National Science Framework for Grades 9-12

Eight practices to be essential elements of the K-12 science and engineering curriculum:

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, information and computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

SEVEN CROSSCUTTING CONCEPTS OF THE FRAMEWORK

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

Compiled by Dave Shellhaas from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* ISBN 978-0-309-21742-2

PHYSICAL SCIENCE

Core and Component Ideas in the Physical Sciences

Core Idea PS1: Matter and Its Interactions

- PS1.A: Structure and Properties of Matter
- PS1.B: Chemical Reactions
- PS1.C: Nuclear Processes

Core Idea PS2: Motion and Stability: Forces and Interactions

- PS2.A: Forces and Motion
- PS2.B: Types of Interactions
- PS2.C: Stability and Instability in Physical Systems

Core Idea PS3: Energy

- PS3.A: Definitions of Energy
- PS3.B: Conservation of Energy and Energy Transfer
- PS3.C: Relationship Between Energy and Forces
- PS3.D: Energy in Chemical Processes and Everyday Life

Core Idea PS4: Waves and Their Applications in Technologies for Information Transfer

- PS4.A: Wave Properties
- PS4.B: Electromagnetic Radiation
- PS4.C: Information Technologies and Instrumentation.

CORE IDEA PS1: MATTER AND ITS INTERACTIONS

How can one explain the structure, properties, and interactions of matter?

PS1.A: Structure and Properties of Matter

How do particles combine to form the variety of substances one observes?

- ***By the end of grade 12.*** Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. Stable forms of matter are those in which the electric and magnetic field energy is minimized. A stable molecule has less energy, by an amount known as the binding energy, than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.

PS1.B: Chemical Reactions
How do substances combine or change (react) to make new substances? How does one characterize and explain these reactions and make predictions about them?

- ***By the end of grade 12.*** Chemical processes, their rates, and whether or not energy is absorbed or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in total binding energy (i.e., the sum of all bond energies in the set of molecules) that are matched by changes in kinetic energy. In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. Chemical processes and properties of materials underlie many important biological and geophysical phenomena.

PS1.C: Nuclear Processes
What forces hold nuclei together and mediate nuclear processes?

- ***By the end of grade 12.*** Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve changes in nuclear binding energies. The total number of neutrons plus protons does not change in any nuclear process. Strong and weak nuclear interactions determine nuclear stability and processes. Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials from the isotope ratios present. Normal stars burn out after having converted all of the material in their cores to iron. Elements more massive than iron are formed by fusion processes only in the extreme conditions of supernova explosions, which explains why they are relatively rare.

CORE IDEA PS2: MOTION AND STABILITY: FORCES AND INTERACTIONS
How can one explain and predict interactions between objects and within systems?

PS2.A: Forces and Motion
How can one predict an object's continued motion, changes in motion, or stability?

- ***By the end of grade 12.*** Newton's second law accurately predicts changes in the motion of macroscopic objects, but it requires revision for subatomic scales or for speeds close to the speed of light. Momentum is a property of objects, defined for a particular frame of reference, that depends on their mass and speed. (Boundary: No details of quantum physics or relativity are included at this grade level. There is just the observation that, at the relevant scales, multiple phenomena necessitate revisions to Newton's laws and that these two theories developed to provide more adequate explanations.) In any system, total momentum is always conserved. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in momentum of objects outside the system.

PS2.B: Types of Interactions
What underlying forces explain the variety of interactions observed?

- ***By the end of grade 12.*** Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are mediated by fields that can transfer energy through space. Magnets or changing electric fields cause magnetic fields; electric charges or changing magnetic fields cause electric fields. Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. The strong and weak nuclear interactions are important inside atomic nuclei—for example, they determine the patterns of which nuclear isotopes are stable and what kind of decays occur for unstable ones.

PS2.C: Stability and Instability in Physical Systems
Why are some physical systems more stable than others?

- ***By the end of grade 12.*** Systems often change in predictable ways; understanding the forces that drive the transformations and cycles within a system, as well as the forces imposed on the system from the outside, help to predict its behavior under a variety of conditions. When a system has a great number of component pieces, one may not be able to predict much about its precise future. For such systems (e.g., with very many colliding molecules), one can often predict average but not detailed properties and behaviors (e.g., average temperature, motion, and rates of chemical change but not the trajectories or other changes of particular molecules). Systems may evolve in unpredictable ways when the outcome depends sensitively on the starting condition and the starting condition cannot be specified precisely enough to distinguish between different possible outcomes.

CORE IDEA PS3: ENERGY
How is energy transferred and conserved?

PS3.A: Definitions of Energy
What is energy?

- ***By the end of grade 12.*** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's *total* energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, electrical and magnetic fields, and heat. Terms for energy as viewed at this scale are seldom well defined; for example, "mechanical energy" generally refers to some combination of motion and stored energy in an operating machine. "Chemical energy" generally is used to mean the energy that can be released or stored in chemical processes, and "electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. Historically, different units and names were used for the energy present in these different phenomena, and it took some time before the relationships between them were recognized. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. Electromagnetic radiation (such as light and X-rays) can be modeled as a wave or as particles.

PS3.B: Conservation of Energy and Energy Transfer
What is meant by conservation of energy?
How is energy transferred between objects or systems?

- ***By the end of grade 12.*** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on relative particle positions and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system. Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). Any object or system that can degrade with no added energy is unstable. Eventually it will do so, but if the energy releases throughout the transition are small, the process duration can be very long (e.g., long-lived radioactive isotopes).

PS3.C Relationship Between Energy and Forces
How are forces related to energy?

- ***By the end of grade 12.*** Force fields (gravitational, electric, and magnetic) contain energy and can transmit energy across space from one object to another. When two objects interacting through a force field change relative position, the energy stored in the force field is changed. Each force between the two interacting objects acts in the direction such that motion in that direction would reduce the energy in the force field between the objects. However, prior motion and other forces also affect the actual direction of motion.

PS3.D: **Energy in Chemical Processes and Everyday Life**
How do food and fuel provide energy?
If energy is conserved, why do people say it is produced or used?

- ***By the end of grade 12.*** Nuclear fusion processes in the center of the sun release the energy that Earth receives through radiation. The main way in which that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. A variety of multistage physical and chemical processes in living organisms, particularly within their cells, account for the transport and transfer (release or uptake) of energy needed for life functions. All forms of electricity generation and transportation fuels have associated economic, social, and environmental costs and benefits, both short and long term. Although energy cannot be destroyed, it can be converted to less useful forms—for example, to heat in the surrounding environment. Machines are judged as efficient or inefficient based on the amount of energy input needed to perform a particular useful task. Inefficient machines are those that produce more waste heat while performing the task and thus require more energy input. It is therefore important to design for high efficiency so as to reduce costs, waste materials, and many environmental impacts.

CORE IDEA PS4: WAVES AND THEIR APPLICATIONS IN TECHNOLOGIES FOR INFORMATION TRANSFER

How are waves used to transfer energy and information?

PS4.A: Wave Properties
What are the characteristic properties and behaviors of waves?

- ***By the end of grade 12.*** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. The reflection, refraction, and transmission of waves at an interface between two media can be modeled on the basis of these properties. Combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. Resonance is a phenomenon in which waves add up in phase in a structure, growing in amplitude due to some energy input. Structures have particular frequencies at which they resonate. This phenomenon (e.g., waves in a stretched string, vibrating air in a pipe) is used in speech and in the design of all musical instruments.

PS4.B: Electromagnetic Radiation
What is light?
How can one explain the varied effects that involve light?
What other forms of electromagnetic radiation are there?

- ***By the end of grade 12.*** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. Quantum theory relates the two models. (Boundary: Quantum theory is not explained further at this grade level.) Because a wave is not much disturbed by objects that are small compared with its wavelength, visible light cannot be used to see such objects as individual atoms. All electromagnetic radiation travels through a vacuum at the same speed, called the speed of light. Its speed in any other given medium depends on its wavelength and the properties of that medium. When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. Photovoltaic materials emit electrons when they absorb light of a high-enough frequency.

PS4.C: Information Technologies and Instrumentation
How are instruments that transmit and detect waves used to extend human senses?

- ***By the end of grade 12.*** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experience in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and to storing and interpreting the information contained in them. Knowledge of quantum physics enabled the development of semiconductors, computer chips, and lasers, all of which are now essential components of modern imaging, communication, and information technologies. (Boundary: Details of quantum physics are not formally taught at this grade level.)

LIFE SCIENCE

Core and Component Ideas in Life Sciences

Core Idea LS1: From Molecules to Organisms: Structures and Processes

- LS1.A: Structure and Function
- LS1.B: Growth and Development of Organisms
- LS1.C: Organization for Matter and Energy Flow in Organisms
- LS1.D: Information Processing

Core Idea LS2: Ecosystems: Interactions, Energy, and Dynamics

- LS2.A: Interdependent Relationships in Ecosystems
- LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
- LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- LS2.D: Social Interactions and Group Behavior

Core Idea LS3: Heredity: Inheritance and Variation of Traits

- LS3.A: Inheritance of Traits
- LS3.B: Variation of Traits

Core Idea LS4: Biological Evolution: Unity and Diversity

- LS4.A: Evidence of Common Ancestry and Diversity
- LS4.B: Natural Selection
- LS4.C: Adaptation
- LS4.D: Biodiversity and Humans

CORE IDEA LS1: FROM MOLECULES TO ORGANISMS: STRUCTURES AND PROCESSES

How do organisms live, grow, respond to their environment, and reproduce?

LS1.A: Structure and Function

How do the structures of organisms enable life's functions?

- ***By the end of grade 12.*** Systems of specialized cells within organisms help them perform the essential functions of life, which involve chemical reactions that take place between different types of molecules, such as water, carbohydrates, lipids, and nucleic acids. All cells contain genetic information in the form of DNA, which is where genes are located. Genes contain the instructions that code for the configuration of molecules called proteins, which carry out the work of cells. Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Outside that range (e.g., at a too high or too low external temperature, with too little food or water available), the organism cannot survive. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system.

LS1.B: Growth and Development of Organisms
How do organisms grow and develop?

- ***By the end of grade 12.*** In multicellular organisms, growth occurs via a process called mitosis: a fertilized cell divides successively into many cells, with each parent cell passing identical genetic material to two daughter cells. As successive subdivisions of an embryo's cells occur, programmed genetic instructions and small differences in their immediate environments activate or inactivate different genes, which cause the cells to develop differently—a process called differentiation. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the entire body. In sexual reproduction, a specialized type of cell division called meiosis occurs and results in the production of sex cells, such as gametes (sperm and eggs) or spores, which contain only one member from each chromosome pair in the parent cell.

LS1.C: Organization for Matter and Energy Flow in Organisms
How do organisms obtain and use the matter and energy they need to live and grow?

- ***By the end of grade 12.*** The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. Thes ugar molecules thus formed contain carbon, hydrogen, and oxygen, and some trace minerals that are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. For example, aerobic (in the presence of oxygen) cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Anaerobic (without oxygen) cellular respiration follows a different and less efficient chemical pathway to provide energy in cells. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy loss to the surrounding environment. Matter and energy are conserved in each change. This is true of all biological systems, from individual cells to ecosystems.

LS1.D: Information Processing

How do organisms detect, process, and use information about the environment?

- ***By the end of grade 12.*** In complex animals, the brain is divided into several distinct regions and circuits, each of which primarily serves dedicated functions, such as visual perception, auditory perception, interpretation of perceptual information, guidance of motor movement, and decision making about actions to take in the event of certain inputs. In addition, some circuits give rise to emotions and memories that motivate organisms to seek rewards, avoid punishments, develop fears, or form attachments to members of their own species and, in some cases, to individuals of other species (e.g., mixed herds of mammals, mixed flocks of birds). The integrated functioning of all parts of the brain is important for successful interpretation of inputs and generation of behaviors in response to them.

CORE IDEA LS2: ECOSYSTEMS: INTERACTIONS, ENERGY, AND DYNAMICS

How and why do organisms interact with their environment,
and what are the effects of these interactions?

LS2.A: Interdependent Relationships in Ecosystems

How do organisms interact with the living and nonliving environment to obtain matter and energy?

- ***By the end of grade 12.*** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

How do matter and energy move through an ecosystem?

- ***By the end of grade 12.*** Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved; some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. Competition among species is ultimately competition for the matter and energy needed for life. Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

LS2.C: Ecosystem Dynamics, Functioning, and Resilience
What happens to ecosystems when the environment changes?

- ***By the end of grade 12.*** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more-or-less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction_of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

LS2.D: Social Interactions and Group Behavior
How do organisms interact in groups so as to benefit individuals?

- ***By the end of grade 12.*** Animals, including humans, having a strong drive for social affiliation with members of their own species and will suffer, behaviorally as well as physiologically, if reared in isolation, even if all their physical needs are met. Some forms of affiliation arise from the bonds between offspring and parents. Other groups form among peers. Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives.

CORE IDEA LS3: HEREDITY: INHERITANCE AND VARIATION OF TRAITS

How are characteristics of one generation passed to the next?
How can individuals of the same species and even siblings have different characteristics?

LS3.A: Inheritance of Traits

How are the characteristics of one generation related to the previous generation?

- ***By the end of grade 12.*** In all organisms the genetic instructions for forming species characteristics are carried in the chromosomes. Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function [7].

LS3.B: Variation of Traits

Why do individuals of the same species vary in how they look, function, and behave?

- ***By the end of grade 12.*** The information passed from parents to offspring is coded in the DNA molecules that form the chromosomes. In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.

IDEA LS4: BIOLOGICAL EVOLUTION: UNITY AND DIVERSITY

How can there be so many similarities among organisms yet so many different kinds of plants, animals, and microorganisms?
How does biodiversity affect humans?

LS4.A: Evidence of Common Ancestry and Diversity

What evidence shows that different species are related?

- ***By the end of grade 12.*** Genetic information, like the fossil record, also providesevidence of evolution. DNA sequences vary among species, but there are many overlaps and common features; the ongoing branching that produces multiple lines of descent can be inferred from the DNA composition of organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.

LS4.B: Natural Selection
How does genetic variation among organisms affect survival and reproduction?

- ***By the end of grade 12.*** Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits which positively affect survival are more likely to be reproduced and thus are more common in the population.

LS4.C: Adaptation
How does the environment influence populations of organisms over multiple generations?

- ***By the end of grade 12.*** Natural selection is the result of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's_limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. Natural selection leads to adaptation, that is to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change. Changes in the physical environment, whether naturally occurring or human-induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline—and sometimes the extinction—of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or too drastic, the opportunity for the species' evolution is lost.

LS4.D: Biodiversity and Humans
What is biodiversity, how do humans affect it, and how does it affect humans?

- ***By the end of grade 12.*** Biodiversity results from the formation of new species (speciation) minus the loss of species (extinction). Biological extinction, being irreversible, is a critical factor in reducing the planet's natural capital. Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. These problems have the potential to cause a major wave of biological extinctions—as many species or populations of a given species, unable to survive in changed environments, die out—and the effects may be harmful to humans and other living things. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. And sustaining biodiversity so that landscapes of recreational or inspirational value are preserved is essential to supporting and enhancing human life.

EARTH SCIENCE

Core and Component Ideas in Earth and Space Sciences

Core Idea ESS1: Earth's Place in the Universe

- ESS1.A: The Universe and Its Stars
- ESS1.B: Earth and the Solar System
- ESS1.C: The History of Planet Earth

Core Idea ESS2: Earth's Systems

- ESS2.A: Earth Materials and Systems
- ESS2.B: Plate Tectonics and Large-Scale System Interactions
- ESS2.C: The Roles of Water in Earth's Surface Processes
- ESS2.D: Weather and Climate
- ESS2.E: Biogeology

Core Idea ESS3: Earth and Human Activity

- ESS3.A: Natural Resources
- ESS3.B: Natural Hazards
- ESS3.C: Human Impacts on Earth Systems
- ESS3.D: Global Climate Change

CORE IDEA ESS1: EARTH'S PLACE IN THE UNIVERSE

What is the universe, and what is Earth's place in it?

ESS1.A: The Universe and Its Stars

What is the universe, and what goes on in stars?

- ***By the end of grade 12.*** The star called the sun is changing and will burn out over a life span of approximately 10 billion years. The sun is just one of a myriad of stars in the Milky Way galaxy, and the Milky Way is just one of hundreds of billions of galaxies in the universe. The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.

ESS1.B: Earth and the Solar System

What are the predictable patterns caused by Earth's movement in the solar system?

- ***By the end of grade 12.*** Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other bodies. Gradual changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes.

ESS1.C: The History of Planet Earth

How do people reconstruct and date events in Earth's planetary history?

- ***By the end of grade 12.*** Radioactive-decay lifetimes and isotopic content in rocks provide a way of dating rock formations and thereby fixing the scale of geological time. The continents' rocks (some as old as 4 billion years or more) are much older than rocks on the ocean floor (less than 200 million years), where tectonic processes continually generate new rocks and remove old ones. Although active geological processes, such as plate tectonics (link to ESS2.B) and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.

CORE IDEA ESS2: EARTH'S SYSTEMS

How and why is the earth constantly changing?

ESS2.A: Earth Materials and Systems

How do the major earth systems interact?

- ***By the end of grade 12.*** Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts. Evidence from deep probes and seismic waves, reconstructions of historical changes in the earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid but plastic mantle, and a solid surface crust. The top part of the mantle, along with the crust, forms structures known as tectonic plates (link to ESS2.B). Motions of the mantle and its plates are driven by convection (i.e., the flow of matter due to the energy transfer from the interior outward and the gravitational movement of denser materials toward the interior). The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic dust clouds) to intermediate (ice ages) to very-long-term tectonic cycles.

ESS2.B: Plate Tectonics and Large-Scale System Interactions
Why do the continents move, and what causes earthquakes and volcanoes?

- ***By the end of grade 12.*** The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle. This energy moves through and out of the planet's interior, primarily by mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.

ESS2.C: The Roles of Water in Earth's Surface Processes
How do the properties and movements of water shape Earth's surface and affect its systems?

- ***By the end of grade 12.*** The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; and lower the viscosities and melting points of rocks.

ESS2.D: Weather and Climate
What regulates weather and climate?

- ***By the end of grade 12.*** Global climate is a dynamic balance on many different time scales among energy from the sun falling on Earth; the energy's reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems; and the energy's reradiation into space. Climate change can occur if any part of Earth's systems is altered. Geological evidence indicates that past climate changes were either sudden changes caused by alterations in the atmosphere; longer term changes (e.g., ice ages) due to variations in solar output, Earth's orbit, or the tilt of its axis; or even more gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen. The time scales of these changes varied from a few to millions of years. Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate (link to ESS3.D). Global climate models incorporate scientists' best knowledge of physical and chemical processes and of the interactions of relevant systems. They are tested by their ability to fit past climate variations. Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and the biosphere. Hence the outcomes depend on human behaviors (link to ESS3.D) as well as on natural factors that involve complex feedbacks among Earth's systems (link to ESS2.A).

ESS2.E: Biogeology
How do living organisms alter Earth's processes and structures?

- ***By the end of grade 12.*** The many dynamic and delicate feedbacks between the biosphere and other earth systems cause a continual co-evolution of Earth's surface and the life that exists on it.

CORE IDEA ESS3: EARTH AND HUMAN ACTIVITY

How do Earth's surface processes and human activities affect each other?

ESS3.A: Natural Resources
How do humans depend on Earth's resources?

- ***By the end of grade 12.*** Resource availability has guided the development of human society. All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks, as well as benefits. New technology and regulation can change the balance of these factors.

ESS3.B: Natural Hazards
How do natural hazards affect individuals and societies?

- ***By the end of grade 12.*** Natural hazards and other geological events have shaped the course of human history by destroying buildings and cities, eroding land, changing the course of rivers, and reducing the amount of arable land. These events have significantly altered the sizes of human populations and have driven human migrations. Natural hazards can be local, regional, or global in origin, and their risks increase as populations grow. Human activities can contribute to the frequency and intensity of some natural hazards.

ESS3.C: Human Impacts on Earth Systems
How do humans change the planet?

- ***By the end of grade 12.*** The sustainability of human societies and of the biodiversity that supports them require responsible management of natural resources not only to reduce existing adverse impacts but also to get things right in the first place. Scientists and engineers can make major contributions—for example, by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. When the source of a problem is understood and international agreement can be reached, it has been possible to regulate activities to reverse or avoid some global impacts (e.g., acid rain, the ozone hole).

ESS3.D: Global Climate Change

How do people model and predict the effects of human activities on Earth's climate?

- ***By the end of grade 12.*** Because global climate changes usually happen too slowly for individuals to recognize them directly, scientific and engineering research—much of it based on studying and modeling past climate patterns—is essential. The current situation is novel, not only because the magnitudes of humans' impacts are significant on a global scale but also because humans' abilities to model, predict, and manage future impacts are greater than ever before. Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities, as well as to changes in human activities. Thus science and engineering will be essential both to understanding the possible impacts of global climate change and to informing decisions about how to slow its rate and consequences—for humanity as well as for the rest of the planet.

ENGINEERING, TECHNOLOGY, AND APPLICATION OF SCIENCE

Core and Component Ideas in Engineering, Technology, and Application of Science

Core Idea ETS1: Engineering Design

- ETS1.A. Defining and Delimiting an Engineering Problem
- ETS1.B: Developing Possible Solutions
- ETS1.C: Optimizing the Design Solution

Core Idea ETSA2: Links Among Engineering, Technology, Science, and Society

- ETS2.A: Interdependence of Science, Engineering, and Technology
- ETS2.B: Influence of Engineering, Technology and Science
- on Society and the Natural World

CORE IDEA ETS1: ENGINEERING DESIGN

How do engineers solve problems?

ETS1.A. Defining and Delimiting an Engineering Problem

What is a design for?
What are the criteria and constraints of a successful solution?

- ***By the end of grade 12.*** Design criteria and constraints, which typically reflect the needs of the end-user of a technology or process, address such things as the product's or system's function (what job it will perform and how), its durability, and limits on its size and cost. Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. But whatever the scale, the first things that engineers do is define the problem and specify the criteria and constraints for potential solutions.

ETS1.B: Developing Possible Solutions

What is the process for developing potential design solutions?

- ***By the end of grade 12.*** Complicated problems may need to be broken down into simpler components in order to develop and test solutions. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. Testing should lead to improvements in the design through an iterative procedure. Both physical models and computers can be used in various ways to aid in the engineering design process. Physical models, or prototypes, are helpful in testing product ideas or the properties of different materials. Computers are useful for a variety of purposes, such as in representing a design in 3-D through CAD software; in troubleshooting to identify and describe a design problem; in running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

ETS1.C: Optimizing the Design Solution

How can the various proposed design solutions be compared and improved?

- ***By the end of grade 12.*** The aim of engineering is not simply to find a solution to a problem but to design the best solution under the given constraints and criteria. Optimization can be complex, however, for a design problem with numerous desired qualities or outcomes. Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. The comparison of multiple designs can be aided by a trade-off matrix. Sometimes a numerical weighting system can help evaluate a design against multiple criteria. When evaluating solutions, all relevant considerations, including cost, safety, reliability, and aesthetic, social, cultural, and environmental impacts, should be included. Testing should lead to design improvements through an iterative process, and computer simulations are one useful way of running such tests.

CORE IDEA ETS2: LINKS AMONG ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY

How are engineering, technology, science, and society interconnected?

ETS2.A: Interdependence of Science, Engineering, and Technology

What are the relationships among science, engineering, and technology?

- ***By the end of grade 12.*** Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. For example, developing a means for safely and securely disposing of nuclear waste will require the participation of engineers with specialties in nuclear engineering, transportation, construction, and safety; it is likely to require as well the contributions of scientists and other professionals from such diverse fields as physics, geology, economics, psychology, and sociology.

ETS2.B: Influence of Engineering, Technology and Science on Society and the Natural World
How do science, engineering, and the technologies that result from them affect the ways in which people live? How do they affect the natural world?

- ***By the end of grade 12.*** Modern civilization depends on major technological systems, including those related to agriculture, health, water, energy, transportation, manufacturing, construction, and communications. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Widespread adoption of technological innovations often depends on market forces or other societal demands, but it may also be subject to evaluation by scientists and engineers and to eventual government regulation. New technologies can have deep impacts on society and the environment, including some that were not anticipated or that may build up over time to a level that requires attention or mitigation. Analysis of costs, environmental impacts, and risks, as well as of expected benefits, is a critical aspect of decisions about technology use.