Pennsylvania Integrated Standards for Science, Environment and Ecology (Grades 6-12)

Contents

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Introduction

The *Pennsylvania Integrated Standards for Science, Environment and Ecology (Grades 6-12)* use a three-dimensional approach to guide the study of the physical sciences, life sciences and Earth and space sciences at the middle and high school levels. The standards highlight the critical intersections of these disciplines with environmental science, ecology and agriculture, as well as engineering, technology and applications of science. These three-dimensional standards integrate disciplinary core ideas, practices in science and engineering and crosscutting concepts into a coherent set of expectations for student learning that build progressively across the grade bands for middle school (6-8) and high school (9-12).

The new Pennsylvania standards build upon the *National Research Council's* (NRC's) *A Framework for K-12 Science Education* (*The Framework*). Like *The Framework*, the *Pennsylvania Integrated Standards for Science, Environment and Ecology (Grades 6-12)* are based on current research in student learning and take a three-dimensional approach that integrates disciplinary core ideas, practices in science and engineering and crosscutting concepts into a coherent set of expectations for student learning that builds progressively across grades. The expectations laid out in the middle and high school science, environment and ecology standards build upon those in the companion standards for elementary school, the *Pennsylvania Integrated Standards for Science, Environment, Ecology, Technology and Engineering (Grades K-5).* In addition to this set of K-12 standards for science education, separate technology and engineering education standards for middle and high school were also developed: the *Pennsylvania Technology and Engineering Standards (Grades 6-12)*.

Pennsylvania's Vision

Businesses and industries are growing in Pennsylvania, and they want skilled and well-educated workers who are prepared for the 21st century economy. Students need to be equipped with the knowledge and skills to enter the workforce and to be successful in a science- and technology-driven global economy.

To best prepare students for the 21st century economy, Pennsylvania aims to establish an equitable and innovative culture so every student can be included in science, engineering, technology, environment and ecology education. *Pennsylvania's Standards for Integrated Science, Environment and Ecology* were established on the following foundational beliefs:

- Every student is capable of science, engineering, technological and environmental literacy.
- Science, environment, ecology, technology and engineering can be explored through an integrated and active learning process.
- Iteration and reflection are a critical component of the learning process.
- Success depends upon the partnerships between educators, students, families, postsecondary providers and institutions, legislators, businesses and industries.

These draft standards were developed with this vision in mind, with contributions and voices of stakeholders across the commonwealth.

Development of the Standards

The Pennsylvania State Board of Education directed PDE to begin the process of updating Pennsylvania's *Academic Standards for Science and Technology* (2002) and *Academic Standards for Environment and Ecology* (2002) to align them with current research and best practices. From February through March 2020, 14 stakeholder engagement sessions were held across the state and virtually. Of the more than 960 members of the public who provided input at these sessions, most were elementary and secondary educators, school administrators, postsecondary educators, student teachers, business and industry representatives, community not-for-profit organization representatives, parents and students. Their feedback was captured in a report that summarized the current research and best practices regarding science, environment, ecology, technology and engineering standards (see Ferguson et al., 2020).

In April 2020, PDE solicited applications from interested members of the public to serve on committees to review and revise the standards. Applicants were selected through a multi-reviewer process on the basis of their depth and breadth of expertise in curriculum and standards development, understanding of the existing standards and current research, equity and access in education and meeting needs of diverse learners and overall education experience. Each selected committee member was approved by the State Board of Education in May 2020.

In June and July, the committees met to review the stakeholder input as well as research-based frameworks and guidelines—such as the National Research Council's (NRC's) *A Framework for K–12 Science Education: Practices, Crosscutting Concepts*, *and Core Ideas* (2012), North American Association for Environmental Education's (NAAEE) *K–12 Environmental Education: Guidelines for Excellence* (2019), Ecological Society of America's (ESA) *Four-Dimensional Ecology Education (4DEE) framework* (2018), International Technology and Engineering Educators Association's (ITEEA) *Standards for Technological and Engineering Literacy (STEL)* (2020), International Society for Technology in Education's *(ISTE) Standards for Students* (2019), National Council for Agricultural Education (NCAE) *Agriculture, Food and Natural Resources (AFNR) Career Cluster Content Standards* (2015) and other national and international frameworks. Committee members also conducted close reads to share relevant information from Pennsylvania-specific documents, such as *Pennsylvania's Academic Standards for Science and Technology* (2002) and *Academic Standards for Environment and Ecology* (2002) to inform the development of the revised standards. Committee members collaborated to identify key content within those research-informed frameworks and other key national and international standards in science, environment, ecology, technology, engineering and agriculture.[1] They sought to identify cross-content connections while adding sustainability, PA Career Ready Skills and other PA-specific contexts.

Over nine full-day convenings, the committee members discussed the essential elements of academic standards. Attention to equity and access surfaced as foundational in the development of the standards. Equity in the context of the standards can be defined as a foundation of knowledge and skills critical for and accessible to all students, as well as "a characteristic of the instructional environment that increases the capacity for everyone to participate in meaningful learning" (Windschitl, Thompson, & Braaten, 2018, p. 12). This begins with standards that are crafted to allow for the individual and personalized experiences, knowledge and skills that students bring with them to the classroom.

Following recommendations from current research to ensure equitable opportunities exist for all students and research indicating how students learn best, committee members drafted these revised standards based on the committees' commitment to equity and inclusivity to open doors to STEM fields for all students. Therefore, the practices embedded in the standards provide an equitable on-ramp for all students as they transition their developing and experience-based notions of the scientific world to conceptions that are scientifically based.

The *PA Integrated Standards for Science, Environment and Ecology (Grades 6-12)* were developed in parallel with the *PA Integrated Standards for Science, Environment, Ecology, Technology and Engineering (Grades K-5)*. In this document, as well as in the *PA Integrated Standards for Science, Environment, Ecology, Technology and Engineering (Grades K-5)*, the organization and presentation of the standards are similar, thus creating a cohesive K-12 integrated approach to science, environment and ecology education in Pennsylvania.

What Is an Integrated Science, Environment and Ecology Education?

The interconnectedness of the world and its impact on science, environment, ecology, technology and engineering have never been more prominent. Engineering, technology and science are fields critical to innovation, and a commitment through the standards to expose all students to scientific and engineering practices can spark interest in the study of STEM or future STEM careers (National Science Foundation [NSF], 2010). Presenting the standards for science, environment, ecology and agricultural together in a single document provides content support in these areas to middle and high school teachers and makes the standards more accessible when developing innovative STEM curricula that integrate related content.

Understanding the components of ecological systems and their interrelationships with social systems and technologies is vital to the development of STEM-literate citizens. These components incorporate the disciplines of resource management, agricultural diversity, government and the impact of human actions on natural systems. This interaction leads to the study of watersheds, threatened and endangered species and pest management, and to the development of associated laws and regulations. Integrating science, environment and ecology

[1] Content and steering committee members reviewed over 30 research-based frameworks, guidelines and Pennsylvania-specific documents, such as the Pennsylvania Environmental Literacy Plan and the 22 Pa. Code Chapter 4 Academic Standards and Assessment.

in the science standards emphasizes the deep interconnectedness among these areas. This encourages integrated teaching across these disciplines in a way that not only presents these critical concepts in their full context, but also promotes equity by ensuring that environment, ecology, engineering, technology and applications of science are well covered in science courses across grades K-12.

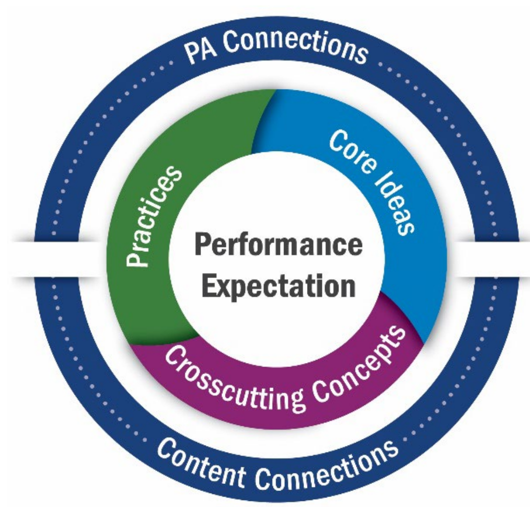
Scientific, Environmental and Technological Literacy in Pennsylvania

Pennsylvania's workforce is continually influenced by the needs of an economy driven by science and technology. To best prepare each of Pennsylvania's 1.7 million students for the future workforce, educators need innovative standards that develop a scientific, environmentally and technologically literate citizenry. "Literacy" requires more than possessing knowledge; literacy requires being able to apply knowledge. A scientifically and environmentally literate person can apply the knowledge, concepts, skills, processes and practices of those fields to real-life situations. This includes engaging in scientific inquiry and applying science concepts and processes to make decisions for oneself, participate in civic and cultural affairs and contribute to society and the economy through one's work (Ashbrook, 2020). Environmental literacy also requires knowledge and understanding of environmental concepts, problems and issues in order to make informed decisions concerning the local and global environment that will improve the well-being of individuals and societies through participation in civic life (NAAEE, 2019). Technologically literate individuals, in addition to being able to use and understand technology, can apply science knowledge and skills to develop solutions to real-world problems and appreciate the distinctions and relationships between engineering, technology and applications of science.

Structure of the Standards

The *Pennsylvania Integrated Standards for Science, Environment and Ecology (6-12)* build upon the National Research Council's (NRC's) *A Framework for K-12 Science Education (The Framework)* and the *Next Generation Science Standards (NGSS)*. The main dimensions of *The Framework* and the *Pennsylvania Integrated Standards for Science, Environment and Ecology (6-12)* are similar; however, there are aspects that are specific to the *Integrated Pennsylvania Standards for Science, Environment and Ecology* (Figure 1).

Figure 1. Structure of the Pennsylvania Standards for Integrated Science, Environment and Ecology



Like *The Framework*, the *Pennsylvania Integrated Standards for Science, Environment and Ecology (6-12)* are built around three dimensions that are integrated into the set of specific standards at each grade level—Disciplinary Core Ideas (DCIs), Science and Engineering Practices and Crosscutting Concepts—described below.

DCIs reflect essential ideas in science that all students should understand by the end of grade 12. DCIs are included for four major disciplines or domains in the natural sciences—physical sciences, life sciences and Earth and space sciences—as well as for engineering, technology and applications of science. Within each of these four domains, there is a set of Disciplinary Core Ideas (Core Ideas) presented by grade band (Table 1).

Table 1. Domains and Core Ideas by Grade Bands

Domains	Core Ideas for Grades 6-8	Core Ideas for Grades 9-12
Physical Sciences	• Structure and Properties of Matter • Chemical Reactions • Forces and Interactions • Energy • Waves and Electromagnetic Radiation	• Structure and Properties of Matter • Chemical Reactions • Forces and Interactions • Energy • Waves and Electromagnetic Radiation
Life Sciences	• Structure and Function, and Information Processing • Matter and Energy in Organisms and Ecosystems • Interdependent Relationships in Ecosystems • Growth, Development and Reproduction of Organisms • Natural Selection and Adaptations	• Structure and Function • Matter and Energy in Organisms and Ecosystems • Interdependent Relationships in Ecosystems • Inheritance and Variation of Traits • Natural Selection and Evolution
Earth and Space Sciences	• Space Systems • History of Earth • Earth's Systems • Weather and Climate • Human Impacts	• Space Systems • History of Earth • Earth's Systems • Weather and Climate • Human Sustainability
Engineering, Technology and Applications of Science[2]	• Define Problems • Develop Solutions • Improve Designs	• Define Problems • Develop Solutions • Improve Designs

[2]The discipline of Engineering, Technology and Applications includes two core ideas: Engineering Design and Links Among Engineering, Technology, Science, and Society. Specific DCIs are included for the area of Engineering Design but not for Links Among Engineering, Technology, Science, and Society. Rather, connections to the latter core idea are identified for DCIs within the science disciplines, where appropriate.

Science and Engineering Practices

The Science and Engineering Practices are behaviors that are critical in investigating, modeling and explaining the world, as well as in developing solutions to societal problems. The eight Science and Engineering practices are:

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

The Crosscutting Concepts bridge disciplinary boundaries and unify the study of science and engineering. In addition to the seven Crosscutting Concepts from *The Framework,* sustainability is added as an eighth Crosscutting Concept in the *PA Standards for Integrated Science, Environment and Ecology (6-12)*. Sustainability refers to meeting the needs of the present without compromising the ability of future generations to meet their needs (Stone & Barlow, 2005, p. xiii). The eight Crosscutting Concepts that appear in the *PA Standards for Integrated Science, Environment and Ecology (6-12)* are:

1. Patterns;
2. Cause and effect;
3. Scale, proportion and quantity;
4. Systems and system models;
5. Energy and matter;
6. Structure and function;
7. Stability and change; and
8. Sustainability.

Each component of a standard is explained in more detail below. For terms related to the standards, see Appendix A.

Anatomy of a PA Standard

As illustrated below (Table 2), the standards for each Core Idea are organized in a table with three main sections: (1) Performance Expectation(s), (2) foundation boxes and (3) connections. Appendix B provides an example of a completed standard.

Table 2. Standard Structure

Grade Level: Domain from Earth and space sciences; environment and ecology; life sciences; physical sciences; or technology and engineering

<table>
<tr><td colspan="4">Core Idea:</td></tr>
<tr><td colspan="4">Performance Expectation (PE): Students who demonstrate understanding can:</td></tr>
<tr><td colspan="4">Dimensions</td></tr>
<tr><td>Science and Engineering Practices</td><td>Disciplinary Core Ideas</td><td colspan="2">Crosscutting Concepts</td></tr>
<tr><td colspan="4">PA Connections: Integration of EE, T&E, PA Career Ready Skills and PA Context</td></tr>
<tr><td colspan="4">Connections to Other Standards</td></tr>
<tr><td>ELA
PA Core Standards: ELA</td><td>Math
PA Core Standards: Math</td><td>Educational Technology (ISTE Standards for Students)</td><td>Agriculture, Food, and Natural Resources (AFNR) Career Cluster Content Standards; NAAEE Guidelines for Excellence</td></tr>
</table>

Performance Expectations**:** Below the Core Idea is a box containing a set of performance expectations. Each Core Idea includes one or more performance expectations written as tasks that students at the specified grade level should be able to complete to demonstrate mastery of the content.

Foundation Boxes: Below the Performance Expectations box are three foundation boxes, which list (from left to right) the specific Science and Engineering Practices, Disciplinary Core Ideas and Crosscutting Concepts used to develop the set of Performance Expectations.

PA Connections: Below the Foundation boxes are links to possible PA connections that allow for integrated science instruction that leverages local and regional context as well as connections to Pennsylvania's *Academic Standards for Science and Technology* (2002), *Academic Standards for Environment and Ecology* (2002) and PA Career Ready Skills. PA connections also allow for integrated science instruction that leverages local and regional context.

Connections to Other Standards: In addition to the PA connections above, connection boxes are provided for the *PA Core Standards for English Language Arts (ELA)* and *PA Core Standards for Mathematics; ISTE Standards for Students; the Agriculture, Food and Natural Resources (AFNR) Career Cluster Content Standards; and the K–12 Environmental Education: Guidelines for Excellence* (2019*)* (NAAEE). These sections are described in further detail below.

How to Use the Standards

Performance Expectations

Performance expectations (PEs) are statements of what students should know and be able to do. Each PE is written to include a practice, core idea and crosscutting concept. Each standard includes both the PE(s) and the contents of the three foundation boxes. In Pennsylvania, all students should be held accountable for demonstrating their achievement of all PEs, which are written to allow for multiple means of assessment. Students should demonstrate proficiency in all of these standards by the end of grade 12. Following the PEs are clarification statements that provide suggested examples or clarification to the PEs. PEs may also contain assessment boundary statements, which set limits or parameters for large-scale assessment. Further, the PEs are not meant to limit the curriculum, nor are they a set of instructional or assessment tasks.

Foundation Boxes

PEs are the result of the integration of the three dimensions that appear in the foundation boxes. As curriculum and instruction are developed, these dimensions must be taught together. The three dimensions of Science and Engineering Practices, Disciplinary Core Ideas and Crosscutting Concepts should be assessed together. While new in the proposed *PA Standards for Integrated Science, Environment and Ecology (6-12),* the (1) inclusion of and (2) assessment with practices can already be seen across the *PA Core Standards for English Language Arts* and *the PA Core Standards for Mathematics*. For example, in all three content areas, students are expected to engage in argumentation from evidence; construct explanations; obtain, synthesize, evaluate and communicate information; and build a knowledge base through content rich texts across the three subject areas.

Connection Boxes

The connection boxes are included to support curriculum and instruction and, where possible, connect to Pennsylvania's other academic standards and PA Career Ready Skills.

PA Connections: PA connections are provided to leverage opportunities in curriculum and instructional design for students to engage in local, regional contexts and phenomena in Pennsylvania. Some connections to the Pennsylvania *Academic Standards for Environment and Ecology* (2002)[3] appear as associated phenomena in the PA Connections boxes. Other PA Connection statements not derived from the 2002 standards are also included where there are

[3] Connections to the *Pennsylvania Academic Standards for Environment and Ecology* (2002) are only included if they are not explicitly covered by the new standards developed based on *The Framework*.

opportunities to relate standards to regional and local phenomena. Each standard also includes PA Connections to Career Ready Skills. Educators can use this table in conjunction with the PA Career Ready Skills Continuum to identify ways to integrate teaching science, environment and ecology and technology and engineering with related employability skills at any grade level. For the development of the PA connections related to PA Career Ready Skills, see Appendix C.

Connections to Other Standards: Connection boxes are also included to create a more coherent version of the standards by illustrating how each PE connects to state or national documents, including the *PA Core Standards for English Language Arts and the PA Core Standards for Mathematics*, *ISTE Standards for Students*, NAAEE *Guidelines for Excellence*, and NCAE *AFNR Career Cluster Content Standards*. These can be especially useful in curriculum and instructional design for identifying natural fits for technology, agriculture and environmental education. The cross-walked standards can be explicitly taught in the context of attaining the related PE. The cross-walked standards are not a complete list of all potential crosswalks. Depending on how standards are used in local curriculum development, additional crosswalks may be identified.

Resources for Integration

The *Pennsylvania Integrated Standards for Science, Environment and Ecology (6-12)* are designed to be used in developing integrated classroom learning experiences and formative and summative assessments. Pennsylvania is fortunate to be rich with environmental learning and nature centers, STEM ecosystems and public libraries and community-based organizations that provide out-of-school time for STEM and environmental education. Environment and ecology and STEM providers across the state are valuable resources for providing age-appropriate lessons, opportunities, expertise and outdoor real-life experiences for Pennsylvania students so that classroom educators can more easily integrate the standards.

Standards for Grades 6-8[4] [5]

Physical Science

Structure and Properties of Matter

1. Develop models to describe the atomic composition of simple molecules and extended structures
2. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
3. Develop a model that predicts and describes changes in particle motion, temperature and state of a pure substance when thermal energy is added or removed.

Chemical Reactions

1. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.
2. Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.
3. Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.*

Forces and Interactions

1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.*
2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

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[4] The asterisk (*) indicates that the Performance Expectation is integrating Engineering Design.

[5] The language of the standards is adapted from, informed by or taken from the: National Research Council (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*; International Society for Technology in Education Standards. (2019) *ISTE standards for students;* International Technology and Engineering Educators Association (ITEEA) (2020) *Standards for Technological and Engineering Literacy* (STEL); NGSS Lead States (2013) *Next generation science standards: For states, by states;* National Council for Agricultural Education (2015) *Agriculture, food and natural resources (AFNR) career cluster content standards;* Pennsylvania State Board of Education (2002) *Academic standards for science and technology;* Pennsylvania Department of Education (2002) *Safety guidelines for elementary and technology education teachers;* Pennsylvania Department of Education (n.d.) *Pennsylvania career ready skills continuum; Pennsylvania Association for Environmental Educators. (September 2015) Pennsylvania environmental literacy plan; Pennsylvania State Board of Education (2002). Academic standards for environment and ecology. North American Association for Environmental Education (2014) State environmental literacy plans: 2014 status report.* North American Association for Environmental Education (2019) *K–12 environmental education: Guidelines for excellence* and other research informed frameworks, guidelines and documents.

4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

Energy

1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass and to the speed of an object.
1. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.
2. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*
3. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.
4. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Waves and Electromagnetic Radiation

1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.
2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
3. Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.

Life Science

Structure, Function, and Information Processing

1. Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.
2. Develop and use a model to describe the function of a cell as a whole and the ways the parts of cells contribute to the function.
3. Use arguments supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
4. Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.

Matter and Energy in Organisms and Ecosystems

1. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.
2. Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.
3. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
4. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
5. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Interdependent Relationships in Ecosystems

1. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.
2. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*

Growth, Development, and Reproduction of Organisms

1. Use arguments based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants, respectively.
2. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.
3. Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.
4. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.
5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.

Natural Selection and Adaptations

1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.

2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.
3. Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.
4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.
5. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.

Earth and Space Science

Space Systems

1. Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.
2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.
3. Analyze and interpret data to determine scale properties of objects in the solar system.

History of Earth

1. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.
2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.
3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.

Earth's Systems

1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.
2. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
3. Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.

Weather and Climate

1. Collect data to provide evidence for how the motion and complex interactions of air masses result in changes in weather conditions.

2. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.
3. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

Human Impacts

1. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.
2. Apply scientific principles to design a method for monitoring and minimizing human impact on the environment.*
3. Construct an argument supported by evidence for how increases in human population and per capita consumption of natural resources impact Earth's systems.

Engineering, Technology, and Applications of Science

Engineering Design (Define Problems, Develop Solutions and Improve Designs)

1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Standards for Grades 9-12[6] [7]

Physical Science

Structure and Properties of Matter

1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
2. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
3. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
4. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*

Chemical Reactions

1. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
2. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
3. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
4. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*
5. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

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[6] The asterisk (*) indicates that the Performance Expectation is integrating Engineering Design.

[7] The language of the standards is adapted from, informed by or taken from the: National Research Council (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*; International Society for Technology in Education Standards. (2019) *ISTE standards for students;* International Technology and Engineering Educators Association (ITEEA) (2020) *Standards for Technological and Engineering Literacy* (STEL); NGSS Lead States (2013) *Next generation science standards: For states, by states;* National Council for Agricultural Education (2015) *Agriculture, food and natural resources (AFNR) career cluster content standards;* Pennsylvania State Board of Education (2002) *Academic standards for science and technology;* Pennsylvania Department of Education (2002) *Safety guidelines for elementary and technology education teachers;* Pennsylvania Department of Education (n.d.) *Pennsylvania career ready skills continuum; Pennsylvania Association for Environmental Educators. (September 2015) Pennsylvania environmental literacy plan; Pennsylvania State Board of Education (2002). Academic standards for environment and ecology. North American Association for Environmental Education (2014) State environmental literacy plans: 2014 status report.* North American Association for Environmental Education (2019) *K–12 environmental education: Guidelines for excellence* and other research informed frameworks, guidelines and documents.

Forces and Interactions

1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
3. Apply scientific and engineering ideas to design, evaluate and refine a device that minimizes the force on a macroscopic object during a collision.*
4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

Energy

1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
3. Design, build and refine a device that works within given constraints to convert one form of energy into another form of energy.*
4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Waves and Electromagnetic Radiation

1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
2. Evaluate questions about the advantages of using digital transmission and storage of information.
3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other.

4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*

Life Science

Structure and Function

1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.
2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

Matter and Energy in Organisms and Ecosystems

1. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.
2. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.
3. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.
4. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
5. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.
6. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

Interdependent Relationships in Ecosystems

1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.
2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

3. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
4. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*
5. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.
6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*

Inheritance and Variation of Traits

1. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.
2. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
3. Make and defend a claim based on evidence that inheritable genetic variations may result from (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.
4. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Natural Selection and Evolution

1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.
5. Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Earth and Space Science

Space Systems

1. Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.
2. Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.
3. Communicate scientific ideas about the way stars, over their life cycle, produce elements.
4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

History of Earth

1. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
2. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.
3. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

Earth's Systems

1. Analyze geoscience data to make the claim that one change to Earth's surface can create feedback that causes changes to other Earth systems.
2. Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.
3. Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
4. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
5. Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.

Weather and Climate

1. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
2. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Human Sustainability

1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*
3. Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
5. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

Engineering, Technology, and Applications of Science

Engineering Design (Define Problems, Develop Solutions and Improve Designs)

1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

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Appendix A. Glossary

A Framework for K-12 Science Education (*The Framework*): The seminal report, created by the National Research Council (NRC), which defines a new way of teaching science, three dimensionally, based on current scientific and educational research.

Assessment Boundary: Specify limits to large-scale assessment; they are not meant to put limits on what can be taught or how it is taught, but to provide guidance to assessment developers.

Clarification Statement: Supply examples or additional clarification and emphasis to the language of the performance expectations.

Coherence: Refers to conceptual building of knowledge and skills over the course of lessons, units or years of instruction. This is in contrast to asking students to learn discrete pieces of content.

Connections boxes: Found as part of the architecture of a standards page, these highlight some of the links between the listed standard, the previous *Academic Standards for Science and Technology* (2002), *Academic Standards for Environment and Ecology* (2002), *PA Core Standards for English Language Arts* (ELA) and *PA Core Standards for Mathematics* and the International Society for Technology (ISTE) *Standards for Students*, as well as the Agriculture, Food and Natural Resources (AFNR) *Career Cluster Content Standards* (9-12), ITEEA *Standards for Technological and Engineering Literacy* (STEL) and NAAEE *K-12 Environmental Education: Guidelines for Excellence.*

Crosscutting Concepts (CCCs): Previously identified as themes, these are concepts that permeate across the natural and engineered world. They help students make connections between prior experiences and new learning. They help students figure out novel phenomena or design solutions to problems.

Curriculum: As defined for the purpose of this standards document, the curriculum is the blueprint designed to grow students toward achieving a standard over a grade level/ band over the course of a semester/ year. It is written by local/district personnel. Curriculum includes learning progressions, lesson plans, assessment for learning and teacher guides.

Disciplinary Core Ideas (DCIs): The fundamental ideas that are necessary for understanding a given science discipline. The core ideas all have broad importance within or across science or engineering disciplines, provide a key tool for understanding or investigating complex ideas and solving problems, relate to societal or personal concerns and can be taught over multiple grade levels at progressive levels of depth and complexity.

Foundation box: Each standard is three-dimensional, integrating elements from a Science and Engineering Practice (SEP), Disciplinary Core Idea (DCI) and Crosscutting Concept (CCC). These elements, which create the foundation for each standard, are listed in foundation boxes underneath the standard in the architecture of the standards.

Habits of mind: Identified as "dispositions" in the Science and Technology and Environment and Ecology Standards: A National Landscape Scan and Pennsylvania Stakeholder Feedback report, these traits are what students should tend to when engaging in science and engineering practices alone and with others. Stakeholder feedback emphasized that students should develop habits of mind regarding science, environment and ecology and technology and engineering. Therefore, the committee created a list of habits of mind that students need in the classroom and in the workforce. Appendix C presents a crosswalk of the committee's habits of mind with Pennsylvania's Career Ready Skills to show the relationships with and overlap of each.

Instruction: A teacher's daily plan to implement the curriculum. This may include a lesson plan, formative or summative assessment and differentiation based on the learner's needs.

PA Career Ready Skills: The PA Career Ready Skills are social-emotional learning progressions that support the development of a student's career preparedness. By design, the PA Career Ready Skills reflect priorities to ensure youth are career ready and prepared to meet the demands of the 21st century workforce. The PA Career Ready Skills are grouped into three domains: self-awareness and self-management, establishing and maintaining relationships and social problem-solving skills.

Pennsylvania (PA) connections: Provide opportunities for students to connect standards to local or regional phenomena to increase student engagement. PA connections provide PA-related examples that teachers can use to implement a curriculum designed to master said standard.

Performance Expectations (PEs): Statements of what students should know and be able to do with what they know.

Phenomena: Observable events.

Science and Technology and Environment and Ecology Standards: A National Landscape Scan and Pennsylvania Stakeholder Feedback (Pennsylvania Landscape Report): Commissioned by the Pennsylvania State Board of Education, this report captures the current research and best practices regarding science standards as well as the feedback from 14 stakeholder engagement sessions held across the commonwealth.

Science and Engineering Practices (SEPs): Critical practices that scientists and engineers use to investigate phenomena and solve problems through questioning.

Standards: End-of-instruction goals or benchmarks for student proficiency.

Sustainability: A community's ability to "satisfy its needs and aspirations without diminishing the chances of future generations" (Stone & Barlow, 2005, p. xiii).

Three dimensions: The three dimensions are the Science and Engineering Practices ("the Practices" or SEPs), Disciplinary Core Ideas (DCIs) and Crosscutting Concepts (CCCs).

Three-dimensional learning: Developing and using elements of the three dimensions purposefully (i.e., to explain phenomena or design solutions to problems). Lessons and units aligned to the standards should be three-dimensional; that is, they should allow students to actively engage with the practices and apply the crosscutting concepts to deepen their understanding of core ideas across science disciplines while tending to appropriate dispositions.

Appendix B. Example of a Standard

<table>
<tr><td colspan="3">Core Idea: MS. Chemical Reactions</td></tr>
<tr><td colspan="3">Performance Expectations: MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide and mixing zinc with hydrogen chloride.] [Assessment boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability and odor.]</td></tr>
<tr><th>Practices</th><th>DCIs</th><th>CCCs</th></tr>
<tr><td>Analyzing and Interpreting Data
Analyzing data in 6-8 builds on K-5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.
• Analyze and interpret data to determine similarities and differences in findings.
___
Connections to Nature of Science
Scientific Knowledge is Based on Empirical Evidence
• Science knowledge is based upon logical and conceptual connections between evidence and explanations.</td><td>PS1.A: Structure and Properties of Matter
• Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
PS1.B: Chemical Reactions
• Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.</td><td>Patterns
• Macroscopic patterns are related to the nature of microscopic and atomic-level structure.</td></tr>
<tr><td colspan="3">PA PA Connections: PA Career Ready Skills and PA Context</td></tr>
<tr><td colspan="3">Connections to Other Standards: 3.4.A, 3.1.B, 3.2.B, 3.1.C, 3.1.E, 3.2.B</td></tr>
<tr><td>ELA
RST.6-8.1
RST.6-8.7</td><td>Math
MP.2
6.RP.A.3
6.SP.B.4
6.SP.B.5</td><td>ISTE/Ed Tech
5. Computational Thinker</td></tr>
</table>

Appendix C. Intersection of Pennsylvania's Career Ready Skills, Dispositions and Habits of mind

Stakeholder engagement sessions captured stakeholder feedback regarding the dispositions that all students should learn and be able to do as a part of a comprehensive K-12 science program. Using the student dispositions recommended by stakeholders, the Pennsylvania Career Ready Skills Continuum and research on habits of mind and the inclusion of dispositions in exemplar academic standards, committee members proposed lists of habits of mind relevant to the academic disciplines and the needs of Pennsylvania learners. Appendix C presents a crosswalk of the committee's habits of mind with the Pennsylvania Career Ready Skills to show the relationships and overlap of each. Educators can use this table in conjunction with the PA Career Ready Skills Continuum to identify ways to integrate teaching science, environment and ecology and technology and engineering with related employability skills at any grade level.

Habits of mind/Dispositions Aligned to Pennsylvania Career Ready Skills			
The three domains of Pennsylvania Career Ready Skills and related employability skills			
A. Self-Awareness and Self-Management (Recognize and regulate emotions) *Related employability skills:* Respect, Dependability and Reliability, Communication, Professionalism, Teamwork, Integrity, Business Fundamentals, Adaptability, Initiative, Planning and Organizing B. Establishing and Maintaining Relationships (Communicate and collaborate amongst diversity) *Related employability skills:* Problem-Solving, Decision Making, Critical Thinking, Integrity, Teamwork, Adaptability, Professionalism, Communication, Respect C. Social Problem-Solving Skills (Demonstrate empathy and respectful choice) *Related employability skills:* Teamwork, Integrity, Communication, Respect, Customer Focus, Critical Thinking, Professionalism, Reading, Writing, Problem-Solving			
PA Career Ready Skills domains that align to each of the dispositions/habits of mind			
Dispositions/ Habits of mind	**Domain A:** Self-Awareness and Self-Management	**Domain B:** Establishing and Maintaining Relationships	**Domain C:** Social Problem-Solving Skills
Science core ideas and practices			
Resilience or grit			
Intellectual curiosity			
Empathy			⊙
Integrity	⊙	⊙	⊙
Self-efficacy			
Adaptability	⊙	⊙	

Habits of mind/Dispositions Aligned to Pennsylvania Career Ready Skills			
Initiative	○		
Open-minded			
Drive			
Ownership			
Advocate			
Ethical			
Self-awareness/self-management	○		
Establishing and maintaining relationships		○	
Social problem-solving		○	○
Environment and ecology core ideas and practices			
Patience			
Teamwork	○	○	○
Trial and error			
Individual resiliency			
Critical thinking		○	○
Collaboration		○	
Recognizing rights and responsibilities			
Recognizing efficacy and developing agency	○		
Accepting personal responsibility			
Working with flexibility, creativity and openness		○	
Self-awareness/Self-management	○	○	
Establishing and maintaining relationships		○	
Social problem-solving			○

Habits of mind/Dispositions Aligned to Pennsylvania Career Ready Skills			
Technology and engineering practices			
Creativity			
Persistence (goal directed) and perseverance			
Empathy		○	○
Collaboration		○	
Communication	○	○	○
Attention to ethics			
Systems thinking			
Critical thinking		○	○
Self-awareness/Self-management	○	○	
Establishing and maintaining relationships		○	
Social problem-solving			○

The Pennsylvania Career Ready Skills Continuum is available from PDE at: https://www.education.pa.gov/K-12/CareerReadyPA/CareerReadySkills/Toolkit/Pages/Continuum.aspx