building new molecules; carbon dioxide moves from the environment to organisms, where it is metabolized and incorporated in carbohydrate, protein, nucleic acid or lipids; and nitrogen and phosphorous are essential for building nucleic acids and proteins. In aerobic organisms, oxygen is vital in energy transformations through combustion; it also serves as an electron acceptor.

In addition to its role in development and differentiation, programmed cell death (apoptosis) allows molecules to be reused and helps maintain homeostasis. Disruption of normal apoptotic processes can lead to developmental abnormalities, including loss of immune function and webbing between fingers and toes in humans.

Enduring Understanding 2B

Growth, reproduction and homeostasis require that cells create and maintain internal environments that are different from their external environments.

Cell membranes separate the internal environment of the cell from the hostile external environment. The specialized structure of the membrane described in the *fluid mosaic model* allows the cell to be selectively permeable, with homeostasis maintained by the constant movement of molecules across the membrane. Passive transport does not require the input of energy because movement of molecules occurs from high to low concentrations; examples of passive transport are osmosis, diffusion and facilitated diffusion. Active transport requires both energy and transport proteins to move molecules from low to high concentrations across a membrane. Active transport establishes concentration gradients vital for homeostasis, including sodium/potassium pumps in nerve impulse conduction, and proton gradients in electron transport chains in photosynthesis and cellular respiration. Exocytosis and endocytosis move large molecules across cell membranes.

Eukaryotic cells also maintain internal membranes that partition the cell into specialized regions. These membranes allow cell processes to operate with optimal efficiency by decreasing conflicting interactions and increasing surface area for chemical reactions to occur. Each compartment or membrane-bound organelle allows for localization of reactions, including energy transformation in mitochondria and production of proteins in the rough endoplasmic reticulum.

Enduring Understanding 2C

Organisms use feedback mechanisms to regulate growth and maintain homeostasis.

Negative and positive feedback mechanisms allow organisms to respond to changes in their internal and external environments. Positive feedback loops amplify activities, moving the response away from its initial set point. Organisms use negative feedback to maintain optimum internal environments and homeostasis; a change in the controlled variable activates a mechanism to limit further change. Examples of negative feedback responses include temperature regulation in animals and plant responses to drought. Models are used to represent positive and negative feedback mechanisms. Alterations in feedback mechanisms can have deleterious effects, including diabetes and Grave's disease in humans and the inability of plants to tolerate water stress during drought.

Enduring Understanding 2D

Growth and homeostasis of a biological system are influenced by changes in the system's environment.

All biological systems, from cells to ecosystems, are influenced by complex biotic and abiotic interactions. Availability of resources influences activities in cells and organisms; examples include cell density, biofilms, temperature responses, and response to nutrient and water availability. Resources affect a population's stability in terms of its size and genetic composition; examples include fecundity versus death rates, and global distribution of food for humans.

Homeostatic mechanisms reflect both continuity due to common ancestry and change due to evolution in different environments. Supporting evidence includes a sampling of homeostatic control systems across phyla and species of microbes, plants and animals. Additionally, organisms have evolved various mechanisms for obtaining nutrients and getting rid of wastes, including gas exchange, osmoregulation and nitrogenous waste production. Disruptions to homeostasis affect biological processes. Plants and animals have evolved a variety of chemical defenses against infections, which are one cause for such disruptions. In addition, disruptions also impact the balance of an ecosystem and the interactions between specific organisms therein.

Enduring Understanding 2E

Many biological processes involved in growth, reproduction and homeostasis include temporal aspects.

Timing and coordination of developmental, physiological and behavioral events are regulated by multiple mechanisms. Timing and coordination are necessary for an organism's normal development. Cell differentiation results from the expression of genes for tissue-specific proteins, and the induction of transcription factors during development results in sequential gene expression. Genetic mutations can result in abnormal development. Physiological events in plants involve interactions between environmental stimuli and internal molecular signals; in animals, "biological clocks" synchronize with environmental cycles and cues. Organisms also act on information and communicate it to others, often resulting in changes in behavior. Communication and cooperative behavior tend to increase the fitness of both the individual and the population.

Enduring Understanding 3A

Heritable information provides for continuity of life.

The organizational basis of all living systems is heritable information. The proper storage and transfer of this information are critical for life to continue at the cellular, organism and species level. Reproduction occurs at the cellular and organism level. In order for the progeny to continue subsequent generational cycles of reproduction, each progeny needs to receive heritable genetic instructions from the parental source. This information is passed to the subsequent generation via DNA. Viruses, as exceptional entities, can contain either DNA or RNA as heritable genetic information. The chemical structures of both DNA and RNA provide mechanisms that ensure that information is preserved and passed to subsequent generations. There are important chemical and structural differences between DNA and RNA that result in different stabilities and modes of replication. In order for information stored in DNA to direct cellular processes, the information needs to be transcribed (DNA → RNA) and translated (RNA → protein). The products of these processes determine metabolism and cellular activities, and thus the phenotypes upon which evolution operates.

In eukaryotic organisms, heritable information is packaged into chromosomes that carry essential heritable information that must be passed to progeny cells. Mitosis provides a mechanism that ensures that each daughter cell receives an identical and complete set of chromosomes and ensures fidelity in the transmission of heritable information. Mitosis allows for asexual reproduction of organisms in which progeny are genetically identical to the parental cell and for genetic information transfer to subsequent generations. Unicellular organisms and some multicellular organisms have various mechanisms to ensure genetic variation.

Sexual reproduction of diploid organisms involves the recombination of heritable information from both parents through fusion of gametes during fertilization. The two gametes that fuse to form a new progeny zygote each contain a single set (n) of chromosomes. Meiosis reduces the number of chromosomes from diploid (2n) to haploid (n) by following a single replication with two divisions. The random assortment of maternal and paternal chromosomes at fertilization and random exchanges between sister chromosomes increase genetic variation; thus, the four gametes, while carrying the same number of chromosomes, are genetically unique with respect to individual alleles and allele combinations. The random combination of gametes at fertilization re-establishes the diploid nature of the organism and provides an additional mechanism for generating genetic variation. Consequently, every zygote is genetically different. Natural selection operates on populations through the phenotypic differences (traits) that individuals display. Meiosis followed by fertilization provides a spectrum of possible phenotypes on which natural selection acts, and variation contributes to the long-term continuation of species.

Some phenotypes are products of action from single genes. These single gene traits provided the experimental system through which Mendel was able to describe a model of inheritance. The processes that chromosomes undergo during meiosis provide a mechanism that accounts for the random distribution of traits, the independence of traits, and the fact some traits tend to stay together as they are transmitted from parent to offspring. Mendelian genetics can be applied to many phenotypes, including some human genetic disorders and the ethical, social and medical issues can surround such genetic disorders.

While some traits are determined by the actions of single genes, most traits result from the interactions of multiple genes or interactions between genes and the environment. These traits often exhibit a spectrum of phenotypic properties that allow for a wider range of observable traits, including weight, height and coat color in animals.

Enduring Understanding 3B

Expression of genetic information involves cellular and molecular mechanisms.

Structure and function in biology result from the presence of necessary genetic information and the correct expression of this information. The expression of the genetic material controls the cell products, and these products determine the metabolism and nature of the cell. Most cells within an organism contain the same set of genetic instructions, but the expression of specific genes determines the structure and function of the cell. Some genes are continually expressed, while the expression of most is regulated. Regulation allows more efficient energy utilization, resulting in increased metabolic fitness. Gene expression is controlled by environmental signals and development cascades that involve both regulatory and structural genes. A variety of different DNA gene regulatory systems are found in nature. Two of the best studied are the inducible and repressible regulatory systems (i.e., operons) in bacteria; several regulatory pathways across phyla use a combination of positive and negative regulatory motifs. In eukaryotes, gene regulation and expression are more complex, which reflect the increased complexity and involve many factors, including regulatory DNA sequences and other small molecules.

Multicellular organisms have developmental pathways from zygote to adult, yet all cells contain the same complement of DNA. The developmental sequences are predominately determined and programmed by differential gene expression. The gene that is expressed and the level of expression are determined by both internal and external signals. In multicellular organisms, cell-to-cell interactions and cell-to-cell signaling via small molecules modulate and control gene expression and cell function. For example, morphogens help to determine spatial development, and hormones can influence cell metabolism. Developmental gene sequences have an evolutionary origin and are conserved across species; for example, HOX genes are present in genome sequences from *Drosophila* to humans. Errors or changes in regulation of genes involved in development often lead to severe, detrimental and even bizarre consequences.

Enduring Understanding 3C

Transfer of genetic information may produce variation.

Genetic information is a repository of instructions necessary for the survival, growth and reproduction of an organism. In order for the information to be useful, it needs to be processed by the cell. Processing includes replication, decoding and transfer of the information. When genetic information changes (either through natural processes or genetic engineering), the results may be observable changes in the organism. At the molecular level, these changes may be the result of mutations in the genetic material, the effects of which may be seen when the information is processed, to yield a polypeptide. The processes of transcription, mRNA processing and translation may not be perfect, and errors can occur that alter phenotypes. External factors in the environment can affect the degree or potential for variations that result from information transfer, and biological processes are impacted directly and indirectly by the environment. These processes can be beneficial under certain circumstances, and although errors are rare, cellular mechanisms have evolved that correct errors and their effects. Genetic variations at the genome level, when expressed as phenotypes, are subject to natural selection; this, in turn, leads to evolution.

Since all organisms, as well as viruses, exist in a dynamic environment, mechanisms that increase genetic variation are vital for species to survive and evolve. In a meiotic organism, the transfer process whereby each gamete receives a one set of chromosomes also ensures that this set is unique and different from that of the parent. Random processes such as the transposition of DNA regions ("jumping genes") occur in both eukaryotes and bacteria, and contribute to genetic variation. Bacteria divide by binary fission and do not have the random assortment processes that are available to eukaryotic organisms. Nonetheless, mechanisms have evolved in bacteria that ensure genetic variation beyond the variation that is introduced through normal DNA metabolism, e.g., replication, repair and recombination. Bacteria are unique in that bacterial genetic information can be transmitted or exchanged horizontally between individuals through a variety of processes, including conjugation, transduction and transformation. This type of exchange yields rapid dissemination of new phenotypes within and between bacterial populations, allowing for rapid evolution.

The basic structure of viruses includes a protein capsid that surrounds and protects the genetic information (genome) that can be either DNA or RNA. Viruses have a unique mechanism of replication that is dependent on the host metabolic machinery to produce necessary viral components and viral genetic material. Some classes of viruses use RNA without a DNA intermediate; however, retroviruses, such as HIV, use a DNA intermediate for replication of their genetic material. Some viruses produce variation by integrating into the host genetic material. In bacteria, this is referred to as lysogenesis, whereas in eukaryotic cells this is referred to as transformation. Since viruses use the host metabolic pathways, the viruses experience the same potential as the host for genetic variation that results from DNA metabolism.

Enduring Understanding 3D

Cells communicate by generating, transmitting and receiving chemical signals.

For cells to function in a biological system, they need to communicate with other cells and respond to their external environment. Cell-to-cell communication is ubiquitous in biological systems, from simple Archaea and Eubacteria to complex multicellular organisms. The basic chemical processes by which cells communicate are shared across evolutionary lines of descent, and communication schemes are the products of evolution. Cell-to-cell communication is a component of higher-order biological organization and responses. In multicellular organisms, cell-to-cell and environment-to-cell chemical signaling pathways direct complex behaviors, ranging from cellular and organ differentiation to whole-organism physiological responses. Certain signal pathways involve direct cell-to-cell contact and operate over very short distances, and may be determined by the structure of the organism or organelle, including plasmodesmata in plants and receptor-to-recognition protein interaction in the vertebrate immune system.

Chemical signals allow cells to communicate without physical contact. The distance between the signal generating cell(s) and the responding cell can be small or large. In this type of signaling pathway, there is often a gradient response, and threshold concentrations are required to trigger the communication pathway.

Chemical signaling pathways in cells are determined by the properties of the molecules involved and concentrations of signal and receptor molecules and the binding affinities (fit) between signal and receptor. The signal can be a small molecule, a protein, or a physical force or presence (e.g., pressure or sunlight). The receptor molecule is always a protein with specificity for the signal molecule; this allows pathways to be specific, and the response to be correct and appropriate. The receptor protein often is the initiation point for a signal cascade that ultimately results in a change in gene expression, protein activity, or physiological state of the cell or organism, including cell death (apoptosis). Defects in any part of the signal pathway often lead to severe or detrimental conditions, including faulty development, metabolic diseases, cancer or death.

Understanding signaling pathways allows humans to modify and manipulate biological systems and physiology. An understanding of the human endocrine system, for example, allowed the development of birth control, as well as medicines that control depression, blood pressure and metabolism. Other examples include the ability to control/modify ripening in fruit, agricultural production (growth hormones) and biofilm control.

Enduring Understanding 3E

Transmission of nonheritable information results in changes within and between biological systems.

Genetic information that is passed to subsequent generations is the material on which evolution operates. However, nonheritable information transmission also determines critical roles that influence behavior within and between cells, organisms and populations. These responses are dependent upon or influenced by underlying genetic information, and decoding in many cases is complex and affected by external conditions. For example, biological rhythms, mating behaviors, flowering, animal communications and social structures are dependent on and elicited by external signals, and may encompass a range of responses and behaviors. Learning, in which responses are modified by experience, may alter transmission of information but generally does not determine the specific outcome. In other cases, the behavioral response (e.g., nesting in birds and suckling in mammals) is "hardwired" or innate, and does not need to be learned.

Animals have evolved organ systems that sense and process external information that is used to facilitate and enhance survival, growth and reproduction. These include sensory systems that monitor and detect physical and chemical signals from the environment and other individuals in the population, and that influence an animal's well-being. The nervous system interfaces with sensory and internal body systems to coordinate responses and behaviors from movement to metabolism to respiration. Loss of function and coordination within the nervous system often results in severe consequences, including changes in behavior, loss of body functions and even death.

An appreciation and knowledge of the structure and function of the nervous system are needed to understand this coordination. Features of an animal's nervous system are evolutionarily conserved, and the basic cellular structure of neurons is the same among species. The physiological and cellular processes for signal formation and propagation involve specialized membrane proteins, signaling molecules and ATP. Neurological signals can operate over and result in changes across significant distances within an organism, and they coordinate responses. The brain serves as a master neurological center for processing information and directing responses, and different regions of the brain serve different functions. Structures and associated functions for animal brains are products of evolution, and increasing complexity follows evolutionary lines. Higher-order organisms have larger and more complex brains than lower-order organisms, with behavioral sophistication ensuing.

Many types of organisms exist in communities. The success of communities is reflected by the success of individuals as well as the actions and behaviors of individuals within the community. Individual behavior influences community behavior, and both are the products of information recognition, processing and transmission. Communication among individuals within a population increases the fitness of the population. Cooperative behavior within a population provides benefits to the population and to the individuals within the population. Examples of benefits include protection from predators, acquisition of prey and resources, sexual reproduction, recognition of offspring and genetic relatedness, and transmission of learned responses.

Enduring Understanding 4A

Interactions within biological systems lead to complex properties.

All biological systems, from cells to ecosystems, are composed of parts that interact with each other. When this happens, the resulting interaction develops characteristics not found in the individual parts alone. In other words, "the whole is greater than the sum of its parts," a phenomenon sometimes referred to as "emergent properties."

At the molecular level, the properties of a polymer are determined by its subcomponents and their interactions. For example, a DNA molecule is composed of a series of nucleotides that can be linked together in various sequences; the resulting polymer carries hereditary material for the cell as well as information that controls cellular activities. Other polymers important to life include carbohydrates, lipids and proteins. The interactions between the constituent parts of polymers, their order, their molecular orientation, and their interactions with their environment define the structure and function of the polymer.

At the cellular level, organelles interact with each other and their environment as part of a coordinated system that keeps the cell alive, growing and reproducing. For example, that a chloroplast produces triose through the process of photosynthesis is only part of the story; once a triose is synthesized, it may be packaged by the Golgi body and distributed to the edge of the cell to become part of cellulose fiber comprising the cell wall. Similarly, several organelles are involved in the manufacture and export of protein. The repertory of subcellular organelles determines cell structure and differentiation; for instance, the components of plant leaf cells are different from the components of plant root cells, and the compenents of human liver cells are different from those in the retina. Thus, myriad interactions of different parts at the subcellular level determine the functioning of the entire cell, which would not happen with the activities of individual organelles.

Interactions between gene expression and external stimuli, such as water, temperature or nutrient levels, result in specialization of cells, organs and tissues. Additionally, cells, organs and tissues may change as the result of gene expression triggered by internal cues, including regulatory proteins and growth factors, that result in the structural and functional divergence of cells. Differentiation of the germ layers during vertebrate gastrulation is an example of one such divergence. The progression of stem cells to terminal cells can also be explained by the interaction of stimuli and genes.

Organisms exhibit complex properties due to interactions of their constituent parts, and interactions and coordination between organs and organ systems provide essential biological activities for the organism as a whole. Examples include membrane receptors and chemotaxis, vessels and hearts, and roots and shoots of plants. Environmental factors such as temperature can trigger responses in individual organs, which, in turn, affect the entire organism.

Interactions between populations within communities also lead to complex properties. As environmental conditions change in time and space, the structure of the community changes both physically and biologically and results in a mosaic in the landscape. A community is composed of different populations of organisms that interact with each other in either negative or positive ways (e.g., competition, parasitism and mutualism), and community ecology seeks to understand the manner in which groupings of species are distributed in nature, how they are influenced by their abiotic environment, and by species interactions. The mix of species in both number and diversity defines the structure of the community. The physical structure of the community includes abiotic factors, such as the depth and flow of water in a stream, as well as spatial configuration of organisms, such as the canopy of trees. Community patterns in space can be measured and assessed using mathematical approaches to calculate the diversity of its constituent species, which can then be used to develop models to evaluate changes in the community that are caused by the environment. Community change following disturbances is sometimes predictable (e.g., succession following a wildfire) and in other cases is random and unpredictable (e.g., founder effect).

At the ecosystem level, interactions among living organisms with their environment result in the movement of matter and energy. Ecosystems include producers, consumers, decomposers, a pool of organic matter, and the physiochemical environment that provides the living conditions for the biotic components. Matter, but not energy, can be recycled within an ecosystem via biogeochemical cycles. Energy flows through the system and can be converted from one type to another — e.g., the energy available in sunlight is converted to chemical bond energy via photosynthesis. Models of ecosystems include knowledge of individual organisms in relation to the environment and the diverse interactions that populations have with one another (e.g., food chains and webs). The impact of changes in biotic and abiotic factors can be predicted. Human activities affect ecosystems on local, regional and global scales.

Enduring Understanding 4B

Competition and cooperation are important aspects of biological systems.

Interactions, including competition and cooperation, play important roles in the activities of biological systems at all levels of organization. Living systems require myriad chemical reactions on a constant basis, and each of these chemical reactions relies on the cooperation between a particular enzyme and specific substrates, coenzymes and cofactors. Chemical inhibitors may compete for the active sites of enzymes, which in turn affect the ability of the enzyme to catalyze its chemical reactions. Thus, interactions between molecules affect their structure and function. Other examples of this phenomenon include receptor–ligand interactions and changes in protein structure due to amino acid sequence.

Interactions between cells and their components affect the fitness of the organism. Similar cells may compete with each other when resources are limited. For instance, organisms produce many more spores or seeds than will germinate. Competition for resources determines which are successful and produce offspring. In the immune system, competition for antigen binding sites determines which B-cell lineages are stimulated to reproduce. Cooperation between cells improves efficiency and converts sharing of resources into a net gain in fitness for the organism. Examples include inflammation during infection or tissue damage, and cooperation between subcellular organelles for metabolic activities.

The cooperation of parts extends to the organism that is depending on the coordination of organs and organ systems, such as between the digestive and excretory systems of an animal or the roots and shoots of a plant. Cooperation within organisms increases efficiency in the use of matter and energy. For example, without the coordination and cooperation of its shoot and roots, a plant would be unable to survive if its root system was too small to absorb water to replace water lost through transpiration by the shoot. Similarly, exchange of oxygen and carbon dioxide in an animal depends on the functioning of the respiratory and circulatory systems. Furthermore, population interactions influence patterns of species distribution and abundance, and global distribution of ecosystems changes substantially over time.

Enduring Understanding 4C

Variation within biological systems affects interactions with the environment.

A biological system that possesses many components different from each other often has greater flexibility to respond to changes in its environment. This phenomenon is sometimes referred to as "robustness." Variation in molecular units provides cells with a wider range of functions; cells with multiple copies of genes or heterozygous genes possess a wider range of functions compared to organisms with less genetic diversity, while cells with myriad enzymes can catalyze myriad chemical reactions.

Environmental factors influence the expression of an organism's genotype. In humans, intelligence and height are examples of complex traits that can be influenced by environmental conditions. However, even simple single-gene traits are influenced by the environment; for example, flower color in some species of plants is dependent upon the pH of the environment. Some organisms possess the ability to respond flexibly to environmental signals to yield phenotypes that allow them to adapt to changes in the environment in which they live. For example, fish, some vertebrate organisms and chicken eggs can switch sexes depending on temperature changes, while parthenogenesis can be triggered by reproductive isolation. Plant seed dormancy can increase survivability of a species, and viruses possess both lysogenic and lytic life cycles.

The level of variation in a population affects its dynamics. The fitness of a population in its ability to respond to a changing environment is often measured in terms of genomic diversity. Species with little genetic diversity, such as a population of plants that reproduces asexually or a very small population exhibiting a genetic bottleneck effect, are at risk for long-term success and survival. Diversity of species within an ecosystem may influence stability of the ecosystem. Ecosystems with little species diversity are often less resilient to changes caused by the environment. The role of keystone species, predators, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem. For example, the removal of sea otters or mollusks can drastically affect a marine ecosystem, and the introduction of an exotic plant or animal species can likewise affect the stability of a terrestrial ecosystem.

Appendix C: AP Chemistry Enduring Understandings

The following appendix represents the enduring understandings that will be increasingly the focus and the end goals of the AP Chemistry course.

Enduring Understanding 1A

All matter is made of atoms. There are a limited number of types of atoms; these are the elements.

The concept of atoms as the building blocks of all matter is a fundamental premise of the discipline of chemistry. This construct provides the foundation for conceptualizing, interpreting and explaining the macroscopic properties and transformations observed inside and outside the laboratory in terms of the structure and properties of the constituent materials. The concept of the mole enables chemists to relate measured masses in the laboratory to the number of particles present in a sample. This model also provides the basis for the experimental determination of the purity of a sample through chemical analysis. The most important aspect of this content is not the memorization of laws and definitions, but rather the ability to explain how laws and relationships arise because of the atomic nature of matter.

Enduring Understanding 1B

The atoms of each element have unique structures arising from interactions between electrons and nuclei.

The shell model arises from experimental data, and it forms a basis for understanding the relative energies of electrons in an atom. The model is based on Coulomb's law and qualitatively predicts ionization energies, which can be measured in the lab. Understanding how the shell model is consistent with the experimental data is a key learning goal for this content, rather than the memorization of the patterns of electron configurations.

Enduring Understanding 1C

Elements display periodicity when organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of elements. Periodicity is a useful principle for understanding and predicting trends in atomic properties, in the composition of materials, and in generating ideas for designing new materials.

Although a simple shell model is not the currently accepted best representation of atomic structure, it is an extremely useful model that can be used qualitatively to explain and/or predict many atomic properties and trends in atomic properties. In particular, the arrangement of electrons into shells and subshells is reflected in the structure of the periodic table and in the periodicity of many atomic properties. Many of these trends in atomic properties are important for understanding the properties of molecules, and for being able to explain how the structure of the constituent molecules or atoms relates to the macroscopic properties of materials. Being aware of the quantum mechanical model as the currently accepted best model for the atom is important for scientific literacy.

Enduring Understanding 1D

Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.

Because the experimental measurement of ionization energy provides a window into the overall electronic structure of the atom, this content provides rich opportunities to explore how scientific models can be constructed and refined in response to available data. The modern use of mass spectrometry provides another example of how experimental data can be used to test (and, in this case, refute) a scientific model.

Enduring Understanding 1E

Atoms are conserved in physical and chemical processes, but not in nuclear processes.

The conservation of mass in chemical and physical transformations is a fundamental concept, and is a reflection of the atomic model of matter. This concept plays a key role in much of chemistry, in both quantitative determinations of quantities of materials involved in chemical systems and transformations, and in the conceptualization and representation of those systems and transformations. Because some isotopes of many elements are radioactive, nuclear transformations are also an important aspect of chemistry.

Energy is not conserved during nuclear transformations, and the interconversion of mass and energy involves much larger amounts of energy than in typical chemical or physical transformations. There are numerous applications of nuclear transformations in the modern world.

Enduring Understanding 2A

Matter can be described by its physical properties. The physical properties generally depend on the spacing between the particles (atoms, molecules, ions) and the forces of attraction between the particles.

There is a relationship between the macroscopic properties of solids, liquids and gases and the structure of the constituent particles of those materials on the molecular and atomic scale. The properties of solids, liquids and gases also reflect the relative orderliness of the arrangement of particles in those states, their relative freedom of motion, and the nature and strength of the interactions between them. For gases, volumetric relationships can be used to describe ideal behavior, and a conceptual understanding of that behavior can be constructed based on the atomic model and a relatively simple kinetic molecular theory.

Solutions are an important class of mixtures; of particular importance is a conceptual understanding of the molecular level of the structure and composition of a liquid solution. In addition, the energetics of solution formation can be understood qualitatively through consideration of the interactions and structure of the components before and after the creation of the solution.

Enduring Understanding 2B

Forces of attraction between particles (including the noble gases and different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.

Chemists categorize intermolecular interactions based on the structural features that give rise to the interaction. Although there are some trends in the relative strengths of these interactions, the specific structure and size of the particles involved can play a very important role in determining the overall strength of a particular intermolecular (or intramolecular) interaction. The properties of condensed phases and of many crucial biological structures are determined by the nature and strength of these interactions. Deviation from ideal gas behavior is generally a reflection of the presence of intermolecular interactions between gas particles. Thus, in all phases, the structure of particles on the molecular level is directly related to the properties of both the particles themselves as well as the behavior of macroscopic collections of those molecules.

Enduring Understanding 2C

The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.

Covalent bonds, ionic bonds and metallic bonds are distinct from (and significantly stronger than) typical intermolecular interactions. Covalent chemical bonds can be modeled as the sharing of one or more pairs of valence electrons between two atoms in a molecule. The extent to which this sharing is unequal can be predicted from the relative electronegativities of the atoms involved; the relative electronegativities can generally be understood through application of the shell model and Coulomb's law. The Lewis structure model, combined with valence shell electron pair repulsion (VSEPR), can be used to predict many structural features of covalently bonded molecules and ions. Ionic bonding is the phrase used to describe the strong Coulombic interaction between ions in an ionic substance. The bonding in metals is characterized by delocalization of valence electrons. Electronegativity can be used to reason about the type of bonding present between two atoms.

Enduring Understanding 2D

The type of bonding can be deduced from the properties of the solid state.

In solids, the properties of the material reflect the nature and strength of the interactions between the constituent particles. For this reason, the type of bonding that predominates in a solid material, and the nature of the interactions between the particles composing the solid, can generally be inferred from the observed macroscopic properties of the material. Properties such as vapor pressure, conductivity as a solid and in an aqueous solution, and relative brittleness or hardness can generally be explained in this way.

Although recognizing the properties that can be associated with a particular type of bonding is valuable in categorizing materials, students can provide evidence of deeper conceptual understanding by relating those properties to the structure of the materials on the molecular scale and by being able to make reasoned predictions of the properties of a solid based on its constituent particles.

Enduring Understanding 3A

Chemical changes are represented by a balanced chemical reaction that identifies the ratios with which reactants react and products form.

Chemical reactions are the primary means by which transformations in matter occur. Chemical equations efficiently communicate the rearrangements of atoms that occur during a chemical reaction. Describing a chemical change can include different forms of the equation, such as molecular ionic and net ionic. The equation provides information about atoms, ions and/or molecules reacting at the particulate level, as well as quantitative information about stoichiometry at the macroscopic level. Many chemical reactions involve small whole-number ratios of reactants and products as expressed by the stoichiometric coefficients of the balanced reaction. Many modern materials are composed of non-stoichiometric combinations of the constituent elements. A deep conceptual understanding of stoichiometry can be achieved through consideration of these non-stoichiometric compounds.

Enduring Understanding 3B

Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other, such as synthesis, decomposition, acid–base and oxidation-reduction reactions.

There are a vast number of possible chemical reactions. In order to study and make predictions and comparisons concerning such a wide array of reactions, chemists have devised ways to classify them. Because of their prevalence in the laboratory and in real-world applications, two categories of reactions that are of particular importance are acid–base reactions and oxidation-reduction reactions. Also, a key contribution of chemistry to society is the creation of new materials or compounds that benefit the health and welfare of the community. Most often, these reactions can be considered as synthesis reactions, another important reaction category.

Enduring Understanding 3C

Chemical and physical transformations may be observed in several ways and typically involve a change in energy.

An important component of full understanding of chemical change involves direct observation of that change; thus, laboratory experiences are essential for the AP Chemistry student to develop an appreciation of the discipline. At the AP course level, observations are made on macroscopically large samples of chemicals; these observations must be used to infer what is occurring at the particulate level. This ability to reason about observations at one level (macroscopic) using models at another level (particulate) provides an important demonstration of conceptual understanding and requires extensive laboratory experience. The difference between physical and chemical change is best explained at the particulate level. Laboratory observations of temperature change accompanying physical and chemical transformations are manifestations of the energy changes occurring at the particulate level. This has practical applications, such as energy production via combustion of fuels (chemical energy conversion to thermal energy) and/or batteries (chemical energy conversion to electrical energy).

Enduring Understanding 4A

Reaction rates are determined by measuring changes in concentrations of reactants or products over time, and depend on temperature and other environmental factors.

The rate of a reaction is the rate at which reactants are converted to products, and is given in terms of the change in concentrations with time. Rates of reactions span a wide range and generally increase with reactant concentrations and with temperature. The rate may be measured by monitoring the concentrations as a function of time, and the results of many experiments may be summarized with a mathematical expression known as the rate law. The rate law gives the dependence of the rate on reactant concentrations and contains a proportionality constant called the rate constant. The rate constant contains the dependence of the rate on temperature, surface area and other environmental factors.

Enduring Understanding 4B

Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.

Reactions proceed through elementary steps involving one or more reactants. In a unimolecular reaction, collisions with other molecules activate the reactant so that it is converted into product. In bimolecular and higher-order reactions, collisions between reactants lead to formation of products, provided that both the energy of the collision and the relative orientation of reactants are favorable for reaction. A successful collision can be viewed as proceeding along some single reaction coordinate. The energy profile along this reaction coordinate provides a useful construct for reasoning about the connection between the energetics of a reaction and the rate of the reaction. In particular, this profile includes the activation energy required to overcome the energetic barrier between reactants and products.

Enduring Understanding 4C

Many reactions proceed via a series of elementary reactions.

Many reactions proceed through a series of elementary reactions or steps, and this series of steps is referred to as the reaction mechanism. The steps of the mechanism sum to give the overall reaction; the overall reaction specifies the stoichiometry. The overall rate of the reaction is an emergent property of the rates of the individual reaction steps. For many reactions, one step in the reaction mechanism is slow enough to limit the rate of the overall reaction. For such reactions, this rate-limiting step sets the rate of the overall reaction. Reaction intermediates, which are formed by a step in the reaction mechanism and then consumed by a following step, play an important role in multistep reactions, and their experimental detection is an important means of investigating reaction mechanisms.

Enduring Understanding 4D

Reaction rates may be increased by the presence of a catalyst.

Catalysts, such as enzymes in biological systems and the surfaces in an automobile's catalytic converter, increase the rate of a chemical reaction. Catalysts may function by lowering the activation energy of an elementary step in a reaction, thereby increasing the rate of that elementary step but leaving the mechanism of the reaction otherwise unchanged. Other catalysts participate in the formation of a new reaction intermediate, thereby opening up a new reaction mechanism that provides a faster pathway between reactants and products.

Enduring Understanding 5A

Two systems with different temperatures that are in thermal contact will exchange energy as heat.

Chemical systems are continually undergoing random motion. The temperature of a system is a direct measure of the average kinetic energy associated with this random motion. When chemical systems that have different temperatures are placed in thermal contact, kinetic energy is transferred from the hotter object to the cooler object until the temperatures become equal. This transfer of kinetic energy is referred to as heat transfer.

An understanding of heat as the exchange of energy between a system of higher temperature and a system at lower temperature is fundamental. Many practical applications exist, such as weather prediction, design of heating and cooling systems, and regulation of the rates of chemical reactions.

Enduring Understanding 5B

Energy is neither created nor destroyed but only transformed from one form to another.

The conservation of energy plays an important role in reasoning about the transfer of energy in chemical systems. A molecular system has energy that is a function of its current state. The energy of a system changes when the state of the system changes. For instance, when the temperature of the system changes, when a substance melts or boils, or when a chemical reaction occurs, the energy changes. Conservation of energy implies that any change in the energy of a system must be balanced by the transfer of energy either into or out of the system. This energy transfer can take the form of either heat transfer or work; all forms of energy transfer other than heat transfer are called work. Examples of mechanical work include the expansion of a gas against a piston in engines. The change in energy associated with a chemical process is an important aspect of such processes that characterize, for instance, the amount of energy that can be obtained from a fuel system. Because the change in energy associated with a given process is proportional to the amount of substance undergoing that process, this change is best described on a per-mole (or per-gram) basis, as in heat capacities (for heating/cooling), enthalpies of fusion or vaporization (for physical transformations), and enthalpies of reaction (for chemical transformations). Calorimetry provides a convenient means to measure changes in energy and thus to experimentally determine heat capacities, or enthalpies of physical and chemical transformations.

Enduring Understanding 5C

Breaking bonds requires energy, and making bonds releases energy.

Chemical bonds arise from attractive interactions between negatively charged electrons and the positively charged nuclei of the atoms that make up the bond. As electrons approach a positive charge, the potential energy of a system is lowered. Therefore, having electrons shared between atoms results in the system's being in a lower energy state, which can only happen if energy is somehow released. Thus, making chemical bonds releases energy. The converse is true for the opposing process. In order to break a chemical bond, energy must be put into the system to overcome the attractive interaction between the shared electrons and the nuclei of the bonded atoms. When considering chemical reactions, however, it is important to recognize that in most cases, both bond breaking and bond formation occurs. The overall energy change is determinable from looking at all the energy inputs (to break bonds) and the energy outputs (to form bonds). There are several ways to calculate energy changes for reactions, including traditionally used methods involving enthalpy of formation. One compelling conceptual model for this calculation is to use average bond energies or enthalpies to determine the energy change of a reaction. Many practical examples of chemistry take place in solvents (often water); thus, the determination of overall changes in energy for a reaction must include consideration of any solvent interactions with reactants and products.

Enduring Understanding 5D

Electrostatic forces arise between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.

The same essential interaction that forms chemical bonds — electrostatic attraction — also explains the attractive forces as nonbonded atoms draw near to each other. Chemists refer to these interactions as intermolecular (between molecules). For molecular systems, these forces are understood in terms of charge distributions leading to dipoles (permanent or induced) that then attract each other. The most common categories for these interactions are (a) dipole–dipole, (b) dipole-induced dipole and (c) induced dipole–induced dipole (dispersion) forces. Hydrogen bonding is an important, specialized form of dipole–dipole interactions. These forces may occur (a) between small molecules, (b) between different large molecules or (c) between different regions of the same large molecule. The distinction at the particulate level between electrostatic interactions of nonbonded atoms and those of chemically bonded atoms provides the cleanest distinction between a chemical and physical process. A physical process generally involves nonbonded interactions, and a chemical process involves breaking and/or forming covalent bonds. In many systems involving large molecules — both biochemical systems and synthetic polymer systems — the nonbonded interactions play important roles in the observed functions of the systems.

Enduring Understanding 5E

Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.

One of the most powerful applications of thermodynamic principles is the ability to determine whether a process, corresponding to a physical or chemical change, will lie toward the reactant or product side when it reaches a steady equilibrium state. The standard change in Gibbs free energy, $\Delta G° = \Delta H° - T\Delta S°$, is used to make this determination. If $\Delta G° < 0$, then products are favored at equilibrium, and the forward process is considered to be "thermodynamically favored." Conversely, if $\Delta G° > 0$, then reactants are favored at equilibrium, and the reverse process is considered to be "thermodynamically favored." Both the enthalpy change ($\Delta H°$) and entropy change ($\Delta S°$) are closely related to the structure and nature of the components of the system; for this reason, it is often possible to make qualitative determinations concerning the sign (and magnitude) of $\Delta G°$ without explicit calculation. Enthalpy changes are closely related to the relative bond energies (and relative strengths of intermolecular interactions) of the reactants and products; entropy changes are generally related to the states of the components and the number of individual particles present. In this way, the Gibbs energy provides a framework based on molecular structure and intermolecular interactions for understanding why some chemical reactions are observed to proceed to near completion, while others reach equilibrium with almost no products being formed. Some processes that are not thermodynamically favored — for example, the recharging of a battery — can be driven to occur through the application of energy from an external source (in this case, an electrical current). Importantly, in biochemical systems some reactions that oppose the thermodynamically favored direction are driven by coupled reactions. Thus, a cell can use energy to create order — a direction that is not thermodynamically favored — via coupling with thermodynamically favored reactions. For example, many biochemical syntheses are coupled to the reaction in which ATP is converted to ADP + phosphate.

In some cases, processes that are thermodynamically favored are not observed to occur because of some kinetic constraint; quite often, there is a high activation energy to be overcome in order for the process to proceed. Thus, although Gibbs energy can be used to determine which direction of a chemical process is thermodynamically favored, it provides no information about the rate of the process, or the nature of the process on the microscopic scale.

Enduring Understanding 6A

Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.

A collection of molecules undergoing a reversible reaction can adopt a number of configurations, which are constrained by the stoichiometry and which can be ordered by the extent to which the reactants have been converted to products. As reactants are converted to products, the reactant concentrations drop; thus, the rate of the forward reaction decreases. Simultaneously, the product concentrations increase and the rate of the reverse reaction increases. At some intermediate point, the concentrations of reactants and products are such that the rates of the forward and reverse reactions balance, and there is no net conversion between reactants and products. A system that has reached this steady state is at chemical equilibrium. The relative proportions of reactants and products at equilibrium are specified by the equilibrium constant, K, which may be used both quantitatively, to predict concentrations at equilibrium, and qualitatively, to reason about the relative amounts of reactants and products present at equilibrium.

Enduring Understanding 6B

Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.

Chemical equilibrium is a dynamic state in which the rate of the forward and reverse reactions is equal. A change in conditions, such as addition of a chemical species, change in temperature, or change in volume, can cause the rate of the forward and reverse reactions to fall out of balance. Such a change is called a stress on the system. The system is then temporarily out of equilibrium, and there is a net conversion between reactants and products until a new equilibrium state is established. This net conversion is referred to as a shift of the chemical reaction. Le Chatlier's principle provides a convenient means to reason qualitatively about the direction of the shift that results from various possible stresses.

Enduring Understanding 6C

Chemical equilibrium plays an important role in acid–base chemistry and in solubility.

The proton-exchange reactions of acid–base chemistry are reversible reactions that reach equilibrium quickly, and so much of acid–base chemistry can be understood by applying the principles of chemical equilibrium. Most acid–base reactions have either large or small K, so qualitative conclusions regarding the equilibrium state can often be drawn without extensive computations. The dissolution of a solid in a solvent is also a reversible reaction that often reaches equilibrium quickly and therefore can be understood by applying the principles of chemical equilibrium.

Enduring Understanding 6D

The equilibrium constant is established by the difference in Gibbs free energy between reactants and products, and the temperature.

The magnitude of the equilibrium constant, K, specifies the relative proportion of reactants and products present at equilibrium. This is directly related to the change in Gibbs free energy associated with the reaction, $\Delta G°$. The species that have the lower free energy (reactants versus products) have larger relative concentrations at equilibrium. For both reactants and products to be present with significant concentrations at equilibrium (i.e., for K to be near 1), the magnitude of $\Delta G°$ must be roughly equivalent to the thermal energy (RT).

Appendix D: AP Physics Enduring Understandings

The following appendix represents the enduring understandings that will be increasingly the focus and the end goals of the AP Physics course.

Enduring Understanding 1A

The internal structure of a system determines many properties of the system.

The distinction is made in this enduring understanding between objects and systems based upon whether internal structure exists (systems) or whether this structure is not present, or can be ignored, in a problem of interest (objects).

Matter builds from fundamental particles that have no internal structure up to systems, such as nuclei, atoms, molecules and macroscopic objects, that do have internal structure. The number and arrangements of atomic constituents cause substances to have different properties. There is much contact with chemistry in this enduring understanding in terms of atomic structure, chemical properties of elements, and the incorporation of concepts leading to the quantum model of the atom: energy levels, quantized parameters and transitions.

Enduring Understanding 1B

Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.

Electric charge is the fundamental property of an object that determines how the object interacts with other charged objects. The interaction of a charged object with a distribution of other charged objects is simplified by the field model, where a distribution of charged objects creates a field at every point, and the charged object interacts with the field. There are two types of electric charge: "positive" and "negative." Protons are examples of positively charged objects, and electrons are examples of negatively charged objects. Neutral objects and systems are those whose net charge is zero. The magnitude of the charge of a proton and of an electron are equal; this is the smallest unit of charge that is found in an isolated object. Electric charge is conserved in all known processes and interactions.

Enduring Understanding 1C

Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same.

Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems. Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems or gravitational fields. From these definitions, there is no classical expectation that these quantities would be identical. Einstein's assumption that these two quantities, experimentally verified to be equivalent, are in fact the same is fundamental to the general theory of relativity.

Mass is conserved in any process, such as change of shape, change of state, or dissolution, when it is not converted to energy or when energy is not converted to mass. Mass is a central concept in this course, and further discussions of mass are found throughout.

Enduring Understanding 1D

Classical mechanics cannot describe all properties of objects.

Physicists developed classical mechanics from the intuitive partition of behavior of nature at the human scale into objects that behaved like particles (e.g., rocks) and systems that behaved like waves (e.g., sound waves). Similarly, in classical mechanics they recognized from experience that the motion of objects would appear differently to observers moving relative to each other, but assumed that measurements of elapsed time would not be affected by motion. As physicists in the late 19th and early 20th century probed the structure of matter at smaller and smaller scales, they discovered that modeling atomic and smaller-scale behavior on these classical intuitions could not explain the experimental results. Ultimately, new mathematical theories were developed that could predict the outcome of experiments, but lacked the intuitive underpinning of the classical view. The mathematics gives unambiguous results, but has no single intuitive reference or analogy that can be described in ordinary language. As a result, the best we can do is to describe certain results of experiments as analogous to classical particle-like behavior and others as analogous to classical wave-like behavior, while recognizing that the underlying nature of the object has no precise analogy in human-scale experience. During the same period, experimental results and theoretical predictions of results in the study of electromagnetic radiation came into conflict with the classical assumption of a common time for all observers. At relative velocities that are large compared with common experience, the special theory of relativity correctly predicts changes in the observed mass, length and elapsed time for objects in relative motion. Because humans have no experience of relative motion at such velocities, we have no intuitive underpinnings to account for this behavior. The physics of large relative velocities will only be treated qualitatively in this course.

Enduring Understanding 1E

Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. Some of the most important fundamental characteristics of matter and space are identified here and employed in other "big ideas."

Matter has properties called density, resistivity and thermal conductivity, which are used when discussing thermodynamics, fluids, electric current and transfer of thermal energy. The values of these quantities depend upon the molecular and atomic structure of the material. Matter and space also have properties called electric permittivity and magnetic permeability. The permittivity and the permeability of free space are constants that appear in physical relationships and in the relationship for the speed of electromagnetic radiation in a vacuum. The electric permittivity and the magnetic permeability of materials both depend upon the material's structure at the atomic level.

Magnetic dipole and electric dipole moments are other properties of matter. An electric dipole consists of a separated pair of positively and negatively charged objects. A current through a loop is an example of a magnetic dipole. These simple moments lead to discussions of important modern applications such as magnetic storage media, antennas, MRI and the relationship between accelerating charges with the production of electromagnetic radiation.

Enduring Understanding 2A

A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.

All of the fundamental forces, including gravitational force, electric force and magnetic forces, are exerted by one object on another object "at a distance"; this means that the two objects involved in the interaction do not "physically touch" each other. To understand and calculate such forces, it is often useful to model them in terms of fields. Forces and the associated fields are vectors, having a magnitude and direction assigned to each point in space. A field model is also useful for describing how scalar quantities, such as temperature and pressure, vary with position. In general, the field created by an array of "sources," such as electric charges, can be calculated by adding the fields created by the individual source objects. This is known as the principle of superposition. Gravitational treatment is in Course 1. Electromagnetic treatment is in Course 2.

Enduring Understanding 2B

A gravitational field is caused by an object with mass.

The gravitational field is the field most accessible to students. The effect of a gravitational field, g, on an object with a mass m positioned in the field is a force of magnitude mg that points in the direction of the field. The gravitational field can be represented mathematically. The gravitational field at a point in space due to a spherical object with mass m is a vector whose magnitude is equal to the gravitational force per unit of mass placed at that point. The direction of the field at that point is toward the center of mass of the source object. The magnitude of the field is equal to $\frac{Gm}{r^2}$, where r is the distance between the center of mass of the object and the point of interest and G is a constant. As with other vector fields, gravitational fields can be represented by a drawing that shows arrows at points uniformly distributed in space.

Enduring Understanding 2C

An electric field is caused by an object with charge.

Coulomb's law of electric force describes the interaction at a distance between two electrically charged objects. By contrast, the electric field serves as the intermediary in the interaction of two objects or systems that have the property of electric charge. In the field view, charged source objects create an electric field. The magnitude and direction of the electric field at a given location is due to the vector sum of the fields created by each of the charged objects that are the source of the field. Another charged object placed at a given location in the field experiences an electrical force. The force depends on the charge on the object and the intensity and direction of the electric field at that location. The concept of the electric field greatly facilitates the description of electrical interactions between multiple point-charged objects or continuous distributions of point-charged objects. In this course, students should be familiar with graphical and mathematical representations of the electric field due to one or more point-charged objects, including an electric dipole, for the field outside a spherically symmetric charged object and for the uniform field far from the edges of oppositely charged parallel plates. They should also be able to calculate the direction and magnitude of the force on a small, charged object due to such electric fields. Electric field representations are to be vectors and not lines.

Enduring Understanding 2D

A magnetic field is caused by a magnet or a moving charged object. Magnetic fields observed in nature always seem to be produced either by moving charges or by magnetic dipoles or combinations of dipoles, and never by single poles.

Knowledge of the properties and sources of magnetic fields is necessary in other "big ideas" dealing with magnetism. That knowledge is critical to student understanding of areas such as geophysical processes and medical applications. Students also should know that magnetic fields observed in nature always seem to be caused by dipoles or combinations of dipoles and never by single poles. A single magnetic pole (a magnetic monopole, such as an isolated north pole of a magnet) has never been observed in nature.

Representations of these fields are important to the skills that students need to develop in the course. The concentric circle pattern of magnetic field vectors around a current-carrying wire and the dipole pattern of field vectors around a bar magnet are needed representations. Many organisms from animals to bacteria navigate using Earth's magnetic field. Earth's field varies over long geological time scales.

Magnetic materials contain magnetic domains that are themselves little magnets. Representations can be drawn of the atomic-scale structure of ferromagnetic materials, such as arrows or smaller bar magnets, that indicate the directional nature of magnets even at these small scales. These magnetic moments lead to discussions of important modern applications such as magnetic storage media.

Enduring Understanding 2E

Physicists often construct a map of "isolines" connecting points of equal value for some quantity related to a field, and use these maps to help visualize the field.

When visualizing a scalar field, it is useful to construct a set of contour lines connecting points at which the field has the same (constant) value. A good example is the set of contour lines on which the gravitational potential energy per unit mass (gravitational equipotentials) have a constant value. Such equipotential lines can be constructed using the electric potential, and can also be associated with temperature and other scalar fields. When considering equipotential lines, the associated vector field (such as the electric field) is always perpendicular to the equipotential lines.

Enduring Understanding 3A

All forces share certain common characteristics when considered by observers in inertial reference frames.

The description of motion, including such quantities as position, velocity or acceleration, depends on the observer, and specifically on the reference frame. When the interactions of objects are considered, we only consider the observers in inertial reference frames. In such reference frames, an object that does not interact with any other objects moves at constant velocity. In inertial references frames, forces are detected by their influence on the motion (specifically the velocity) of an object. Therefore, force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. If a component of the acceleration is observed to be zero, then the sum of the corresponding force components must be zero. A force exerted on an object is always due to its interaction with another object; the two form an action–reaction pair. If one object exerts a force on a second object, the second object always exerts a force of equal magnitude but opposite direction on the first object.

Enduring Understanding 3B

Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$.

Newton's second law describes the acceleration when one or more forces are exerted on the object. The object's acceleration also depends on the inertial mass. Newton's second law is easier to appreciate when the law is written as $\vec{a} = \frac{\Sigma \vec{F}}{m}$, which underscores the cause–effect relationship. The use of a free-body diagram to represent the forces is a powerful tool to help students identify the different external forces that are relevant to a particular situation. The choice of appropriate axes (usually one axis parallel to the direction in which the object will accelerate) and the resolution of forces into components along the chosen set of axes are essential parts of the process of analysis. The set of component forces along an axis corresponds to the list of forces that are combined to cause acceleration along that axis. Constant forces will yield a constant acceleration, but restoring forces, proportional to the displacement of an object, cause oscillatory motion. In this course the oscillatory solution of the law should be the result of experiment, rather than the solution of the differential equation.

Enduring Understanding 3C

At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

In Big Idea 3, the behavior of an object is analyzed without reference to the internal structure of the object. Internal structure is included in Big Idea 4. There are a small number of forces that occur in nature, and the macroscopic ones are considered here. The identification of forces is a key step in the analysis of mechanical systems.

Gravitational forces, electric forces and magnetic forces between objects are all evident on the macroscopic scale. The gravitational force is a weaker force than the electric or magnetic force. However, on the larger scale, the gravitational force dominates. Electric forces dominate the properties of the objects in our everyday experience. However, the many charged particles that interact make the treatment of this everyday force very complex. The complexities are reduced by introducing new concepts such as the friction force as averages over the many particles. Contact forces (e.g. frictional force, buoyant force) result from the interaction of one object touching another object and are ultimately due to microscopic electric forces. The frictional force is due to the interaction between surfaces at rest or in relative motion. Buoyant force is caused by the difference in pressure, or force per unit area, exerted on the different surfaces of the object. It is important for students to study each of these forces and to use free-body diagrams to analyze the interactions between objects.

Enduring Understanding 3D

A force exerted on an object can change the momentum of the object.

The momentum of an object can only change if there is a net force exerted on the object by other objects. Classically, the change in momentum of the object is the product of the net force on the object and the time interval during which the force is exerted. This product is a vector that is called the impulse, and the direction of the impulse is the direction of the change in momentum. The magnitude of the impulse is the area under the force–time curve.

Enduring Understanding 3E

A force exerted on an object can change the kinetic energy of the object.

A net force exerted on an object causes an acceleration of the object, which produces a change in the component of the velocity in the direction of the force. If there is a component of the force in the direction of the object's displacement, the kinetic energy of the object changes. The interaction transfers kinetic energy to or from the object. Only the component of the velocity in the direction of the force is involved in this transfer of kinetic energy. Thus, only the force component in the direction of the object's motion transfers kinetic energy. The amount of energy transferred during a given displacement depends on the magnitude of the force, the magnitude of the displacement, and the relative direction of force and displacement of the object. Since objects have no internal structure, an isolated object can only have kinetic energy.

Enduring Understanding 3F

A force exerted on an object can cause a torque on that object.

An object or a rigid system, which can revolve or rotate about a fixed axis, will change its rotational motion when an external force exerts a torque on the object. The magnitude of the torque due to a given force is the product of the perpendicular distance from the axis to the line of application of the force (the lever arm) and the magnitude of the force. The vector representing the torque is parallel to the axis of revolution or rotation, with its direction given by a right-hand rule. The rate of change of the rotational motion is most simply expressed by defining the rotational kinematic quantities of angular displacement, angular velocity and angular acceleration. This is analogous to the corresponding linear quantities and to defining the rotational dynamic quantities of torque, moment of inertia, and angular momentum (analogous to force, mass and momentum). The behaviors of the angular displacement, angular velocity and angular acceleration can be understood by analogy with Newton's second law for linear motion.

Enduring Understanding 3G

Certain types of forces are considered fundamental.

There are different types of fundamental forces, and these forces can be characterized by their actions at different scales. The fundamental forces discussed in these courses include the electroweak force, the gravitational force and the strong (nuclear) force. The electroweak force unifies the electromagnetic force and the weak force. These two aspects of the electroweak force dominate at different scales, so are discussed separately. All other forces can be thought of as secondary forces, and are ultimately derived from the fundamental forces.

On the scale appropriate to the secondary forces we deal with every day, the electromagnetic aspect of the electroweak force dominates. There are two kinds of charges that can produce both attractive and repulsive interactions. While there are two kinds of charge, there appears to be only a single type of mass. Consequently, gravitational forces are only attractive. Since there are no repulsive contributions to a net force acting at a very large distance, the gravitational force dominates at large scales. The weak aspect of the electroweak force is important at very large stellar scales and at very small nuclear scales, and the strong force dominates inside the nucleus.

Enduring Understanding 4A

The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.

The concept of center of mass allows one to analyze and predict the motion of a system using an approach very similar to the way one can analyze and predict the motion of an object. When dealing with a system of objects, it is useful to first identify the forces that are "internal" and "external" to the system. The internal forces are forces that are exerted between objects in the system, while the external forces are those that are exerted between objects outside the system and objects in the system. Internal forces do not affect the motion of the center-of-mass motion of the system. If F_{net} is the sum of all the external forces, then the acceleration of the center of mass of the system can be calculated using $\vec{a} = \frac{\sum \vec{F}}{m}$. Hence, many of the results for the motion of an object can be applied to the motion of the center of mass of a system.

Enduring Understanding 4B

Interactions with other objects or systems can change the total linear momentum of a system.

When a net external force is exerted on an object or system, linear momentum is transferred to the object or to parts of the system in the direction of the external force. Qualitative comparisons of the change in momentum in different scenarios are important. The change in momentum for a constant–mass system is the product of the mass and the change in velocity. The momentum transferred in an interaction is the product of the average net force and the time interval during which the force is exerted, whether or not the mass is constant. Graphs of force versus time can therefore be used to determine the change in momentum.

Enduring Understanding 4C

Interactions with other objects or systems can change the total energy of a system.

A system of objects can be characterized by its total energy, a scalar that is the sum of the kinetic energy (due to large-scale relative motion of parts of the system), its potential energy (due to the relative position of interacting parts of the system) and its microscopic internal energy (due to relative motion and interactions at the molecular and atomic level of the parts of the system). In general, these quantities can be changed by interactions with other objects or other systems that transfer energy into or out of the system under study. An external force acting parallel to the displacement of an object transfers energy into or out of the system. For a force that is constant in magnitude and direction, the product of the magnitude of the parallel force component and the magnitude of the displacement is called the work. For a constant or variable force, the work can be calculated by finding the area under the force-versus-displacement graph. The force component parallel to the displacement gives the rate of transfer of energy with respect to displacement. Work can result in a change in the kinetic energy, potential energy or internal energy of a system. Positive work transfers energy into the system, while negative work transfers energy out of the system. When a system with a higher temperature transfers energy to a system with a lower temperature, the internal energies of the systems will change. This kind of energy transfer is called heat. Classically, mass conservation and energy conservation are separate laws, but in modern physics we recognize that the mass of a system changes when its energy changes, so that a transfer of energy into a system entails an increase in the mass of that system as well. The relationship between the mass and energy of a system is described by Einstein's famous equation, $E = mc^2$. The large energies realized from nuclear fission and fusion processes result from small reductions in the mass of a system.

Enduring Understanding 4D

A net torque exerted on a system by other objects or systems will change the angular momentum of the system.

A system is a collection of objects, and the interactions of such systems are an important aspect of understanding the physical world. Systems not only translate; they can also rotate. The behavior of such a system of particles requires a specification of their distribution in terms of a moment of inertia and an analysis of an appropriate axis. The existence of a net torque along any direction will cause the object to change its rate of rotation. Many everyday phenomena involve rotating systems. Understanding the effects of a nonzero net torque on a system in terms of the angular momentum leads to a better understanding of systems that roll or rotate. The angular momentum is a quantity that is conserved if the net torque on an object is zero, and this leads to one of the conservation laws discussed in Big Idea 5.

Enduring Understanding 4E

The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

Electric and magnetic forces may be exerted on objects that possess an electric charge. These forces affect the motion of charged objects. If a charged object is part of a system, electric and magnetic forces and fields can affect the properties of the system. One such example involves the behavior of moving charges (i.e., an electric current) in a circuit. The electric current in a circuit can be affected by an applied potential difference or by changing the magnetic flux through the circuit. The behavior of individual circuit elements, such as resistors and capacitors, can be understood in terms of how an applied electric or magnetic field affects charge motion within the circuit element.

Enduring Understanding 5A

Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

Conservation laws constrain the possible motions of the objects in a system of any size, or the outcome of an interaction or a process. For example, with regard to physical systems from the perspective of Newton's second law, each object changes its motion at any instant in response to external forces and torques, its response constrained only by its inertial mass and the distribution of that mass. However, with even a few objects in a system, tracking the motions becomes very complex. Associated with every conservation law is a physical quantity — a scalar or a vector that characterizes a system. In a closed system, that quantity has a constant value, independent of interactions between objects in the system for all configurations of the system. In an open system, the changes of that quantity are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems. Thus, the conservation law constrains the possible configurations of a system. When analyzing a physical situation, the choice of a system and the expression of the conservation laws provide a quick and powerful set of tools to express mathematical constraints relating the variables in the system.

Enduring Understanding 5B

The energy of a system is conserved.

Of all the conservation laws, the conservation of energy is the most pervasive across all areas of physics and across all the sciences. Conservation of energy occurs in all physical, chemical, biological and environmental processes, and these isolated ideas are connected by this enduring understanding. Several of the concepts included under this enduring understanding are actually statements about the conservation of energy: Kirchhoff's loop rule for electric circuits, Bernoulli's equation for fluids, and the change in internal energy of a thermodynamic system due to heat or work. In nuclear processes, interconversion of energy and mass occurs, and the conservation principle is extended.
An object can have kinetic energy; systems can have kinetic energy; however, if they have internal structure, changes in that internal structure can result in changes in internal energy and potential energy. Since energy is conserved in any system regardless of whether that system is physical, biological or chemical, if a closed system's potential energy or internal energy changes, that energy change can result in changes to the system's kinetic energy. In systems that are open to energy transfer, changes in the total energy can be due to external forces (work is done), thermal contact processes (heating occurs), or to emission or absorption of photons (radiative processes). Energy transferred into or out of a system can change kinetic, potential and internal energies of the system. These exchanges provide information about properties of the system. If photons are emitted or absorbed, then there is a change in the electron energy levels for atoms in the system.

Enduring Understanding 5C

The electric charge of a system is conserved.

Conservation of electric charge is a fundamental conservation principle in physics. All processes in nature conserve the net electric charge. The total charge after an interaction or any other type of process always equals the total charge before the interaction or process. A common example is found in electric circuits, in which charge (typically electrons) moves around a circuit or from place to place within a circuit. Any increase or decrease in the net charge in one region is compensated for by a corresponding decrease or increase in the net charge in other regions. In electrostatics, it is common for electrons to move from one object to another, and the number of electrons that leave one object is always equal to the number of electrons that move onto other objects. In some reactions — such as radioactive decay or interactions involving elementary particles — it is possible for the number of charged particles after a reaction or decay to be different than from the number before. However, the *net* charge before and after is always equal. So if a process produces a "new" electron that was not present before the reaction, then a "new" positive charge must also be created so that the net charge is the same before and after the process.

Enduring Understanding 5D

The linear momentum of a system is conserved.

Conservation of linear momentum is another of the important conservation laws. This law holds at all scales, from the subatomic scale to the universe scale. Linear momentum in a system isolated from external forces is constant. Interactions with other objects or systems can change the total linear momentum of a system. Such changes are discussed in 3E and 4B.

When objects collide, the collisions can be elastic or inelastic. In both types of collisions, linear momentum is conserved. The elastic collision of non-rotating objects describes those cases in which the linear momentum stays constant and the kinetic and internal energies of the system are the same before and after the collision. The inelastic collision of objects describes those cases in which the linear momentum stays constant and the kinetic and internal energies of the objects are different before and after the collision.

The velocity of the center of mass of the system cannot be changed by an interaction within the system. In an isolated system that is initially stationary, the location of the center of mass is fixed. When two objects collide, the velocity of their center of mass will not change.

Course 1 includes one-dimensional treatment of conservation of momentum and velocity of the center of mass of the system. Course 2 includes two-dimensional treatment of conservation of momentum and velocity of the center of mass of the system.

Enduring Understanding 5E

The angular momentum of a system is conserved.

The conservation of angular momentum is a consequence of the symmetry of physical laws under rotation, which means that if everything relevant to an experiment is turned through some angle, the results of the experiment will be the same. In nature, conservation of angular momentum helps to explain the vortex of the bathtub drain; the gyre of ocean currents; the changing spin of a dancer, a skater, a gymnast or a diver; the direction of rotation of cyclonic weather systems; and the roughly planar arrangement of planetary systems and galaxies. The angular momentum of a rigid system of objects allows us to describe the linked trajectories of the many objects in the system with a single number, which is unchanging when no external torques are applied. Choosing such a closed system for analyzing a rotational situation allows many problems to be solved by equating the total angular momentum in two configurations of the system.

Enduring Understanding 5F

Classically, the mass of a system is conserved.

The conservation of mass is an important principle that holds up to a certain energy scale where the concepts of mass and energy need to be combined. In this course, conservation of mass is assumed in most problems. Thus, when using $F = ma$, etc., conservation of mass is assumed.

An ideal example of this conservation law is found in the continuity equation, which describes conservation of mass flow rate in fluids. If no mass is entering or leaving a system, then the mass must be constant. If an enclosed fluid flow is uniform and the fluid is also incompressible, then the mass that is entering an area must be equal to the mass that is leaving an area. Fluid flow in engineering and in biological systems can be modeled starting with this enduring understanding, but requires the addition of fluid viscosity for a complete treatment.

Enduring Understanding 6A

A wave is a traveling disturbance that transfers energy and momentum.

When an object moves as a projectile from one place to another, it possesses kinetic energy and momentum. Such a process thus transfers energy and momentum, and also mass, from place to place. A wave is a disturbance that carries energy and momentum from one place to another without the transfer of mass. Some waves are mechanical in nature; this means that they are a disturbance of a mechanical system such as a solid, a liquid or a gas. This system is called the medium through which the wave travels. Mechanical waves are then described in terms of the way they disturb or displace their medium. The propagation properties of the mechanical wave, such as the wave speed, also depend on the properties of the medium. Electromagnetic waves do not require a mechanical medium. They are instead associated with oscillating electric and magnetic fields. Electromagnetic waves can travel through a mechanical medium, such as a solid, but they can also travel through a vacuum.

Enduring Understanding 6B

A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, phase difference, speed and energy.

The properties of periodic waves are important to understanding wave phenomena in the world around us. These properties are period, wavelength, speed in a particular medium, amplitude and frequency of the wave. A simple wave can be described by one sine or cosine function involving the wavelength, amplitude and frequency of the wave. Wave velocities depend upon the properties of the medium, but the speed of a wave is independent of the frequency and wavelength of the wave. The velocity of an electromagnetic wave in a vacuum is a constant, usually referred to as c. In other materials, the velocity of an electromagnetic wave depends on properties of the material.

The frequency of a wave, as perceived by observers, depends upon their motion relative to the source of the wave. If the source is moving away from the observer, the frequency decreases; if the source is moving toward the observer, the frequency increases. This change in observed frequency or wavelength is known as the Doppler Effect and finds uses from astronomy to medicine to radar speed traps.

Enduring Understanding 6C

Only waves exhibit interference and diffraction.

When two or more waves move through the same space, the displacement at a particular point is a result of the superposition, or sum of the displacements due to each of the waves. Depending on the direction of propagation of the waves from the various sources and their phase or time relationship to each other, this principle explains a large variety of phenomena, including standing waves in a musical instrument, rogue waves at sea, and the colors seen in soap bubbles. Where the crest of one wave coincides with the crest of another wave, we see constructive interference, giving a large amplitude of oscillations. Where crest meets trough, we see cancellation or destructive interference. Since the oscillation at a particular point can be treated as a source of waves spreading from that point (Huygen's principle), as waves pass through openings or around objects that are of comparable sizes to the wavelength, we observe that waves can spread or diffract out into the space beyond the edge or obstacle. This accounts, among other things, for our ability to hear around corners but not see around them.

Enduring Understanding 6D

Interference and superposition lead to standing waves and beats.

Interference and superposition of waves find application in many areas. These include musical instruments, lasers, medical imaging and the search for gravitational waves. Two wave pulses can overlap to produce amplitude variations in the resultant wave. At the moment of overlap, the displacement at each point can be determined by superposition, adding the displacements at each point due to the individual pulses. This principle applies to all waves, from pulses to traveling periodic waves. However, Course 1 will treat only mechanical waves, and Course 2 will treat electromagnetic waves.

When incident and reflected traveling waves are confined to a region, their superposition or addition can result in standing waves with constructive and destructive interference at different points in space. Examples include waves on a fixed length of string and sound waves in a tube. When two waves of slightly different frequency superimpose, their superposition or addition can result in beats with constructive and destructive interference at different points in time. Standing waves and beats are important phenomena in music.

Enduring Understanding 6E

The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.

The propagation of a wave depends on the properties of the medium or region through which the wave travels. The speed of a wave, including electromagnetic waves such as light, depends on the material through which it travels. When light (or any other type of wave) travels from one material to another, the frequency remains the same, but the change in wave speed causes a change in the propagation direction, described by Snell's law. This change in direction is termed refraction when light passes through an interface. Reflection occurs when part or all of a wave bounces back from the interface. Both reflection and refraction can be used to form images. The study of image formation with light is called geometrical optics, and it involves the properties of images formed with mirrors and lenses.

Enduring Understanding 6F

Electromagnetic radiation can be modeled as waves or as particles.

One of the great discoveries of modern physics is that electromagnetic radiation, modeled in the 19th century as a classical wave, also has properties that are best interpreted by a particle model. In the particle model of electromagnetic spectra, photons are individual energy packets of electromagnetic waves. The discrete spectra of atoms are evidence that supports the particle model of electromagnetic spectra. The nature of light requires that a different model of light is most appropriate at different scales. Interference is a property of waves, and radio waves traveling different paths can interfere with each other, causing "dead spots" — areas of limited reception. The behavior of waves through a slit or set of slits is discussed in 6C. Wavelengths of electromagnetic radiation range from extremely small to extremely large.

Enduring Understanding 6G

All matter can be modeled as waves or as particles.

At the human scale, a thrown rock moves through space on a well-defined path. The moving mass carries momentum and energy that are transferred on impact to another object or system. A splash in a pond creates a disturbance in the water, spreading in all directions and delivering energy and momentum without transferring mass. These two different forms of interaction have historically served as the metaphors that we attempt to use to explain the physical phenomena we observe. Abstracted into sophisticated mathematical models, they give highly precise predictions at the human scale. However, at other vastly different scales of size and energy, we find that neither model is an exact fit for the phenomena. Instead, we find that each of the metaphors works well to model some aspects of a situation while failing to model other aspects. The successful mathematical treatment of quantum mechanics — combining mathematics derived from both metaphors — goes beyond either model to accurately describe phenomena at the quantum scale, but it leaves us without any simple visual metaphor from our everyday experience. The wave representing a particle indicates the probability of locating that particle at a particular place in space and time. This course treats these wave representations in a qualitative fashion.

Enduring Understanding 7A

The properties of an ideal gas can be explained in terms of a small number of macroscopic variables, including temperature and pressure.

In a gas, all of the molecules are in constant motion and there is a distribution of speeds. Individual speeds may be influenced by collisions with other molecules and with the walls of the container. In an ideal gas, this complicated behavior can be characterized by just a few variables, pressure *(P)*, the combined result of the impacts of molecules, temperature *(T)*, the average kinetic energy of the molecules, and volume *(V)*. Statistical methods are used to relate the state variables of pressure and temperature to the distribution of velocities of the molecules. For the ideal gas model, the equation $PV = nRT$ describes the relationship between the state variables.

In Maxwell's description of the connection between thermodynamic properties and atomic-scale motion, the rate of change of momentum at any surface — including that of the container that holds the gas — increases as temperature increases. Newton's second law expresses the rate of change of momentum as the force, and pressure is force per unit area.

The average kinetic energy of the gas molecules in the system is an average over a distribution of different speeds for individual molecules. The root mean square of the velocity is related to the temperature.

Enduring Understanding 7B

The tendency of isolated systems to move toward states with higher disorder is described by probability.

The transfers of energy that occur in thermal processes depend on a very large number of very small-scale (molecular and atomic) interactions; therefore, these energy transfers are best described by the mathematics of probability. When parts of an isolated system — initially at different temperatures — interact, higher momentum particles are more likely to be involved in more collisions. Consequently, conservation of momentum makes it more likely that kinetic energy will be transferred from higher-energy to lower-energy particles. This process reduces both the number of high-energy particles and the number of low-energy particles until, after many collisions, all interacting parts of a system arrive at the same temperature. The amount of thermal energy needed to change the temperature of a given part of a system will depend on the total mass of that part of the system and on the difference between its initial and final temperature. Neither energy conservation nor momentum conservation laws have any preferred direction in time, yet large-scale processes always tend toward equilibrium and not toward disequilibrium. The second law of thermodynamics describes the tendency of large systems to move toward states with higher disorder. A new state function, entropy, can be defined; it depends only on the configuration of the system and not on how the system arrived at that configuration. Unlike energy, entropy is not conserved but instead always increases for irreversible processes in closed systems.

Enduring Understanding 7C

At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.

This enduring understanding follows on the heels of 1D and 6G. Students need to be aware that classical physics cannot describe everything and that there are new, nonclassical ideas that must be addressed for a more complete understanding of the physical world.

The dynamic properties of quantum mechanical systems are expressed in terms of probability distributions. At this scale, we find that interactions between objects are fundamentally not deterministic, as Newton envisioned, but can only be described by probabilities, which are calculated from the wave function. This gives rise to observed wave properties of matter. One such property is that an electron in an atom has a discrete set of possible energy states. The electron energy levels of the atom can be described in terms of allowable energy transitions due to emission or absorption of photons — processes that are determined by probability. These phenomena form the basis of lasers. The spontaneous radioactive decay of an individual nucleus is described by probability as well. Balancing of mass and charge in nuclear equations can be used to determine missing species in the equation, and to account for pair production and annihilation. These ideas can also be used to understand fission and fusion, one current and one possible future source of energy.

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Glossary

The purpose of this glossary is to communicate and clarify how the College Board is using these terms throughout this standards document. Others may use these terms in slightly different ways; however, for the purposes of the *Science College Board Standards for College Success,* these terms are used in the manner described below. The page references that follow each definition indicate where the term first appears in each section or discipline.

abiotic Nonliving or physical factors within a living system. (Objective LS.1.2, Essential Knowledge [9–12], p. 55)

accuracy Refers to the bias in data — the difference between the mean of the measurements and the reference value, or "true value." (Objective SP.2.1, Essential Knowledge, p. 11; LSM-PE.4.2.4b, p. 73)

amplitude The distance from the equilibrium line to the crest of a wave. This is often viewed as one-half of the total wavelength. Amplitude is always taken to be positive. (PS-PE.4.3.1, p. 105; Objective P.3.3, p. 160)

anomaly Data that is unusual, unique or irregular, either based on what is expected or when it is compared to other data. (Standard SP.3, p. 13)

average speed When an object traveling in a straight line is speeding up, slowing down or traveling at different constant speeds for a series of time intervals, the average speed (s_{ave}) over any interval is obtained by dividing the total distance traveled during that time interval by the total duration of the interval. The mathematical model of average speed is:

$$s_{ave} = \frac{\text{total distance traveled}}{\text{total time of travel}}.$$

When an object travels at different constant speeds for a series of time intervals, the distance and the time interval must be known or calculated for each part of the journey:

$$s_{ave} = \frac{\text{distance 1} + \text{distance 2} + \text{distance 3} \ldots}{\text{time 1} + \text{time 2} + \text{time 3} \ldots}.$$

(PS-PE.1.1.5, p. 89; Objective P.1.1, p. 142)

biotic Biological or living components of a living system; components may be the remains of organisms or the by-products of organisms. (LSH-PE.1.2.2, p. 55)

bolide The generic term for a large, crater-forming projectile from space. (Objective ES.2.4, Essential Knowledge [9–12], p. 35)

characteristics of an interaction An interaction can be classified by the following characteristics: (1) the conditions necessary for the interaction to occur (e.g., two objects must be touching; one object must be charged; one object must be moving; one object must be a solid and the other a fluid); (2) the evidence of the interaction — usually the observed changes; and (3) the variables (e.g., the magnitude of forces, energies and/or fields) that influence the strength of the interaction. (*see also* **force law**) (Standard PS.1, p. 89)

charging by induction A method used to charge a metal object without the metal object touching any other charged object. A charged object is brought near (but does not touch) a metal conductor. A second object that can serve as a source or receiver of charge is brought in contact with the metal conductor, and then it is removed. Finally, the charged object is removed. The metal conductor is left with a charge opposite that of the original charged object. (Objective PS.1.5, p. 94; P-PE.1.5.3, p. 149)

claim An assertion that is based on evidence or knowledge. Claims can be based on the following: natural or human-designed systems and phenomena, observations of the natural world, results of a planned investigation, scientific questions, or answers to a posed question. (Introduction to Science Practices, p. 6; ESH-PE.1.5.3, p. 29; LSM-PE.1.1.3, p. 52; PS-PE.1.1.1e, p. 89; Introduction to Chemistry, p. 112; P-PE.1.1.2, p. 143)

compressional (longitudinal) wave In a compressional (longitudinal) wave (e.g., slinky, sound waves), the particles of the medium vibrate back and forth along the same direction as (parallel to) the wave disturbance. Some waves, such as seismic waves, have both components. (PS-PE.4.3.2a, p. 106)

concept A single word or a short phrase (e.g., species, geographical isolation, solid, atom, repeating pattern). An accepted concept results from an amalgamation of multiple investigations, observations or explanations. The terms "concept," "law" and "principle" are often used interchangeably when describing scientific knowledge. However, the term "concept" is sometimes used to describe a broad category that includes laws and principles. (Introduction to Unifying Concepts, p. 1; Introduction to Science Practices, p. 5; Introduction to Earth Science, p. 21; Introduction to Life Science, p. 49; Introduction to Physical Science, p. 87; Introduction to Chemistry, p. 111; Introduction to Physics, p. 139)

conceptual difficulty An undifferentiated concept, an alternative or naïve conception (sometimes called a misconception), or a mistake or error found in the science and physics education research literature. (Introduction to Physics, p. 141)

condition A variable or the characteristic of the objects, systems, events or processes involved in a problem, situation or phenomenon. The variable is either known (given) or is observed or measured in a subsequent investigation. Some variables are constant; others are changing. When analyzing a situation, problem or phenomenon in order to make predictions or explanations, the conditions must be articulated as the assumptions that characterize the situation and therefore impact the reasoning and evidence that support the prediction or explanation. (Unifying Concepts, p. 2; Introduction to Science Practices, p. 6; Standard PS.1, p. 89; C-PE.1.5.3g, p. 120; Objective P.1.3, Essential Knowledge, p. 147)

data A recorded observation or measurement (e.g., "On June 6, 2007, the number of insect species in field X was 221."). The observation or measurement may be of a natural system or from a designed experimental situation. Observations include direct sensory observations as well as indirect observations (e.g., carbon date of a rock) that use inferences from well-understood science. All observations and measurements have some uncertainty (*see also* **accuracy** and **precision**). (Introduction to Science Practices, p. 5; Objective STS.1.1, p. 19; Introduction to Earth Science, p. 21; Objective LS.1.1, Essential Knowledge [6–8], p. 52; PS-PE.1.1.1b, p. 89; Introduction to Chemistry, p. 112; Introduction to Physics, p. 141)

displacement A vector quantity that represents a change in position. (Standard P.1, p. 142)

drag A force that is exerted in opposition to the relative motion of an object that is in a fluid. (PS-PE.1.2.5, p. 91; Objective P.1.3, p. 145)

elastic material A solid is elastic if it rapidly returns to its original shape after it is stretched, compressed or bent. If the force is not too large, materials such as flesh, tendons, bone, steel, rock and rubber are elastic. Solids and quasi-solids, such as lead, chewing gum, taffy, moist clay and putty, do not return to their original shape after they are distorted. These materials are categorized as plastic (inelastic). (P-PE.1.3.2, p. 146)

electron pair geometry The geometry resulting from mutual repulsions of electron pairs, also known as valence shell electron pair repulsion (VSEPR). (C-PE.1.4.2, p. 118)

energy diagram An energy diagram for a specific event or problem represents the type and direction of energy transfers (e.g., thermal energy transfer [heat], electrical energy transfer) across the boundary of a defined system during a defined time interval. An energy diagram can also include the type and direction (increase, stay the same, decrease) of energy changes within a system (e.g., increase in the kinetic energy of a falling object, decrease in the gravitational potential energy of an Earth–object system). An energy diagram often represents the objects/subsystems within a system and outside the system with a labeled shape (e.g., box, oval) and energy transfers with a labeled arrow. (C-PE.2.4.2, p. 129; P-PE.2.1.1b, p. 151)

evidence Data (from investigations, scientific observations, the findings of other scientists, historic reconstruction and/or archived data) that have been represented, analyzed and interpreted in the context of a specific scientific question. Modes of representing data could include, but are not limited to, verbal summaries, discipline-specific drawings or diagrams, maps, summary charts and tables, frequency plots, bar graphs (histograms), and scatter plots. These representations, based on accepted science knowledge and mathematics processes or procedures, are used to interpret the data in terms of properties, trends or patterns. Interpretations can be represented by linguistic or mathematical models. (Unifying Concepts, p. 4; Introduction to Science Practices, p. 5; Standard ES.1, p. 23; Standard LS.1, p. 52; Standard PS.1, p. 89; Objective C.1.1, p. 114; Standard P.1, p. 142)

fact A scientific claim about well-established properties, correlations or events (e.g., the Sun rises in the East; most solid metal elements expand when heated) — all of which have been determined to always occur in any context. Facts are best seen as claims and evidence of phenomena that come together to develop and refine, or to challenge, scientific explanations. In the history of science, theories sometimes become facts. For example, back in the 20th century, the atomic structure of substances was a theory. Today, the existence of atoms is a fact, due to the modern capability of using tools such as scanning–tunneling microscopes to image individual atoms in substances.[15] (Objective SP.4.3, Essential Knowledge, p. 15; Objective STS.1.3, p. 20; Introduction to Earth Science, p. 22; Introduction to Life Science, p. 49; Introduction to Physical Science, p. 87; Introduction to Chemistry, p. 112; Introduction to Physics, p. 139)

food A substance typically composed of carbohydrates, fats and proteins that come from an organism, a by-product of an organism or the remains of an organism. Provides the matter (atoms and molecules) for the chemical reactions that maintain an organism's structure and provides the chemical energy (carbon–carbon and carbon–hydrogen bonds in the presence of oxygen) to maintain the activity of an organism. (Introduction to Life Science, p. 50)

15. National Research Council, *Taking Science to School: Learning and Teaching Science in Grades K–8* (Washington, D.C.: The National Academies Press, 2007), 2–5.

force diagram A diagram showing all of the forces, both magnitude and direction, acting on an object. (PS-PE.1.2.2, p. 90; Objective P.1.2, p. 144)

force law A force law for an interaction is the empirical approximation or mathematical model of the variables that determine the magnitude of the forces between the two interacting objects. A force law is the third defining characteristic of an interaction. (Standard P.1, p. 142)

frequency The amount of cycles that have been completed in one second. It is measured in hertz (Hz). (PS-PE.4.3.1, p. 105; Objective P.3.3, p. 160)

hypothesis A type of testable explanation (model) of natural systems or phenomena, or of evidence from an investigation. A hypothesis can be proposed prior to data collection and has the components of an explanation: an assertion (claim), desired evidence related to the claim, and reasoning that connects the assertion and the evidence. A hypothesis serves the same role as a scientific question in that it guides the collection and interpretation of data that will support the assertion. A hypothesis must be consistent with accepted scientific knowledge, result in predictions that can be tested through further investigations, and be supported (justified) with reasoning (argumentation). For the purpose of these standards, the development of a hypothesis is achieved through the process of question formulation. (Introduction to Science Practices, p. 6)

insolation **In**coming **sol**ar radi**ation**. The measure of solar radiation on a given surface area per unit of time. (ESM-PE.2.1.2, p. 30)

interaction Two objects (which can be a defined quantity of a solid, liquid or gas) interact when they act on or influence each other to cause some effect. The evidence of the interaction is usually the effect — an observed change (e.g., change in motion, shape, mass, temperature, state) in one or both objects. Interaction is a statement of causality in science. Interactions are described (represented) and explained with forces, energy transfers and fields. An event or process may involve a single interaction between two objects, multiple interactions occurring simultaneously and/or chains of interactions. The duration of events varies from very short to very long. (Unifying Concepts, p. 3; Objective SP.5.1, Essential Knowledge, p. 16; Objective ES.1.1, p. 23; Introduction to Life Science, p. 50; Standard PS.1, p. 89; Objective C.1.2, p. 115; Introduction to Physics, p. 139)

kinetic friction The force of friction acting between two objects while the objects are sliding past each other. The direction of the sliding (kinetic) friction force on an object is opposite to the direction of sliding. (PS-PE.1.3.2, p. 92; Standard P.1, p. 142)

mineral A geologically formed solid that has a highly ordered atomic structure and specific chemical and physical properties. (Introduction to Earth Science, p. 21; Objective LS.4.1, Essential Knowledge [6–8], p. 72)

model Refers to "physical, mathematical, and conceptual models [that] are tools for learning about the things they are meant to resemble."[16] A model can represent physical objects that are too big, too small, too dangerous or unethical for humans to observe or experiment with directly. A model can also represent a concept, principle, law or theory that explains a wide body of evidence that has been gathered in a scientific investigation. While the term "model" can be used to refer to other things, its meaning here is limited to discipline-specific diagrams; flow charts or maps; physical models (e.g., scale models of actual objects, systems); mathematical representations (e.g., graphs, equations); and conceptual models (e.g., imagery, metaphor and analogy). The terms "model" and "representation" are used interchangeably due to the different applications in different disciplines. (Unifying Concepts, p. 1; Introduction to Science Practices, p. 6; ESH-PE.1.1.2a, p. 24; Introduction to Life Science, p. 50; Objective PS.1.1, p. 89; Objective C.1.1, p. 114; Objective P.1.1, p. 142)

motion diagram For middle school (grades 6–8), a motion diagram shows the position at each successive clock reading of one or more objects traveling in one direction in a straight line. The motion diagram gradually becomes more abstract as students move into high school (grades 9–12): (1) dots represent the moving object at specified instants and times along a convenient coordinate axis; (2) the position and velocity are specified at all relevant times at all relevant instants — initial time, final time and instants when the motion of the object changes; and (3) the acceleration is indicated at all relevant times or time intervals. (PS-PE.1.1.1d, p. 89; Objective P.1.1, p. 142)

outlier A measured value that is significantly different from other measured values. If there is reason to believe that the outlier is due to a significant error in measurement, then its value should not be considered when determining the best value. (Standard SP.3, p. 13; LSH-PE.1.2.1c, p. 55; PS-PE.1.1.1d, p. 89)

particle Any atomic–molecular level discrete entity such as an atom, molecule or ion, particularly when depicted in a molecular-level visualization. (ESH-PE.1.1.1f, p. 24; Objective PS.1.5, p. 94; Standard C.1, p. 114; P-PE.1.3.9, p. 146)

precision Refers to the spread in a group of measurements. (Objective SP.2.1, Essential Knowledge, p. 11; LSM-PE.4.2.4b, p. 73)

16. American Association for the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford University Press, 1993), 267.

prediction An assertion (claim) about what might happen under certain conditions concerning a natural phenomenon or the results of a planned investigation. The assertion (claim) is supported by principles, models, theories about natural phenomena, or previous empirical evidence. (Introduction to Science Practices, p. 5; Objective STS.1.2, p. 19; ESH-PE.2.1.2, p. 31; Standard LS.3, p. 65; PS-PE.1.1.4, p. 89; C-PE.1.3.3c, p. 117; P-PE.1.1.7, p. 143)

principle A statement that contains two or more concepts and that describes some relationship or relationships between or among the concepts in the statement (e.g., species can come into existence through geographical isolation; solids consist of atoms, ions or molecules that are closely packed in repeating patterns). The concepts and the relationship(s) between or among the concepts result from an amalgamation of multiple investigations, observations or explanations. In the physical sciences, laws and principles (e.g., gas laws, Newton's laws of motion, law of conservation of energy) are usually expressed mathematically. The terms "concept," "law" and "principle" are often used interchangeably when describing scientific knowledge. However, the term "concept" is sometimes used to describe a broad category that includes laws and principles. (Introduction to Unifying Concepts, p. 1; Objective SP.1.2, Essential Knowledge, p. 9; Introduction to Earth Science, p. 22; Introduction to Life Science, p. 49; Introduction to Physical Science, p. 87; Introduction to Chemistry, p. 111; Introduction to Physics, p. 139)

problem A question to be answered either qualitatively or quantitatively where the question is within a context unfamiliar to the student. A problem can be experimental (lab or demonstration), a project or an authentic, real-world word problem. All problems have three characteristics: (1) there is a motivation for answering the question; (2) the context is real world (i.e., no idealized situations); and (3) some information is observable, measurable or known. Problems should go beyond a simple algorithmic strategy of reasoning (i.e., if all variables are controlled for to measure variable X, and there is a difference in the outcomes, then the conclusion is that X is causal [Chinn & Malhotra, 2002]) and require two or more steps of reasoning. (Introduction to Science Practices, p. 5; Introduction to Science, Technology and Society, p. 19; LSM-PE.2.2.4, p. 60; PS-PE.1.1.5, p. 89; Introduction to Physics, p. 141)

ray diagram A diagram showing the path (direction) of a "beam" of light. A ray always travels in a straight line in all directions from a light source; however, a ray may change direction as a result of external influences (e.g., mirrors, lenses or strong gravitational fields). (P-PE.3.3.2, p. 161)

reasoning Scientific principles that provide justification serving as a link between a claim and the evidence related to an explanation, a model, a hypothesis or a prediction. They also provide additional support for how the evidence supports the claim. Justification and reasoning allow the evidence to be linked to explanations within the larger scientific world of theories. These explanations are relevant to theories within a discipline and are linked to the discipline and the larger body of knowledge that accumulates through empirical studies that are accepted and reviewed by peers. (Introduction to Science Practices, p. 6; Unpacking the Performance Expectation: Earth Science, p. 47; Unpacking the Performance Expectation: Chemistry, p. 138)

recycle To rearrange the constituents of matter (at the most basic level, molecules and elements) from one form to another through various processes (natural and anthropogenic); refers to the conservation of matter, not the colloquial sense of the term. (Standard ES.4, p. 40; Standard LS.4, p. 71)

region of electron density The place around an atom where electron density is high. For example, lone pairs, single bonds, double bonds and triple bonds all count as one center of electron density. (C-PE.1.4.2, p. 118)

reliable Refers to the accuracy and precision of data — whether data are consistent or reproducible. (Standard SP.2, p. 11)

representation A table, graph, equation or diagram that is constructed for the purpose of organizing data. This type of representation differs from that which is created for the purpose of explanation. (*see also* **model**) (Unifying Concepts, p. 4; Introduction to Science Practices, p. 5; ESH-PE.1.1.2, p. 24; LSM-PE.1.1.1, p. 52; PS-PE.1.1.2, p. 89; C-PE.1.1.1, p. 114; Introduction to Physics, p. 141)

scientific explanation Addresses a scientific question or prediction. A scientific explanation includes an assertion (claim) about natural systems or designed objects, systems, or phenomena; the evidence, which can consist of empirical evidence or observations, related to the claim; and reasoning (argumentation) that links the claim with the evidence.[17] A scientific explanation has the following characteristics: (1) it is consistent with other concepts, laws, principles and theories; (2) it describes, explains and predicts how the natural world works; and (3) it is open to questions and possible modifications. All scientific explanations built on evidence and solid reasoning are inherently connected, through the evidence and reasoning, to other investigations and explanations. This network of evidence, investigations and explanations is the foundation of the principles, theories, facts and laws that define a discipline. Depending on the discipline and the portion of the process of investigating a phenomenon, a scientific explanation can play a pivotal role throughout the entire process (i.e., guide investigations, support conclusions drawn from investigations, support predictions based on evidence). (Introduction to Science Practices, p. 7)

17. American Association for the Advancement of Science, 13.

scientific investigation Refers to the diverse ways in which scientists study the natural world and propose explanations that are based on the evidence gathered. A scientific investigation can be experimental in that variables are manipulated while other variables are controlled or kept constant in order to determine the relationship among them. Scientific investigations require identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.[18] (Introduction to Science Practices, p. 6; Objective ES.5.3, p. 45)

scientific question A question that leads to an empirical investigation (collecting and interpreting data to develop an explanation). Types of scientific questions include existence, causal/functional and exploratory questions that involve collecting novel data (NOT testing a hypothesis). (Introduction to Science Practices, p. 5; ESM-PE.5.3.1a, p. 46; LSH-PE.2.2.2a, p. 60; PS-PE.1.1.1a, p. 89; C-PE.1.5.3a, p. 120; P-PE.3.2.3a, p. 159)

space-filling model A model that delineates the surface of a molecule rather than the connections among nuclei (which are depicted in ball-and-stick models). A space-filling model provides a more realistic visualization of the shape outlined by the electrons, whereas a ball-and-stick model allows visualization of the connections and bond angles within a molecule. (C-PE.1.4.1, p. 118)

species Any collection of atoms, molecules or ions of a certain type that is undergoing a change or is being measured. The definition of the term "species" in chemistry, though commonly used in this context, is quite different from the definition of the term as it is used in life science. (C-PE.1.1.2a, p. 114)

static friction The force of friction acting between two interacting objects while there is no relative motion between them. The direction of the sticking (static) friction force is opposite to the direction in which the object would slide if there were no sticking (static) friction. (Objective P.1.3, p. 145)

theory A system of scientific explanations or related observations that has been rigorously tested by the scientific community at large. It is often based on numerous verified hypotheses, and as the theory is tested over time, it is revised but is seldom replaced completely. All scientific theories are subject to continuous testing, and when new evidence comes to light that refutes the theory, the theory must then be abandoned or revised to account for this new evidence; otherwise it cannot be tested and therefore cannot be considered scientific. (Introduction to Science Practices, p. 6; ESH-PE.2.3.2, p. 33; LSM-PE.1.2.4, p. 54; C-PE.1.1.1, p. 114; Objective P.1.5, Essential Knowledge, p. 150)

totally inelastic collision An inelastic collision in which the two colliding objects stick together. After the collision, the two objects (stuck together) travel with the same velocity. (P-PE.2.2.8, p. 153)

trait (biological) Characteristic of an organism that may be related to genetic or environmental factors. As used in life science, the term represents those characteristics that result from the expression of genes. If the term is used to incorporate both genetic and environmental traits, then the environmental source will be indicated in the text. If the term is referring only to the inherited traits (in evolution), it will stand alone. (Introduction to Life Science, p. 50)

transfer (of energy) The term "transfer" is used to describe the movement of energy from one place to another (e.g., from a system to its surroundings, or from a hot object to a cold object). (Unifying Concepts, p. 2; Introduction to Science Practices, p. 8; Objective ES.1.2, Essential Knowledge [6–8], p. 25; Standard LS.2, p. 58; Introduction to Physical Science, p. 88; C-PE.1.6.6, p. 122; Introduction to Physics, p. 140)

transformation (of energy) The term "transformation" is used when the type of energy changes as a result of a series of energy transfers. For example, in a microwave oven, when photons of microwave energy are absorbed by water molecules, the energy is "transformed" into kinetic (thermal) energy (the molecules vibrate faster) and the temperature rises. (Unifying Concepts, p. 2; Standard ES.4, p. 40; Standard LS.2, p. 58; Standard PS.4, p. 103; C-PE.1.3.1, p. 116; P-PE.2.1.4, p. 152)

transverse wave In a transverse wave (e.g., ropes, springs), the particles of material vibrate at right angles to (perpendicular to) the direction in which the wave disturbance moves through the material. (PS-PE.4.3.2a, p. 106)

two-source interference pattern When two sources of two- or three-dimensional mechanical waves are vibrating in sync (i.e., in the same direction at the same time), a pattern of locations of constructive and destructive interference is produced. The interference pattern is determined by the wavelength and the spacing of the two sources. The greater the separation of the sources relative to the wavelength, the larger the number of destructive interference (nodal) curves. (P-PE.3.3.3, p. 161)

valid Refers to the degree in which data provide information relevant to the question being asked or to the inferences and/or predictions that

18. National Research Council, *Inquiry and the National Science Education Standards* (Washington, D.C.: The National Academies Press, 2000), 13–14.

are being made. (Standard SP.2, p. 11)

vector addition To add vectors in one dimension, place the tail of the second vector in the sum at the tip of the first vector, and then place the tail of the third vector in the sum at the tip of the second vector, and so on. The vector representing the sum (the resultant vector) runs from the tail of the first vector to the tip of the last vector. (P-PE.1.2.2c, p. 144)

vector subtraction To subtract two vectors in one dimension, reverse the direction of the vector being subtracted, and then add the inverted vector to the vector from which you are subtracting. The vector representing the difference runs from the tail of the first vector to the tip of the last vector. (Objective P.1.1, p. 142)

wavelength The length (measured in meters) of one complete wave cycle. Thus, after every wavelength, the wave is at a point that is identical to the one where it started — wave motion is periodic. (PS-PE.4.3.1, p. 105; Objective P.3.3, p. 160)

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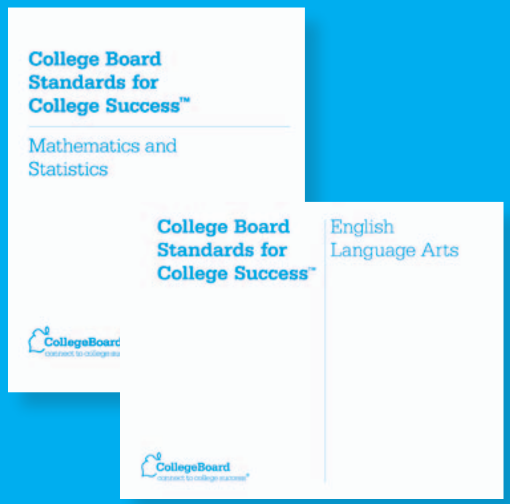

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