Science Standards of Learning

for Virginia Public Schools

Secondary Courses

Science Standards of Learning

Goals

The purposes of scientific investigation and discovery are to satisfy humankind's quest for knowledge and understanding and to preserve and enhance the quality of the human experience. Therefore, as a result of science instruction, students will be able to:

1. Develop and use an experimental design in scientific inquiry
2. Use the language of science to communicate understanding
3. Investigate phenomena using technology
4. Apply scientific concepts, skills, and processes to everyday experiences
5. Experience the richness and excitement of scientific discovery of the natural world through the historical and collaborative quest for knowledge and understanding
6. Make informed decisions regarding contemporary issues taking into account the following:
   - public policy and legislation
   - economic costs/benefits
   - validation from scientific data and the use of scientific reasoning and logic
   - respect for living things
   - personal responsibility
   - history of scientific discovery
7. Develop scientific dispositions and habits of mind including:
   - curiosity
   - demand for verification
   - respect for logic and rational thinking
   - consideration of premises and consequences
   - respect for historical contributions
   - attention to accuracy and precision
   - patience and persistence
8. Explore science-related careers and interests.

K-12 Safety

In implementing the Science Standards of Learning, students must know how to follow safety guidelines, demonstrate appropriate laboratory safety techniques, and use equipment safely while working individually and in groups.

Safety must be given the highest priority in implementing the K-12 instructional program for science. Correct and safe techniques, as well as wise selection of experiments, resources, materials, and field experiences appropriate to age levels, must be carefully considered with regard to the safety precautions for every instructional activity. Safe science classrooms require thorough planning, careful management, and constant monitoring of student activities. Class enrollment should not exceed the designed capacity of the room.

Teachers must be knowledgeable of the properties, use, and proper disposal of all chemicals that may be judged as hazardous prior to their use in an instructional activity. Such information is referenced through the MSDS forms (Materials Safety Data Sheets). The identified precautions involving the use of goggles, gloves, aprons, and fume hoods must be followed as prescribed.

While no comprehensive list exists to cover all situations, the following should be reviewed to avoid potential safety problems. Appropriate safety procedures should be used in the following situations:

- Observing wildlife; handling living and preserved organisms; and contact with natural hazards such as poison ivy, ticks, mushrooms, insects, spiders, and snakes

- Field activities in, near, or over bodies of water
- Handling of glass tubing, sharp objects, glassware, and labware
- Natural gas burners, bunsen burners, and other sources of flame/heat
- Hazards associated with direct sunlight (sunburn and eye damage)
- Use of extreme temperatures and cryogenic materials
- Hazardous chemicals including toxins, carcinogens, flammable and explosive materials
- Acid/base neutralization reactions/dilutions
- Production of toxic gases or situations where high pressures are generated
- Biological cultures, their appropriate disposal, and recombinant DNA
- Power equipment/motors
- High voltage/exposed wiring
- Laser beam, UV, and other radiation.

The use of human body fluids or tissues is generally prohibited for classroom lab activities. Further guidance from the following sources may be taken into account:

- OSHA (Occupational Safety and Health Administration)
- ISEF (International Science and Engineering Fair Rules)
- Public health departments and local school division protocols.

The Role of Instructional Technology in Science Education

The use of current and emerging technologies is essential to the K-12 science instructional program.

Specifically, technology must

- Assist in improving every student's functional literacy. This includes improved communication through reading/information retrieval (the use of telecommunications), writing (word processing), organization and analysis of data (databases, spreadsheets, and graphics programs), selling one's idea (presentation software), and resource management (project management software).
- Be readily available and used regularly as an integral and ongoing part in the delivery and assessment of instruction.
- Include instrumentation oriented toward the instruction and learning of science concepts, skills, and processes. Technology, however, should not be limited to traditional instruments of science such as microscopes, labware, and data-collecting apparatus but should also include computers, robotics, interactive-optical laser discs, video-microscopes, graphing calculators, CD-ROMs, probeware, on-line telecommunication, software and appropriate hardware, as well as other emerging technologies.
- Be reflected in the "instructional strategies" generally developed at the local school division level.

In most cases, the application of technology in science should remain "transparent" unless it is the actual focus of the instruction. One must expect students to "do as a scientist does" and not simply hear about science if they are truly expected to explore, explain, and apply scientific concepts, skills, and processes.

As computer/technology skills are essential components of every student's education, it is important that these skills are a shared responsibility of teachers of all disciplines and grade levels. Please note the computer/technology standards following the grade five and the physical science standards respectively.

Investigate and Understand

Many of the standards in the Science Standards of Learning begin with the phrase "Students will investigate and understand." This phrase was chosen to communicate the range of **rigorous science skills** and **knowledge** levels embedded in each standard. Limiting a standard to one observable behavior such as "describe" or "explain" would have narrowed the interpretation of what was intended to be a rich, highly rigorous, and inclusive content standard.

"Investigate" refers to scientific methodology and implies systematic use of the following inquiry skills:

- Observing
- Classifying and sequencing
- Communicating
- Measuring
- Predicting
- Hypothesizing
- Inferring
- Defining, controlling, and manipulating variables in experimentation

- Designing, constructing, and interpreting models
- Interpreting, analyzing, and evaluating data.

Understand" refers to various levels of knowledge application. In the Science Standards of Learning these knowledge levels include the ability to

- **Recall** or **recognize** important information, key definitions, terminology, and facts
- **Explain** the information in one's own words, comprehend how the information is related to other key facts, and suggest additional interpretations of its meaning or importance
- **Apply** the facts and principles to new problems or situations, recognizing what information is required for a particular situation, explaining new phenomena with the information, and determining when there are exceptions
- **Analyze** the underlying details of important facts and principles, recognizing the key relations and patterns that are not always readily visible
- **Arrange** and **combine** important information, facts, and principles to produce a new idea, plan, procedure, or product
- **Make judgments** about information in terms of accuracy, precision, consistency, or effectiveness.

Therefore, the use of "investigate and understand" allows each content standard to become the basis for a broad range of teaching objectives, which the local school division will develop and refine to meet the intent of the Science Standards of Learning.

Earth Science

The Earth Science standards connect the study of the Earth's composition, structure, processes, and history; its atmosphere, fresh water, and oceans; and its environment in space. The standards emphasize historical contributions in the development of scientific thought about the Earth and space. The standards stress the interpretation of maps, charts, tables, and profiles; the use of technology to collect, analyze, and report data; and science skills in systematic investigation. Problem solving and decision making are an integral part of the standards, especially as they relate to the costs and benefits of utilizing the Earth's resources. Major topics of study include plate tectonics, the rock cycle, Earth history, the oceans, the atmosphere, weather and climate, and the solar system and universe.

ES.1 The student will plan and conduct investigations in which
- volume, area, mass, elapsed time, direction, temperature, pressure, distance, density, and changes in elevation/depth are calculated utilizing the most appropriate tools;
- technologies, including computers, are used to collect, analyze, and report data and to demonstrate concepts and simulate experimental conditions;
- scales, diagrams, maps, charts, graphs, tables, and profiles are constructed and interpreted;
- variables are manipulated with repeated trials; and
- a scientific viewpoint is constructed and defended.

ES.2 The student will demonstrate scientific reasoning and logic by
- analyzing how science explains and predicts the interactions and dynamics of complex Earth systems;
- recognizing that evidence is required to evaluate hypotheses and explanations;
- comparing different scientific explanations for the same observations about the Earth;
- explaining that observation and logic are essential for reaching a conclusion;
- evaluating evidence for scientific theories related to plate tectonics, the structure of the Earth, and its ancient age and origin; and
- making informed judgments related to resource use and its effects on Earth systems.

ES.3 The student will investigate and understand how to read and interpret maps, globes, models, charts, and imagery. Key concepts include
- maps (bathymetric, geologic, topographic, and weather) and star charts;
- imagery (aerial photography and satellite images);
- direction and distance measurements on any map or globe; and
- location by latitude and longitude and topographic profiles.

ES.4 The student will investigate and understand the characteristics of the Earth including
- plate tectonics;
- water in all three states;
- position of the Earth in the solar system; and
- effects of density differences and energy transfer on the activities of the atmosphere, oceans, and Earth's interior.

ES.5 The student will investigate and understand how to identify major rock-forming and ore minerals based on physical and chemical properties. Key concepts include
- properties including hardness, color and streak, luster, cleavage, fracture, and unique properties; and
- uses of minerals.

ES.6 The student will investigate and understand how to identify common rock types based on mineral composition and textures and the rock cycle as it relates to the transformation of rock types. Key concepts include
- igneous (intrusive and extrusive);
- sedimentary (clastic and chemical); and
- metamorphic (foliated and unfoliated) rocks.

ES.7 The student will investigate and understand the differences between renewable and nonrenewable resources. Key concepts include
- fossil fuels, minerals, rocks, water, and vegetation;
- advantages and disadvantages of various energy sources;
- resources found in Virginia;
- use of resources and their effects on standards of living; and

- environmental costs and benefits.

ES.8 The student will investigate and understand geologic processes including plate tectonics. Key concepts include
- how geologic processes are evidenced in the physiographic provinces of Virginia including the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau;
- processes (faulting, folding, volcanism, metamorphism, weathering, erosion, deposition, and sedimentation) and their resulting features; and
- tectonic processes (subduction, rifting and sea floor spreading, and continental collision).

ES.9 The student will investigate and understand how freshwater resources are influenced by geologic processes and the activities of humans. Key concepts include
- processes of soil development;
- development of karst topography;
- identification of groundwater zones including water table, zone of saturation, and zone of aeration;
- identification of other sources of fresh water including aquifers with reference to the hydrologic cycle; and
- dependence on freshwater resources and the affects of human usage on water quality.

ES.10 The student will investigate and understand that many aspects of the history and evolution of the Earth and life can be inferred by studying rocks and fossils. Key concepts include
- traces or remains of ancient, often extinct, life are preserved by various means in many sedimentary rocks;
- superposition, cross-cutting relationships, and radioactive decay are methods of dating bodies of rock;
- absolute and relative dating have different applications but can be used together to determine the age of rocks and structures; and
- rocks and fossils from many different geologic periods and epochs are found in Virginia.

ES.11 The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include
- physical and chemical changes (tides, waves, currents, sea level and ice cap variations, upwelling, and salinity concentrations);
- importance of environmental, geologic, and economic implications;
- systems interactions (energy transfer, weather, and climate);
- features of the sea floor (continental margins, trenches, mid-ocean ridges, and abyssal plains) reflect tectonic processes; and
- public policy issues concerning the oceans.

ES.12 The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics. Key concepts include
- scientific evidence for atmospheric changes over geologic time;
- current theories related to the effects of early life on the chemical makeup of the atmosphere;
- comparison of the Earth's atmosphere to that of other planets;
- atmospheric regulation mechanisms; and
- potential atmospheric compositional changes due to human, biologic, and geologic activity.

ES.13 The student will investigate and understand that energy transfer between the sun, Earth, and the Earth's atmosphere drives weather and climate on Earth. Key concepts include
- observation and collection of weather data;
- prediction of weather patterns; and
- weather phenomena and the factors that affect climate.

ES.14 The student will investigate and understand the planets and other members of the solar system; the history and contributions of the space program; and concepts related to the origin and evolution of the solar system, galaxy, and universe. Key concepts include
- characteristics of the sun, planets, their moons, comets, meteors, and asteroids; and
- cosmology and the origin of stars and stellar systems (the Big Bang, the solar nebular theory, stellar evolution, star systems, nebulae, constellations, and galaxies).

Biology

The standards for Biology are designed to provide students with a detailed understanding of living systems. Emphasis continues to be placed on the skills necessary to examine alternative scientific explanations, actively conduct controlled experiments, analyze and communicate information, and acquire and use scientific literature. The history of biological thought and the evidence that supports it are explored and provide the foundation for investigating biochemical life processes, cellular organization, mechanisms of inheritance, dynamic relationships among organisms, and the change in organisms through time. The importance of scientific research that validates or challenges ideas is emphasized at this level.

BIO.1 The student will plan and conduct investigations in which
- observations of living things are recorded in the lab and in the field;
- hypotheses are formulated based on observations;
- variables are defined and investigations are designed to test hypotheses;
- graphing and arithmetic calculations are used as tools in data analysis;
- conclusions are formed based on recorded quantitative and qualitative data;
- impacts of sources of error inherent in experimental design are identified and discussed;
- validity of data is determined;
- alternative explanations and models are recognized and analyzed;
- appropriate technology is used for gathering and analyzing data and communicating results; and
- research is used based on popular and scientific literature.

BIO.2 The student will investigate and understand the history of biological concepts. Key concepts include
- evidence supporting the cell theory;
- scientific explanations of the development of organisms through time;
- causative agents of disease;
- the evolution of the DNA model; and
- the collaborative efforts of scientists, past and present.

BIO.3 The student will investigate and understand biochemical principles essential for life. Key concepts include
- water chemistry and its impact on life processes;
- the structure and function of macromolecules;
- the nature of enzymes; and
- the significance of and relationship between photosynthesis and respiration.

BIO.4 The student will investigate and understand relationships between cell structure and function. Key concepts include
- characterizing prokaryotic organisms;
- exploring the diversity and variation of eukaryotes;
- building analogies between the activities of a single cell and a whole organism; and
- modeling the cell membrane, cell communication, and cell recognition.

BIO.5 The student will investigate and understand life functions of monerans, protists, fungi, plants, and animals, including humans. Key concepts include
- how their structures are alike and different;
- comparison of their metabolic activities;
- analyses of their responses to the environment;
- maintenance of homeostasis;
- human health issues, human anatomy, body systems, and life functions;
- how viruses compare with organisms; and
- observation of local organisms when applicable.

BIO.6 The student will investigate and understand common mechanisms of inheritance and protein synthesis. Key concepts include
- cell division;
- sex cell formation;
- cell specialization;
- prediction of inheritance of traits based on the laws of heredity;
- effects of genetic recombination and mutation;
- events involved in the construction of proteins; and
- exploration of the impact of DNA technologies.

BIO.7 The student will investigate and understand bases for modern classification systems. Key concepts include
- structural similarities in organisms;
- fossil record interpretation;

- comparison of developmental stages in different organisms;
- examination of protein similarities and differences among organisms;
- comparison of DNA sequences in organisms;
- systems of classification that are adaptable to new scientific discoveries; and
- examination of local flora and fauna where applicable.

BIO.8 The student will investigate and understand how populations change through time. Key concepts include
- examining evidence found in fossil records;
- investigating how variation of traits, reproductive strategies, and environmental pressures impact on the survival of populations;
- recognizing how adaptations lead to natural selection; and
- exploring how new species emerge.

BIO.9 The student will investigate and understand dynamic equilibria within populations, communities, and ecosystems. Key concepts include
- interactions within and among populations including carrying capacities, limiting factors, and growth curves;
- nutrient cycling with energy flow through ecosystems;
- succession patterns in ecosystems;
- the effects of natural events and human influences on ecosystems; and
- analysis of local ecosystems.

Chemistry

The Chemistry standards are designed to provide students with a detailed understanding of the interaction of matter and energy. This interaction is investigated through the use of laboratory techniques, manipulation of chemical quantities, and problem-solving applications. Scientific methodology will be employed in experimental and analytical investigations, and concepts will be illustrated with practical applications.

Technology including graphing calculators and computers will be employed where feasible. Students will understand and use safety precautions with chemicals and equipment. The standards emphasize qualitative and quantitative study of substances and the changes that occur in them. In meeting the chemistry standards, students will be encouraged to share their ideas, use the language of chemistry, discuss problem-solving techniques, and communicate effectively.

CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated, produce observations and verifiable data. Key concepts include
- designated laboratory techniques;
- safe use of chemicals and equipment;
- proper response to emergency situations;
- multiple variables are manipulated with repeated trials;
- accurate recording, organizing, and analysis of data through repeated trials;
- mathematical and procedural error analysis; and
- mathematical manipulations (SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, dimensional analysis, use of scientific calculator).

CH.2 The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of
- mass/atomic number;
- isotopes/half-lives/nuclear particles;
- particle/mass charge;
- families/groups;
- series/periods;
- trends/patterns: atomic/nuclear radii, electronegativity, shielding effect;
- electron configurations/oxidation numbers;
- chemical/physical properties; and
- historical/quantum models.

CH.3 The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include
- nomenclature;
- balancing chemical equations;
- writing chemical formulas—molecular, structural, empirical, and Lewis diagrams;
- bonding types—ionic, covalent;
- reaction types—synthesis, decomposition, single and double replacement, oxidation-reduction, neutralization, nuclear, exothermic and endothermic, spontaneous/non-spontaneous, dissociation ionization;
- physical and chemical equilibrium; and
- reaction rates and kinetics: activation energy, catalysis, degree of randomness.

CH.4 The student will investigate and understand that quantities in a chemical reaction are based on molar relationships. Key concepts include
- avogadro's principle, molar volume;
- stoichiometric relationships;
- partial pressure;
- gas laws;
- solution concentrations;
- chemical equilibrium; and
- acid/base theory: strong/weak electrolytes, dissociation/ionization (pH, pOH), and titration.

CH.5 The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include
- pressure, temperature, and volume;
- vapor pressure;
- partial pressures;
- phase changes;
- molar heats of fusion and vaporization;
- specific heat capacity;
- solutions; and
- colligative properties.

CH.6 The student will investigate and understand how basic chemical principles relate to other areas of chemistry. Key concepts include
- organic and biochemistry;
- nuclear chemistry; and
- environmental chemistry.

Physics

The Physics standards emphasize a more complex understanding of experimentation, the analysis of data, and the use of reasoning and logic to evaluate evidence. The use of mathematics, including algebra, inferential statistics, and trigonometry, is important, but conceptual understanding of physical systems remains a primary concern. Students build on basic physical science principles by exploring in depth the nature and characteristics of energy and its dynamic interaction with matter. Key areas covered by the standards include force and motion, kinetic molecular theory, energy transformations, wave phenomena and the electromagnetic spectrum, light, electricity, fields, and non-Newtonian physics. The standards stress the practical application of physics in other areas of science and technology and how physics affects our world.

PH.1 The student will investigate and understand how to plan and conduct investigations in which
- the components of a system are defined;
- instruments are selected and used to extend observations and measurements of mass, volume, temperature, heat exchange, energy transformations, motion, fields, and electric charge;
- information is recorded and presented in an organized format;
- metric units are used in all measurements and calculations;
- the limitations of the experimental apparatus and design are recognized;
- the limitations of measured quantities through the appropriate use of significant figures or error ranges are recognized; and
- data gathered from non-SI instruments are incorporated through appropriate conversions.

PH.2 The student will investigate and understand how to analyze and interpret data. Key concepts include
- a description of a physical problem is translated into a mathematical statement in order to find a solution;

- relationships between physical quantities are determined using the shape of a curve passing through experimentally obtained data;
- the slope of a linear relationship is calculated and includes appropriate units;
- interpolated, extrapolated, and analyzed trends are used to make predictions;
- inferential statistical tests are applied in evaluating experimental data; and
- analysis of systems employs vector quantities utilizing trigonometric and graphical methods.

PH.3 The student will investigate and understand how to demonstrate scientific reasoning and logic. Key concepts include
- analysis of primary sources to develop and refine research hypotheses;
- analysis of how science explains and predicts relationships; and
- evaluation of evidence for scientific theories and how new discoveries may either modify existing theories or result in establishing a new paradigm.

PH.4 The student will investigate and understand how applications of physics affect the world. Key concepts include
- principles with examples from the real world; and
- exploration of the roles and contributions of science and technology.

PH.5 The student will investigate and understand the interrelationships among mass, distance, force, and time through mathematical and experimental processes. Key concepts include
- linear motion;
- uniform circular motion;
- curvilinear motion;
- Newton's laws of motion;
- gravitation;
- celestial mechanics; and
- work, power, and energy.

PH.6 The student will investigate and understand that quantities including mass, energy, momentum, and charge are conserved. Key concepts include
- kinetic and potential energy;
- elastic and inelastic collisions; and
- electric power and circuit design.

PH.7 The student will investigate and understand that the kinetic molecular theory can be applied to solve quantitative problems involving pressure, volume, and temperature.

PH.8 The student will investigate and understand that energy can be transferred and transformed to provide usable work. Key concepts include
- transformation of energy among forms, including mechanical, thermal, electrical, gravitational, chemical, and nuclear; and
- efficiency of systems.

PH.9 The student will investigate and understand how to use models of transverse and longitudinal waves to interpret wave phenomena. Key concepts include
- wave characteristics (period, wavelength, frequency, amplitude and phase);
- fundamental wave processes (reflection, refraction, diffraction, interference, standing waves, polarization, Doppler effect); and
- light and sound in terms of wave models.

PH.10 The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation. Key concepts include
- the properties and behaviors of radio, microwaves, infra-red, visible light, ultra-violet, X-rays, and gamma rays; and
- current applications based on the wave properties of each band.

PH.11 The student will investigate and understand how light behaves in the fundamental processes of reflection, refraction, and image formation in describing optical systems. Key concepts include
- application of the laws of reflection and refraction;
- construction and interpretation of ray diagrams;
- development and use of mirror and lens equations; and
- predictions of type, size, and position of real and virtual images.

PH.12 The student will investigate and understand how to use the field concept to describe the effects of electric, magnetic, and gravitational forces. Key concepts include
- inverse square laws;
- Newton's law of universal gravitation;
- Coulomb's law; and
- operating principles of motors, generators, and cathode ray tubes.

PH.13 The student will investigate and understand how to diagram and construct basic electrical circuits and explain the function of various circuit components. Key concepts include

- Ohm's law; and
- series, parallel, and combined circuits.

PH.14 The student will investigate and understand that extremely large and extremely small quantities are not necessarily described by the same laws as those studied in Newtonian physics. Key concepts include

- wave/particle duality;
- wave properties of matter;
- matter/energy equivalence;
- quantum mechanics and uncertainty;
- relativity;
- nuclear physics;
- solid state physics;
- superconductivity; and
- radioactivity.