NATIONAL SCIENCE EDUCATION STANDARDS GRADES 9–12

UNIFYING CONCEPTS AND PROCESSES

Systems, Order, and Organization

- A system is an organized group of related objects or components (organisms, machines, fundamental particles, galaxies, ideas, numbers, transportation, and education).
- Students should analyze in terms of systems (mass, energy, objects, organisms, and events).
- Systems have structure and function.
- Feedback and equilibrium are associated with systems.
- Systems can be open or closed.
- The assumption of order establishes the basis for cause-effect relationships and predictability.
- Prediction can be used to explain change. Math can be used to do this through probability.
- Systems have levels of organization (periodic table & classification of organisms).
- Living systems have levels of organization (cells, tissues, organs, organisms, populations and communities).
- Interactions occur in systems.

Evidence, Models, and Explanation

- Evidence should be used in explanations.
- Models can be used in explanations.
- Terms such as hypothesis, model, law, principle, theory, and paradigm are used to explain scientific explanations.

Constancy, Change, and Measurement

- Interactions result in change.
- Changes vary in rate, scale, and pattern, including trends and cycles.
- Math measures change.
- Scientists use the metric system.
- Scale includes understanding that parts of a system might change as its size changes.
- Rate compares one measured quantity with another.

Evolution and Equilibrium

- Evolution is a series of changes. This includes changes in the universe.
- The present is a result of the past.
- Equilibrium is a physical state in which forces and changes occur in opposite and offsetting directions.
- Steady state, balance, and homeostasis describe equilibrium states.

Form and Function

- Form follows function.
- Students should explain function in terms of form and form in terms of function.

A. SCIENCE AS INQUIRY

Abilities Necessary to do Scientific Inquiry

- Identify questions and concepts that guide scientific investigations (form a hypothesis).
- Design and conduct scientific investigations based on knowledge of major concepts, equipment, and safety precautions. Students may need to clarify parts of the experiment using evidence and logic.
- Use technology and math to improve investigations and communications (measurement instruments, calculators, computers, formulas) to present the design and results of the investigation.
- Formulate and revise scientific explanations and models using logic and evidence (models should be physical, conceptual and mathematical).
- Recognize and analyze alternative explanations and models by reviewing current scientific understanding, weighing evidence, and examining the logic.
- Communicate and defend a scientific argument through writing, following procedures, reviewing information, summarizing data, developing diagrams and charts, and speaking clearly.

Understandings about Scientific Inquiry

- Scientists usually inquire about how physical, living, or designed systems function and are guided by conceptual principles and knowledge.
- Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects about the natural world, explain recently observed phenomena, or the testing of prior conclusions.
- Scientists rely on technology to enhance the gathering of data.
- Mathematics is essential to scientific inquiry.
- Scientific explanations should be logical, based on evidence, open to questions and possible modification, and be based on historical and current scientific knowledge.
- Results of scientific inquiry emerge from different types of investigations and communication among scientists.

B. PHYSICAL SCIENCE

Structure of Atoms

- Matter is made of atoms that are composed of smaller components that have mass and electrical charge.
- An atom's nucleus has protons and neutrons which are more massive that its electrons. Atoms that differ in the number of neutrons are called isotopes.
- The nuclear forces that hold the nucleus of an atom together are usually stronger than the electrical forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy (fusion and fission). Fusion is the process responsible for the energy of the sun.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions that emit particles or radiation. Large groups of nuclei decay at a predictable rate and can be used to estimate the age of materials containing radioactive isotopes.

Structure and Properties of Matter

- Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.
- Elements are composed of a single type of atom and are listed in order according to the number of protons. The repeating patterns of physical and chemical properties identify families of elements.
- Bonds between atoms are created when electrons are paired up by being transferred or shared. Atoms may be bonded into molecules or crystalline solids. Compounds are formed when 2 or more atoms bond chemically.
- The physical properties of compounds reflect the nature of the interactions among its molecules.
- Solids, liquids, and gases differ in the distances and angles between molecules or atoms and, therefore, the energy that binds them together.
- Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

Chemical Reactions

- Chemical reactions occur all around us. Complex chemical reactions involving carbon-based molecules take place constantly in every cell of our bodies.
- Chemical reactions may release or consume energy. Burning of fossil fuels release large amounts of energy by losing heat and emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.
- Important reactions involve the transfer of either electrons or hydrogen ions between reacting ions, molecules, or atoms. Chemical bonds can be broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere burning and processing fossil fuels, and formations of polymers, and explosions.
- Chemical reactions can take place in an instant or billions of years.

- Catalysts accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes.

Motions and Forces

- Objects change their motion only when a net force is applied. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.
- Gravitation is a universal force that each mass exerts on any other mass.
- The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel.
- Between any two charged particles, electric force is vastly greater than gravity. Most observable forces can be traced to electric forces acting between atoms and molecules.
- Moving electric charges produce magnetic forces, and moving magnets produce electric forces.

Conservation of Energy and Increase in Disorder

- The total energy in the universe is constant. It can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in other ways. It can never be destroyed. As energy is transferred, the matter involved becomes steadily less ordered.
- All energy is either kinetic (motion), potential (depends on relative position), or is contained by a field.
- Heat consists of random motion and the vibrations of atoms, molecules, or ions.
- Everything tends to become less organized and less orderly over time, thus, in all energy transfers, the overall effect is that the energy is spread out uniformly (i.e. the warming of our surroundings as we burn fossil fuels).

Interactions of Energy and Matter

- Waves have energy and can transfer energy when they interact with matter.
- Electromagnetic waves (radio, microwaves, infrared radiation, visible light, ultraviolet radiation, x-rays, gamma rays) result when a charged object is accelerated or decelerated.
- Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. The wavelengths can be used to identify the substance.
- In some material, electrons flow easily while in others they cannot flow at all. Some have intermediate behavior (semiconductors).

C. LIFE SCIENCE

The Cell

- Cells have structures for carrying out various functions.
- Most cell functions involve chemical reactions (example: breakdown of food).
- Cells store and use information to guide their functions.
- Cell functions are regulated allowing them to respond to the environment coordinating growth and division.
- Plant cells, which contain chloroplasts, conduct photosynthesis using solar energy.
- Complex organisms are made of differentiated cells. Differentiation is regulated by genes.

Molecular Basis of Heredity

- DNA carries a set of instructions for specifying characteristics in organisms. (DNA is a polymer formed from 4 subunits—A, G, C, and T. Each DNA molecule in a cell forms a single chromosome).
- Humans contain 23 pairs of chromosomes one of which is responsible for sex determination (XX—female, XY—male).
- Changes in DNA (mutations) occur spontaneously at low rates.

Biological Evolution

- Species evolve over time.
- Biodiversity is due to over 3.5 billion years of evolution that has filled all available niches with organisms.
- Natural selection can be used to explain the fossil record as well as for molecular similarities among diverse living species.
- The millions of different species are related by descent from common ancestors.

- Biological classifications are based on how organisms are related.

Interdependence of Organisms
- Atoms and molecules cycle throughout the living and non-living parts of the biosphere.
- Energy flows through ecosystems (plants > herbivores > carnivores > decomposers).
- The cooperation and competition of organisms in ecosystems helps to maintain the ecosystem.
- Organisms can reproduce indefinitely but the population size is limited by the ecosystem's resource.
- Humans modify ecosystems (population growth, agriculture, pollution, destruction of habitat), sometimes irreversibly.

Matter, Energy and Organization in Living Systems
- Living systems require a continuous input of energy to maintain homeostasis.
- The energy for life comes primarily from the sun. Plants use the energy to form chemical bonds that can later by used as energy sources.
- The chemical bonds of food molecules contain energy that can be released or stored in cells temporarily in the compound ATP.
- The structure of organisms enables them to carry out the functions of matter and energy necessary to sustain the organism.
- Carrying capacity is due to the availability of matter and energy in an ecosystem.
- As matter and energy flow through different levels of organization in systems, elements are recombined in different ways.

Behavior of Organisms
- Multicellular organisms have complex nervous systems that generate behavior from specialized cells rapidly conducting signals.
- Organisms respond to internal changes and external stimuli. This behavior can be innate or learned, but it must be flexible so as to insure future reproductive success.
- Behaviors have evolved through natural selection.
- Behavioral biology has implications for humans by providing links to psychology, sociology, and anthropology.

D. EARTH AND SPACE SCIENCE

Energy in the Earth System
- Earth systems have internal (radioactive isotopes and gravitational energy) and external sources (sun) of energy that create heat.
- The outward transfer of Earth's internal heat drives convection circulation in the mantle that propels the crustal plates to move.
- Heating of the Earth's surface and atmosphere by the sun drives convection within the atmosphere and the oceans producing winds and ocean currents.
- Global climate is determined by energy transfer from the sun at and near the Earth's surface. It is influenced by cloud cover, Earth's rotation, and the position of mountains and oceans.

Geochemical Cycles
- The Earth is a system containing essentially a fixed amount of each stable chemical, atom, or element. Each element can exist in several different reservoirs and moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.
- Movement of matter between reservoirs is driven by the Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter (i.e. carbon occurs in carbonate rocks, as a carbon monoxide gas in the atmosphere and dissolved in water, and in all organisms as complex molecules that control the chemistry of life).

Origin and Evolution of the Earth System
- The entire solar system formed from nebular dust and gas 4.6 billion years ago and the Earth was very different in the beginning.
- Geologic time can be estimated and observed in rock and fossil sequences using known decay rates of radioactive isotopes.
- Interactions in the Earth's systems (including living) have resulted in its ongoing evolution.

- Evidence for one-celled forms of life extends back more than 3.5 billion years. The evolution of life caused dramatic changes in our atmosphere, which originally did not contain oxygen.

Origin and Evolution of the Universe

- The Big Bang Theory places the origin of the universe between 10 and 20 billion years ago when it began as a hot dense state and has been expanding ever since.
- Early in the history of the universe, matter clumped together by gravitational attraction to form stars and galaxies, which now form most of the visible mass of the universe.
- Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all other elements.

E. SCIENCE AND TECHNOLOGY

Abilities of Technological Design

- Identify a problem or design an opportunity.
- Propose designs and choose between alternative solutions.
- Implement a proposed solution.
- Evaluate the solution and its consequences.
- Communicate the problem, process, and solution.

Understandings about Science and Technology

- Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanation.
- Science often advances with the introduction of new technologies.
- Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
- Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world. Technological design is driven by the need to meet human needs and solve human problems.
- Technological knowledge is often not made public because of patents. Scientific knowledge is made public through presentations at professional meetings and in scientific journals.

F. SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

Personal and Community Health

- Hazards and the potential for accidents exist. Humans can reduce and modify hazards.
- The severity of disease symptoms is dependent on human resistance and the virulence of the disease-producing organism.
- Personal choice concerning fitness and health involves multiple factors.
- An individual's mood and behavior may be modified by substances. The abuse of illegal drugs can result in physical dependence and can increase the risk of injury, accidents, and death.
- Selection of foods and eating patterns determine nutritional balance.
- Families serve basic health needs, especially for young children.
- Sexuality is basic to the physical, mental, and social development of humans.

Population Growth

- Populations grow or decline through the effects of births, deaths, emigration, and immigration.
- Population growth affects the resources used and environmental pollution.
- Sociological factors (cultural norms, percentage of women who are employed, birth control methods) influence birth rates and fertility rates.
- Populations can limit growth.
- Carrying capacity is the maximum number of people in relation to resources and the capacity of Earth systems to support human beings.

Natural Resources

- Human populations use resources in the environment in order to maintain and improve their existence.
- The Earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed.

- Humans use many natural systems as resources. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

Environmental Quality

- Natural ecosystems provide an array of basic processes that affect humans. Quality of the atmosphere, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients are being changed in ways that are detrimental to humans.
- Materials from human societies affect both physical and chemical cycles of the Earth.
- Many factors influence environmental quality, such as population growth, resource use, population distribution, overconsumption, etc.

Natural and Human-Induced Hazards

- Normal adjustments of Earth may be hazardous for humans. Humans live at the interface between the atmosphere driven by solar energy and the upper mantle where convection creates changes in the Earth's solid crust.
- Human activities can enhance potential hazards. Urban growth and waste disposal can accelerate rates of natural change.
- Some hazards happen quickly (earthquakes, volcanic eruptions), and others happen slowly (changes of stream channels, erosion of bridge foundations, sedimentation of lakes and rivers).
- Natural and human-induced hazards present the need for humans to assess potential danger and risk.

Science and Technology in Local, National, and Global Challenges

- Science and technology can indicate what can happen, not what should happen. Humans decide about the use of knowledge.
- Understanding basic concepts and principles of science and technology should come before active debate about the economics, policies, and ethics of various science and technology challenges.
- Progress in science and technology can be affected by social issues and challenges.
- Students should understand the appropriateness and value of basic questions "What can happen?" "What are the odds?"
- Humans have a major effect on other species. For example, the influence of humans on other organisms occurs through land use, which decreases space available to other species, and pollution, which changes the chemical composition of air, soil, and water.

G. HISTORY AND NATURE OF SCIENCE

Science as a Human Endeavor

- Individuals and teams continue to contribute to the scientific enterprise (in the form of a field study or a major scientific problem) as both a hobby and a career.
- Scientists value peer review, truthful reporting, and making public work results.
- Science is part of society and is influenced by societal, cultural, and personal beliefs and ways of viewing the world.

Nature of Scientific Knowledge

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism.
- Scientific explanations must meet these criteria: be consistent with evidence, make accurate predictions, be logical, be open to criticism, report methods and procedures, and make knowledge public.
- All scientific knowledge is subject to change as new evidence becomes available.

Historical Perspectives

- Throughout history, diverse cultures have contributed scientific knowledge and technological inventions that have had an impact on those societies in different parts of the world.
- Changes in science occur as small modifications in knowledge.

Key to Symbols:
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- ◉ The concept is one of the main focuses of the activity; is reinforced.
- ○ The concept is not the main focus of the activity, but it is supported or reinforced.

NATIONAL SCIENCE EDUCATION STANDARDS (Content, 9–12)	We're in This Together (gr. 9–12, p. 44)	Carrying Capacity (gr. 9–12, p. 46)	Birds of Prey (gr. 9–12, p. 111)	Forest in a Jar (gr. 9–12, p. 137)	Fire Ecologies (gr. 9–12, p. 140)	Bottleneck Genes (gr. 9–12, p. 172)	Wildlife on Coins and… (gr. 9–12, p. 208)	Artic Survival (gr. 9–12, p. 234)	Wild Bill's Fate (gr. 9–12,p. 270)	Know Your Legislation:… (gr. 9–12, p. 272)	Wildlife Issues: … (gr. 9–12, p. 297)	Cabin Conflict (gr. 9–12, p. 353)
UNIFYING CONCEPTS AND PROCESSES												
Systems, order, and organization	○	◉	●	◉	◉	◉			○	○	○	○
Evidence, models, and explanation	○	◉	●	●	◉	◉		◉		○	○	○
Constancy, change, and measurement	○	◉	◉	◉	◉		○		○	○	◉	○
Evolution and equilibrium		○	○	●	◉	○						
Form and function					○							
A: SCIENCE AS INQUIRY												
Abilities necessary to do scientific inquiry	◉	◉	◉	◉	◉	○	○	○	○	○	◉	◉
Understanding about scientific inquiry	◉	◉	●	○	◉	○		○			○	○
B: PHYSICAL SCIENCE												
Structure of atoms												
Structure and properties of matter												
Chemical reactions												
Motions and forces												
Conservation of energy and increase in disorder												
Interactions of energy and matter												
C: LIFE SCIENCE												
The cell												
Molecular basis of heredity						○						
Biological evolution			○	○		○						
Interdependence of organisms	◉	◉	○	○	○			○				○
Matter, energy, and organization in living systems		○	○	○	○	○		○				
Behavior of organisms			◉									
D: EARTH AND SPACE SCIENCE												
Energy in the Earth system					○							
Geochemical cycles												
Origin and evolution of the Earth system												
Origin and evolution of the universe												
E: SCIENCE & TECHNOLOGY												
Abilities of technological design					◉				○	○	○	○
Understandings about science and technology					○				○	○	○	○
F: SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES												
Personal and community health	○											
Population growth	○	○		○								
Natural resources	○		○					●			○	○
Environmental quality	◉	○			○							◉
Natural and human-induced hazards	◉				○							
Science and technology in local, national, and global challenges	◉	○							◉	◉	●	○
G: HISTORY AND NATURE OF SCIENCE												
Science as human endeavor					○				○	○	○	○
Nature of scientific knowledge		○	○						○	○		○
Historical perspectives							○				○	

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NATIONAL SCIENCE EDUCATION STANDARDS (Content, 9–12)	**Back from the Brink** (gr. 9–12, p. 355)	**Philosophical Differences** (gr. 9–12, p. 364)	**Turkey Trouble** (gr. 9–12, p. 367)	**Deer Crossing** (gr. 9–12, p. 392)	**From Bison to Bread: …** (gr. 9–12, p. 395)	**Bird Song Survey** (gr. 9–12, p. 406)	**A Picture is Worth a …** (gr. 9–12, p. 409)	**Wildlife Research** (gr. 9–12, p. 418)	**Dropping in on Deer** (gr. 9–12, p. 420)	**Deer Dilemma** (gr. 9–12, p. 426)	**Can Do!** (gr. 9–12, p. 446)	**Sustainability: Then, Now…** (gr. 9–12, p. 449)
UNIFYING CONCEPTS AND PROCESSES												
Systems, order, and organization			◉	◉	○	○		○			○	
Evidence, models, and explanation		○	○	○		○		◉			○	
Constancy, change, and measurement			●		○	◉		◉			○	
Evolution and equilibrium			◉									
Form and function		○				◉						
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Understanding about scientific inquiry		○	○	○	○			●	◉		○	
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Molecular basis of heredity												
Biological evolution												○
Interdependence of organisms	○		○	◉	◉						○	◉
Matter, energy, and organization in living systems					○							
Behavior of organisms			○	○		○		○				
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Abilities of technological design		○	◉	○				●			●	
Understandings about science and technology			○					○			○	
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Population growth			◉		○				○		○	
Natural resources	○			○	○			○		○	○	
Environmental quality			○								○	
Natural and human-induced hazards				○								
Science and technology in local, national, and global challenges		◉			○		○			○	◉	○
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NATIONAL SCIENCE EDUCATION STANDARDS (Content, 9–12)	**Eat and Glow** (gr. 7–10, p. 69)	**When a Whale Is Right** (gr. 9–12, p. 94)	**Sea Turtles International** (gr. 9–12, p. 98)	**Facts and Falsehoods** (gr. 9–12, p. 124)	**The Glass Menagerie** (gr. 9–12, p. 155)	**Dam Design** (gr. 9–12, p. 179)	**Living Research: …** (gr. 9–12, p. 190)
UNIFYING CONCEPTS AND PROCESSES							
Systems, order, and organization	○				●		
Evidence, models, and explanation	⦿			⦿	●	○	
Constancy, change, and measurement					⦿		
Evolution and equilibrium					●		
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