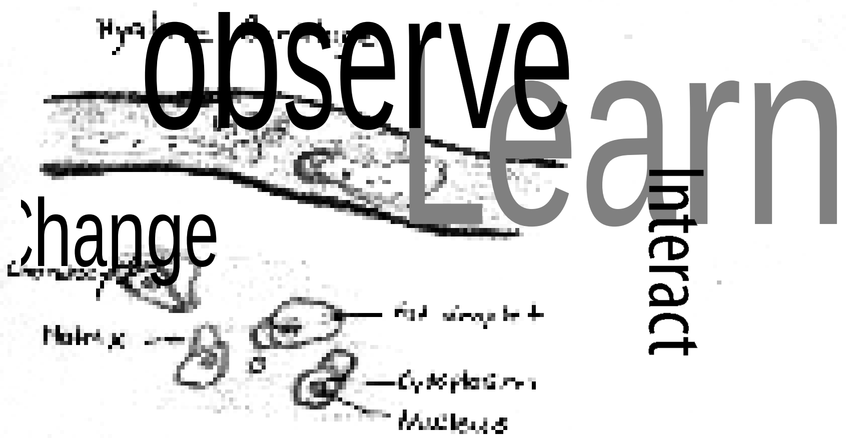
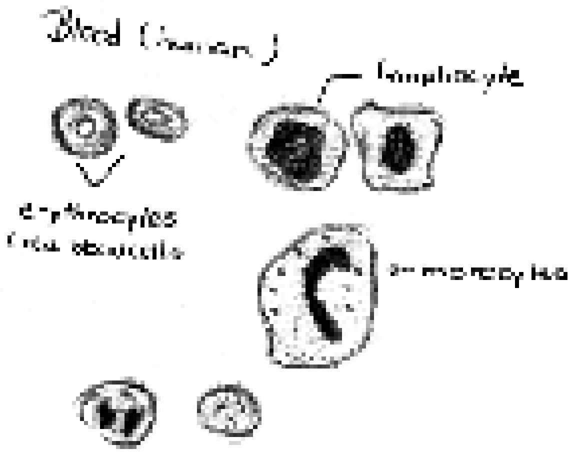
observe

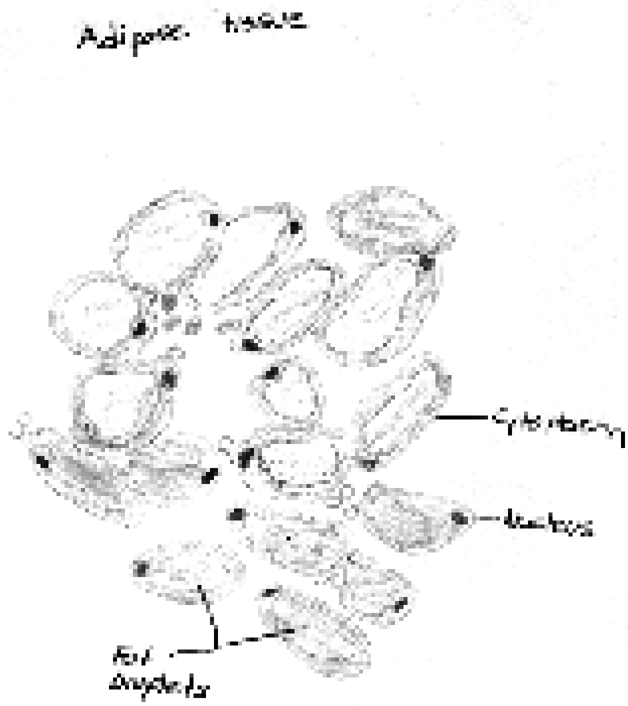
Learn

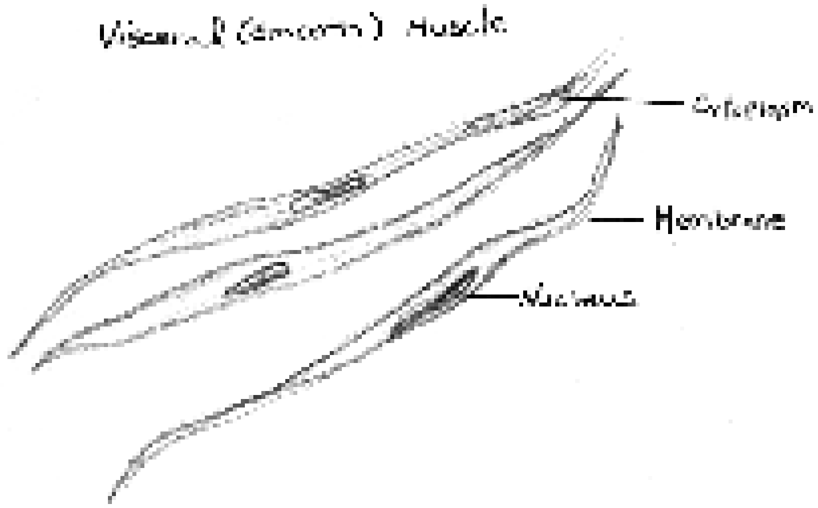
change

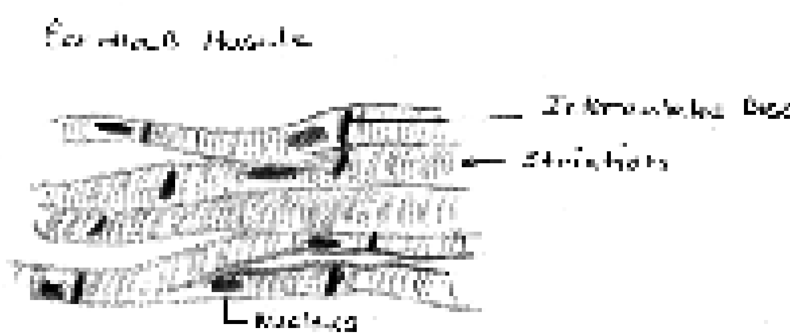
Interact











Student explanations become a baseline for instruction as teachers help students construct explanations aligned with scientific knowledge.

Content Standards: 9-12

Science as Inquiry

CONTENT STANDARD A:
As a result of activities in grades 9-12, all students should develop
- **Abilities necessary to do scientific inquiry**
- **Understandings about scientific inquiry**

DEVELOPING STUDENT ABILITIES AND UNDERSTANDING

For students to develop the abilities that characterize science as inquiry, they must actively participate in scientific investigations, and they must actually use the cognitive and manipulative skills associated with the formulation of scientific explanations. This standard describes the fundamental abilities and understandings of inquiry, as well as a larger framework for conducting scientific investigations of natural phenomena.

In grades 9-12, students should develop sophistication in their abilities and understanding of scientific inquiry. Students can understand that experiments are guided by concepts and are performed to test ideas. Some students still have trouble with variables and controlled experiments. Further, students often have trouble dealing with data that seem anomalous and in proposing explanations based on evidence and logic rather than on their prior beliefs about the natural world.

One challenge to teachers of science and to curriculum developers is making science investigations meaningful. Investigations should derive from questions and issues that have meaning for students. Scientific topics that have been highlighted by current events provide one source, whereas actual science- and technology-related problems provide another source of meaningful investigations. Finally, teachers of science should remember that some experiences begin with little meaning for students but develop meaning through active involvement, continued exposure, and growing skill and understanding.

A critical component of successful scientific inquiry in grades 9-12 includes having students reflect on the concepts that guide the inquiry. Also important is the prior establishment of an adequate knowledge base to support the investigation and help develop scientific explanations. The concepts of the world that students bring to school will shape the way they engage in science investigations, and serve as filters for their explanations of scientific phenomena. Left unexamined, the limited nature of students' beliefs will interfere with their ability to develop a deep understanding of science. Thus, in a full inquiry, instructional strategies such as small-group discussions, labeled drawings, writings, and concept mapping should be used by the teacher of science to gain information about students' current explanations. Those student explanations then become a baseline for instruction as teachers help students construct explanations aligned with scientific knowledge; teachers also help students evaluate their own explanations and those made by scientists.

Students also need to learn how to analyze evidence and data. The evidence they analyze may be from their investigations, other students' investigations, or databases. Data manipulation and analysis strategies need to be modeled by teachers of science and practiced by students. Determining the range of the data, the mean and mode values of the data, plotting the data, developing mathematical functions from the data,and looking for anomalous data are all examples of analyses students can perform. Teachers of science can ask questions, such as "What explanation did you expect to develop from the data?" "Were there any surprises in the data?" "How confident do you feel about the accuracy of the data?"Students should answer questions such as these during full and partial inquiries.

Public discussions of the explanations proposed by students is a form of peer review of investigations, and peer review is an important aspect of science. Talking with peers about science experiences helps students develop meaning and understanding. Their conversations clarify the concepts and processes of science, helping students make sense of the content of science. Teachers of science should engage students in conversations that focus on questions, such as "How do we know?" "How certain are you of those results?" "Is there a better way to do the investigation?" "If you had to explain this to someone who knew nothing about the project, how would you do it?" "Is there an alternative scientific explanation for the one we proposed?" "Should we do the investigation over?" "Do we need more evidence?" "What are our sources of experimental error?" "How do you account for an explanation that is different from ours?"

Questions like these make it possible for students to analyze data, develop a richer knowledge base, reason using science concepts, make connections between evidence and explanations, and recognize alternative explanations. Ideas should be examined and discussed in class so that other students can benefit from the feedback. Teachers of science can use the ideas of students in their class,ideas from other classes, and ideas from texts, databases, or other sources—but scientific ideas and methods should be discussed in the fashion just described.

GUIDE TO THE CONTENT STANDARD

Fundamental abilities and concepts that underlie this standard include

ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

IDENTIFY QUESTIONS AND CONCEPTS THAT GUIDE SCIENTIFIC INVESTIGATIONS. Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations.

DESIGN AND CONDUCT SCIENTIFIC INVESTIGATIONS. Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence,apply logic, and construct an argument for their proposed explanations.

USE TECHNOLOGY AND MATHEMATICS TO IMPROVE INVESTIGATIONS AND COMMUNICATIONS. A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example,measurement is used for posing questions, formulas are used for developing explanations,and charts and graphs are used for communicating results.

FORMULATE AND REVISE SCIENTIFIC EXPLANATIONS AND MODELS USING LOGIC AND EVIDENCE. Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic,and evidence from their investigation.

RECOGNIZE AND ANALYZE ALTERNATIVE EXPLANATIONS AND MODELS. This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal weight. Students should be able to use scientific criteria to find the preferred explanations.

See Teaching Standard B in Chapter 3

COMMUNICATE AND DEFEND A SCIENTIFIC ARGUMENT. Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments.

UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

See Unifying Concepts and Processes

- Scientists usually inquire about how physical,living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.
- Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.

See Content Standard E (grades 9-12)

- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.

See Program Standard C

- Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.
- Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena,investigations,and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.

Physical Science

CONTENT STANDARD B:
As a result of their activities in grades 9-12, all students should develop an understanding of

- **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**

DEVELOPING STUDENT UNDERSTANDING

High-school students develop the ability to relate the macroscopic properties of substances that they study in grades K-8 to the microscopic structure of substances. This development in understanding requires students to move among three domains of thought—the macroscopic world of observable phenomena, the microscopic world of molecules,atoms, and subatomic particles, and the symbolic and mathematical world of chemical formulas, equations, and symbols.

The relationship between properties of matter and its structure continues as a major component of study in 9-12 physical science. In the elementary grades, students studied the properties of matter and the classification of substances using easily observable properties. In the middle grades,they examined change of state,solutions, and simple chemical reactions, and developed enough knowledge and experience to define the properties of elements and compounds. When students observe and integrate a wide variety of evidence, such as seeing copper "dissolved" by an acid into a solution and then retrieved as pure copper when it is displaced by zinc, the idea that copper atoms are the same for any copper object begins to make sense. In each of these reactions, the knowledge that the mass of the substance does not change can be interpreted by assuming that the number of particles does not change during their rearrangement in the reaction.Studies of student understanding of molecules indicate that it will be difficult for them to comprehend the very small size and large number of particles involved. The connection between the particles and the chemical formulas that represent them is also often not clear.

It is logical for students to begin asking about the internal structure of atoms, and it will be difficult, but important, for them to know "how we know." Quality learning and the spirit and practice of scientific inquiry are lost when the evidence and argument for atomic structure are replaced by direct assertions by the teacher and text. Although many experiments are difficult to replicate in school,students can read some of the actual reports and examine the chain of evidence that led to the development of the current concept of the atom. The nature of the atom is far from totally understood; scientists continue to investigate atoms and have discovered even smaller constituents of which neutrons and protons are made.

Laboratory investigation of the properties of substances and their changes through a range of chemical interactions provide a basis for the high school graduate to understand a variety of reaction types and their applications, such as the capability to liberate elements from ore, create new drugs, manipulate the structure of genes, and synthesize polymers.

Understanding of the microstructure of matter can be supported by laboratory experiences with the macroscopic and microscopic world of forces, motion (including vibrations and waves), light,and electricity. These experiences expand upon the ones that the students had in the middle school and provide new ways of understanding the movement of muscles, the transport of materials across cell membranes, the behavior of atoms and molecules, communication technologies, and the movement of planets and galaxies. By this age, the concept of a force is better understood, but static forces in equilibrium and students' intuitive ideas about forces on projectiles and satellites still resist change through instruction for a large percentage of the students.

On the basis of their experiences with energy transfers in the middle grades, high-school students can investigate energy transfers quantitatively by measuring variables such as temperature change and kinetic energy. Laboratory investigations and descriptions of other experiments can help students understand the evidence that leads to the conclusion that energy is conserved. Although the operational distinction between temperature and heat can be fairly well understood after careful instruction, research with high-school students indicates that the idea that heat is the energy of random motion and vibrating molecules is difficult for students to understand.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

STRUCTURE OF ATOMS

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.
- The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fission is the splitting of a large nucleus into smaller pieces. Fusion is the joining of two nuclei at extremely high temperature and pressure, and is the process responsible for the energy of the sun and other stars.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation. The decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate. This predictability can be used to estimate the age of materials that contain 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.
- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements

with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

- Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.
- The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.
- Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart.
- 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

See Content Standard C (Grades 9-12)

- Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies.
- Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.
- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are 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 of fossil fuels, the formation of polymers, and explosions.
- Chemical reactions can take place in time periods ranging from the few femtoseconds (10^{-15} seconds) required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. Reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties—including shape—of the reacting species.
- Catalysts, such as metal surfaces, 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. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F = ma, which is independent of the nature of the force. 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 strength of the gravitational attractive force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.
- The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the force is proportional to the charges, and, as with gravitation, inversely proportional to the square of the distance between them.
- Between any two charged particles, electric force is vastly greater than the gravitational force. Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules.
- Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. These effects help students to understand electric motors and generators.

CONSERVATION OF ENERGY AND THE INCREASE IN DISORDER

See Content Standard C (grades 9-12)

- The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.
- All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
- Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.
- 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. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection and the warming of our surroundings when we burn fuels.

INTERACTIONS OF ENERGY AND MATTER

See Content Standard D (grades 9-12)

- Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.
- Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.
- 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. These wavelengths can be used to identify the substance.
- In some materials, such as metals, electrons flow easily, whereas in insulating materials such as glass they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures some materials become superconductors and offer no resistance to the flow of electrons.

Life Science

CONTENT STANDARD C:
As a result of their activities in grades 9-12, all students should develop understanding of

- **The cell**
- **Molecular basis of heredity**
- **Biological evolution**
- **Interdependence of organisms**
- **Matter, energy, and organization in living systems**
- **Behavior of organisms**

DEVELOPING STUDENT UNDERSTANDING

Students in grades K-8 should have developed a foundational understanding of life sciences. In grades 9-12, students' understanding of biology will expand by incorporating more abstract knowledge, such as the structure and function of DNA, and more comprehensive theories, such as evolution. Students' understandings should encompass scales that are both smaller, for example, molecules, and larger, for example, the biosphere.

Teachers of science will have to make choices about what to teach that will most productively develop student understanding of the life sciences. All too often, the criteria for selection are not clear, resulting in an overemphasis on information and an underemphasis on conceptual understanding. In describing the content for life sciences, the national standards focus on a small number of general principles that can serve as the basis for teachers and students to develop further understanding of biology.

Because molecular biology will continue into the twenty-first century as a major frontier of science, students should understand the chemical basis of life not only for its own sake, but because of the need to take informed positions on some of the practical and ethical implications of humankind's capacity to manipulate living organisms.

In general, students recognize the idea of species as a basis for classifying organisms, but few students will refer to the genetic basis of species. Students may exhibit a general understanding of classification. However, when presented with unique organisms, students sometimes appeal to "everyday" classifications, such as viewing jellyfish as fish because of the term "fish," and penguins as amphibians because they live on land and in water.

Although students may indicate that they know about cells, they may say that living systems are made of cells but not molecules, because students often associate molecules only with physical science.

Students have difficulty with the fundamental concepts of evolution. For example, students often do not understand natural

Fossils

The investigation in this example centers on the use of fossils to develop concepts about variation of characteristics in a population, evolution—including indicators of past environments and changes in those environments, the role of climate in biological adaptation, and use of geological data. High-school students generally exhibit interest in fossils and what the fossils indicate about organisms and their habitats. Fossils can be purchased from scientific supply houses, as well as collected locally in some places. In the investigation described here, the students conduct an inquiry to answer an apparently simple question: Do two slightly different fossils represent an evolutionary trend? In doing the activity, students rely on prior knowledge from life science. They use mathematical knowledge and skill. The focus of the discussion is to explain organized data.

[This example highlights some elements of Teaching Standards A, B, D, and E; 9-12 Content Standards A, C, D and the Unifying Concepts and Processes; and Program Standards A and C.]

The investigation begins with a task that students originally perceive as easy—describing the characteristics of two brachiopods to see if change has occurred. The student inquiries begin when the teacher, Mr. D., gives each student two similar but slightly different fossils and asks the students if they think an evolutionary trend can be discerned. The openness and ambiguity of the question results in mixed responses. Mr. D. asks for a justification of each answer and gently challenges the students' responses by posing questions such as: "How do you know? How could you support your answer? What evidence would you need? What if these fossils were from the same rock formation? How do you know that the differences are not normal variations in this species? What if the two fossils were from rock formations deposited 10 millions years apart? Can you tell if evolution has or has not occurred by examining only two samples?"

Mr. D. shows students two trays, each with about 100 carefully selected fossil brachiopods. He asks the students to describe the fossils. After they have had time to examine the fossils, he hears descriptions such as "They look like butterflies," and "They are kind of triangular with a big middle section and ribs." Then he asks if there are any differences between the fossils in the two trays. The students quickly conclude that they cannot really tell any differences based on the general description, so Mr. D. asks how they could tell if the fossil populations were different. From the ensuing discussion, students determine that quantitative description of specific characteristics, such as length, width, and number of ribs are most helpful.

Mr. D. places the students in groups of four and presents them with two trays of brachiopods. They are told to measure, record, and graph some characteristics of the brachiopod populations. The students decide what they want to measure and how to do it. They work for a class period measuring and entering their data on length and width of the brachiopods in the populations in a computer database. When all data are entered, summarized, and graphed, the class results resemble those displayed in the figure.

The students begin examining the graphs showing frequency distribution of the length and width of fossils. As the figure

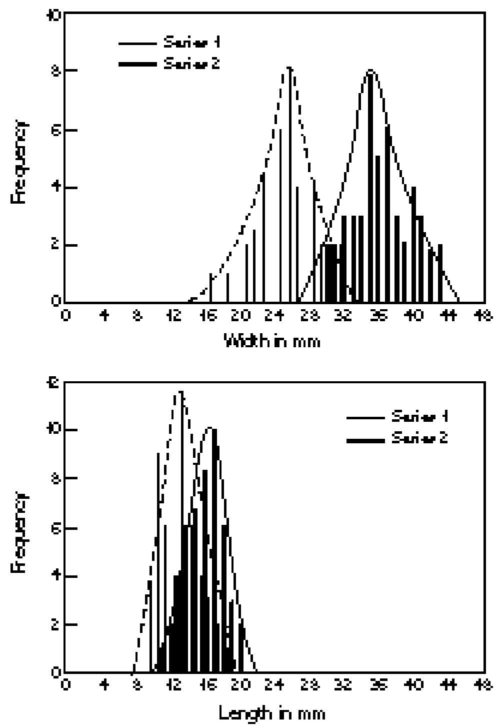


Figure 1. Graph showing characteristics of branchiopod populations.

indicates, the results for either dimension show a continuous variation for the two populations. Students observe that regardless of the dimension measured, the mean for the two populations differs.

After the graphs are drawn, Mr. D. asks the students to explain the differences in the populations. The students suggest several general explanations: evolution has not occurred—these are simply different kinds of brachiopods; evolution has occurred—the differences in the means for length and width demonstrate evolutionary change in the populations; evolution has not occurred—the differences are a result of normal variations in the populations.

Mr. D. takes time to provide some background information that the students should consider. He notes that evolution occurs in populations, and changes in a population's environment result in selection for those organisms best fit for the new environment. He continues with a few questions that again challenge the students' thinking: Did the geological evidence indicate the environment changed? How can you be sure that the fossils were not from different environments and deposited within a scale of time that would not explain the degree of evolutionary change? Why would natural selection for differences in length and width of brachiopods occur? What differences in structure and function are represented in the length and width of brachiopods?

The students must use the evidence from their investigations and other reviews of scientific literature to develop scientific explanations for the aforementioned general explanations. They take the next class period to complete this assignment.

After a day's work by the students on background research and preparation, Mr. D. holds a small conference at which the students' papers are presented and discussed. He focuses students on their ability to ask skeptical questions, evaluate the use of evidence, assess the understanding of geological and biological concepts, and review aspects of scientific inquiries. During the discussions, students are directed to address the following questions: What evidence would you look for that might indicate these brachiopods were the same or different species? What constitutes the same or different species? Were the rocks in which the fossils were deposited formed at the same or different times? How similar or different were the environments of deposition of the rocks? What is the effect of sample size on reliability of conclusions?

selection because they fail to make a conceptual connection between the occurrence of new variations in a population and the potential effect of those variations on the long-term survival of the species. One misconception that teachers may encounter involves students attributing new variations

Many misconceptions about the process of natural selection can be changed through instruction.

to an organism's need, environmental conditions, or use. With some help, students can understand that, in general, mutations occur randomly and are selected because they help some organisms survive and produce more offspring. Other misconceptions center on a lack of understanding of how a population changes as a result of differential reproduction (some individuals producing more offspring), as opposed to all individuals in a population changing. Many misconceptions about the process of natural selection can be changed through instruction.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

THE CELL

See Unifying Concepts and Processes

- Cells have particular structures that underlie their functions. Every cell is surrounded by a membrane that separates it from the outside world. Inside the cell is a concentrated mixture of thousands of different molecules which form a variety of specialized structures that carry out such cell functions as energy production, transport of molecules, waste disposal, synthesis of new molecules,and the storage of genetic material.
- Most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell.
- Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires.
- Cell functions are regulated. Regulation occurs both through changes in the activity of the functions performed by proteins and through the selective expression of individual genes. This regulation allows cells to respond to their environment and to control and coordinate cell growth and division.
- Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.
- Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. In the development of

these multicellular organisms, the progeny from a single cell form an embryo in which the cells multiply and differentiate to form the many specialized cells, tissues and organs that comprise the final organism. This differentiation is regulated through the expression of different genes.

THE MOLECULAR BASIS OF HEREDITY

See Content Standard B (grades 9-12)

- In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular "letters") and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome.
- Most of the cells in a human contain two copies of each of 22 different chromosomes. In addition, there is a pair of chromosomes that determines sex: a female contains two X chromosomes and a male contains one X and one Y chromosome. Transmission of genetic information to offspring occurs through egg and sperm cells that contain only one representative from each chromosome pair. An egg and a sperm unite to form a new individual. The fact that the human body is formed from cells that contain two copies of each chromosome—and therefore two copies of each gene—explains many features of human heredity, such as how variations that are hidden in one generation can be expressed in the next.
- Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms.Only mutations in germ cells can create the variation that changes an organism's offspring.

BIOLOGICAL EVOLUTION

See Unifying Concepts and Processes

- Species evolve over time. Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection by the environment of those offspring better able to survive and leave offspring.
- The great diversity of organisms is the result of more than 3.5 billion years of evolution that has filled every available niche with life forms.
- Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life forms, as well as for the striking molecular similarities observed among the diverse species of living organisms.
- The millions of different species of plants, animals,and microorganisms that live on earth today are related by descent from common ancestors.
- Biological classifications are based on how organisms are related.Organisms are classified into a hierarchy of groups and subgroups based on similarities which reflect their evolutionary relationships. Species is the most fundamental unit of classification.

THE INTERDEPENDENCE OF ORGANISMS

- The atoms and molecules on the earth cycle among the living and nonliving components of the biosphere.
- Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers.
- Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years.
- Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite. This fundamental tension has profound effects on the interactions between organisms.
- Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors is threatening current global stability, and if not addressed, ecosystems will be irreversibly affected.

MATTER, ENERGY, AND ORGANIZATION IN LIVING SYSTEMS

See Unifying Concepts and Processes

- All matter tends toward more disorganized states.Living systems require a continuous input of energy to maintain their chemical and physical organizations. With death, and the cessation of energy input, living systems rapidly disintegrate.
- The energy for life primarily derives from the sun. Plants capture energy by absorbing light and using it to form strong (covalent) chemical bonds between the atoms of carbon-containing (organic) molecules. These molecules can be used to assemble larger molecules with biological activity (including proteins, DNA, sugars, and fats). In addition, the energy stored in bonds between the atoms (chemical energy) can be used as sources of energy for life processes.
- The chemical bonds of food molecules contain energy. Energy is released when the bonds of food molecules are broken and new compounds with lower energy bonds are formed. Cells usually store this energy temporarily in phosphate bonds of a small high-energy compound called ATP.
- The complexity and organization of organisms accommodates the need for obtaining, transforming, transporting, releasing, and eliminating the matter and energy used to sustain the organism.
- The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials.
- As matter and energy flows through different levels of organization of living systems—cells, organs, organisms, communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into

the environment as heat. Matter and energy are conserved in each change.

THE BEHAVIOR OF ORGANISMS

- Multicellular animals have nervous systems that generate behavior. Nervous systems are formed from specialized cells that conduct signals rapidly through the long cell extensions that make up nerves. The nerve cells communicate with each other by secreting specific excitatory and inhibitory molecules. In sense organs, specialized cells detect light, sound, and specific chemicals and enable animals to monitor what is going on in the world around them.
- Organisms have behavioral responses to internal changes and to external stimuli. Responses to external stimuli can result from interactions with the organism's own species and others, as well as environmental changes; these responses either can be innate or learned. The broad patterns of behavior exhibited by animals have evolved to ensure reproductive success. Animals often live in unpredictable environments, and so their behavior must be flexible enough to deal with uncertainty and change. Plants also respond to stimuli.
- Like other aspects of an organism's biology, behaviors have evolved through natural selection. Behaviors often have an adaptive logic when viewed in terms of evolutionary principles.
- Behavioral biology has implications for humans, as it provides links to psychology, sociology, and anthropology.

Earth and Space Science

CONTENT STANDARD D:
As a result of their activities in grades 9-12, all students should develop an understanding of

- **Energy in the earth system**
- **Geochemical cycles**
- **Origin and evolution of the earth system**
- **Origin and evolution of the universe**

DEVELOPING STUDENT UNDERSTANDING

During the high school years, students continue studying the earth system introduced in grades 5-8. At grades 9-12, students focus on matter, energy, crustal dynamics, cycles, geochemical processes, and the expanded time scales necessary to understand events in the earth system. Driven by sunlight and earth's internal heat, a variety of cycles connect and continually circulate energy and material through the components of the earth system. Together, these cycles establish the structure of the earth system and regulate earth's climate. In grades 9-12, students review the water cycle as a carrier of material, and deepen their understanding of this key cycle to see that it is also an important agent for energy transfer. Because it plays a central role in establishing and maintaining earth's climate and the production of many mineral and fossil fuel resources, the students' explorations are also directed toward the carbon cycle. Students use and extend their understanding of how the processes of radiation, convection, and conduction transfer energy through the earth system.

In studying the evolution of the earth system over geologic time, students develop a deeper understanding of the evidence, first introduced in grades 5-8, of earth's past and unravel the interconnected story of earth's dynamic crust, fluctuating climate, and evolving life forms. The students' studies develop the concept of the earth system existing in a state of dynamic equilibrium. They will discover that while certain properties of the earth system may fluctuate on short or long time scales, the earth system will generally stay within a certain narrow range for millions of years. This long-term stability can be understood through the working of planetary geochemical cycles and the feedback processes that help to maintain or modify those cycles.

As an example of this long-term stability, students find that the geologic record suggests that the global temperature has fluctuated within a relatively narrow range, one that has been narrow enough to enable life to survive and evolve for over three billion years. They come to understand that some of the small temperature fluctuations have produced what we perceive as dramatic effects in the earth system, such as the ice ages and the extinction of entire species. They explore the regulation of earth's global temperature by the water and carbon cycles. Using this background, students can examine environmental changes occurring today and make predictions about future temperature fluctuations in the earth system.

Looking outward into deep space and deep time, astronomers have shown that we live in a vast and ancient universe. Scientists assume that the laws of matter are the same in all parts of the universe and over billions of years. It is thus possible to understand the structure and evolution of the universe through laboratory experiments and current observations of events and phenomena in the universe.

. . . as many as half of the students in this age group will need many concrete examples and considerable help in following the multistep logic necessary to develop the understandings described here.

Until this grade level, astronomy has been largely restricted to the behavior of objects in the solar system. In grades 9-12, the study of the universe becomes more abstract as students expand their ability to comprehend large distances, long time scales, and the nature of nuclear reactions. The age of the universe and its evolution into galaxies, stars, and planets—and eventually life on earth—fascinates and challenges students.

The challenge of helping students learn the content of this standard will be to present understandable evidence from sources that range over immense timescales—and from studies of the earth's interior to observations from outer space. Many students are capable of doing this kind of thinking, but as many as half will need concrete examples and considerable help in following the multistep logic necessary to develop the understandings described in this standard. Because direct experimentation is usually not possible for many concepts associated with earth and space science, it is important to maintain the spirit of inquiry by focusing the teaching on questions that can be answered by using observational data, the knowledge base of science, and processes of reasoning.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

ENERGY IN THE EARTH SYSTEM

- Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation.

See content Standard B (grades 9-12)

- The outward transfer of earth's internal heat drives convection circulation in the mantle that propels the plates comprising earth's surface across the face of the globe.
- Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents.
- Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges 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 chemical reservoirs. Each element on earth 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. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

It is important to maintain the spirit of inquiry by focusing the teaching on questions that can be answered by using observational data, the knowledge base of science, and processes of reasoning.

THE ORIGIN AND EVOLUTION OF THE EARTH SYSTEM

- The sun, the earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. The early earth was very different from the planet we live on today.
- Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates of radioactive isotopes present in rocks to measure the time since the rock was formed.
- Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of

the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years.

- Evidence for one-celled forms of life—the bacteria—extends back more than 3.5 billion years. The evolution of life caused dramatic changes in the composition of the earth's atmosphere, which did not originally contain oxygen.

THE ORIGIN AND EVOLUTION OF THE UNIVERSE

See Content Standard A (grades 9-12)

- The origin of the universe remains one of the greatest questions in science. The "big bang" theory places the origin between 10 and 20 billion years ago, when the universe began in a hot dense state; according to this theory, the universe has been expanding ever since.
- Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars. Billions of galaxies, each of which is a gravitationally bound cluster of billions of stars, now form most of the visible mass in 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 the other elements.

Science and Technology

CONTENT STANDARD E:
As a result of activities in grades 9-12, all students should develop

- **Abilities of technological design**
- **Understandings about science and technology**

DEVELOPING STUDENT ABILITIES AND UNDERSTANDING

This standard has two equally important parts—developing students' abilities of technological design and developing students' understanding about science and technology. Although these are science education standards,the relationship between science and technology is so close that any presentation of science without developing an understanding of technology would portray an inaccurate picture of science.

In the course of solving any problem where students try to meet certain criteria within constraints,they will find that the ideas and methods of science that they know, or can learn, can be powerful aids. Students also find that they need to call on other sources of knowledge and skill, such as cost, risk, and benefit analysis, and aspects of critical thinking and creativity. Learning experiences associated with this standard should include examples of technological achievement in which science has played a part and examples where technological advances contributed directly to scientific progress.

Students can understand and use the design model outlined in this standard. Students respond positively to the concrete, practical,outcome orientation of design problems before they are able to engage in the abstract, theoretical nature of many scientific inquiries. In general, high school students do not distinguish between the roles of science and technology. Helping them do so is implied by this standard. This lack of distinction between science and technology is further confused by students' positive perceptions of science, as when they associate it with medical research and use the common phrase "scientific progress." However, their association of technology is often with environmental problems and another common phrase, "technological problems." With regard to the connection between science and technology, students as well as many adults and teachers of science indicate a belief that science influences technology. This belief is captured by the common and only partially accurate definition "technology is applied science." Few students understand that technology influences science. Unraveling these misconceptions of science and technology and developing accurate concepts of the role, place, limits, possibilities and relationships of science and technology is the challenge of this standard.

The choice of design tasks and related learning activities is an important and difficult part of addressing this standard. In choosing technological learning activities, teachers of science will have to bear in mind some important issues. For example, whether to involve students in a full or partial design problem; or whether to engage them in meeting a need through technology or in studying the technological work of others. Another issue is how to select a task that brings out the various ways in which science and technology interact, providing a basis for reflection on the nature of technology while learning the science concepts involved.

In grades 9-12, design tasks should explore a range of contexts including both those immediately familiar in the homes, school, and community of the students and those from wider regional, national, or global contexts. The tasks should promote different ways to tackle the problems so that different design solutions can be implemented by different students. Successful completion of design problems requires that the students meet criteria while addressing conflicting constraints. Where constructions are involved, these might draw on technical skills and understandings developed within the science program, technical and craft skills developed in other school work, or require developing new skills.

Over the high school years, the tasks should cover a range of needs, of materials, and of different aspects of science. For example,a suitable design problem could include assembling electronic components to control a sequence of operations or analyzing the features of different athletic shoes to see the criteria and constraints imposed by the sport, human anatomy, and materials. Some tasks should involve science ideas drawn from more than one field of science. These can be complex, for example, a machine that incorporates both mechanical and electrical control systems.

Although some experiences in science and technology will emphasize solving problems and meeting needs by focusing on products, experience also should include problems about system design, cost, risk, benefit, and very importantly, tradeoffs.

Because this study of technology occurs within science courses, the number of these activities must be limited. Details specified in this standard are criteria to ensure quality and balance in a small number of tasks and are not meant to require a large number of such activities. Many abilities and understandings of this standard can be developed as part of activities designed for other content standards.

GUIDE TO THE CONTENT STANDARD

Fundamental abilities and concepts that underlie this standard include

ABILITIES OF TECHNOLOGICAL DESIGN

See Content Standard A (grades 9-12)

IDENTIFY A PROBLEM OR DESIGN AN OPPORTUNITY. Students should be able to identify new problems or needs and to change and improve current technological designs.

PROPOSE DESIGNS AND CHOOSE BETWEEN ALTERNATIVE SOLUTIONS. Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes.

IMPLEMENT A PROPOSED SOLUTION. A variety of skills can be needed in proposing a solution depending on the type of technology that is involved. The construction of artifacts can require the skills of cutting, shaping, treating, and joining common materials—such as wood, metal, plastics, and textiles. Solutions can also be implemented using computer software.

EVALUATE THE SOLUTION AND ITS CONSEQUENCES. Students should test any solution against the needs and criteria it was designed to meet. At this stage, new criteria not originally considered may be reviewed.

See Teaching Standard B

COMMUNICATE THE PROBLEM, PROCESS, AND SOLUTION. Students should present their results to students, teachers, and others in a variety of ways, such as orally, in writing, and in other forms—including models,diagrams, and demonstrations.

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 explanations. Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines.
- Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.
- 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, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans

adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world.

- Technological knowledge is often not made public because of patents and the financial potential of the idea or invention. Scientific knowledge is made public through presentations at professional meetings and publications in scientific journals.

Science in Personal and Social Perspectives

CONTENT STANDARD F:
As a result of activities in grades 9-12, all students should develop understanding of

- **Personal and community health**
- **Population growth**
- **Natural resources**
- **Environmental quality**
- **Natural and human-induced hazards**
- **Science and technology in local, national, and global challenges**

DEVELOPING STUDENT UNDERSTANDING

The organizing principles for this standard do not identify specific personal and societal challenges, rather they form a set of conceptual organizers, fundamental understandings, and implied actions for most contemporary issues. The organizing principles apply to local as well as global phenomena and represent challenges that occur on scales that vary from quite short—for example, natural hazards—to very long—for example, the potential result of global changes.

By grades 9-12, many students have a fairly sound understanding of the overall functioning of some human systems, such

The organizing principles apply to local as well as global phenomena.

as the digestive, respiratory, and circulatory systems. They might not have a clear understanding of others, such as the human nervous, endocrine, and immune systems. Therefore, students may have difficulty with specific mechanisms and processes related to health issues.

Most high school students have a concept of populations of organisms, but they have a poorly developed understanding of the relationships among populations within a community and connections between populations and other ideas such as competition for resources. Few students understand and apply the idea of interdependence when considering interactions among populations, environments, and resources. If, for example, students are asked about the size of populations and why some populations would be larger, they often simply describe rather than reason about interdependence or energy flow.

Students may exhibit a general idea of cycling matter in ecosystems, but they may center on short chains of the cyclical process

Photosynthesis

In this example, Ms. M. believes that her understanding of the history of scientific ideas enriches her understanding of the nature of scientific inquiry. She also wants the students to understand how ideas in science develop, change, and are influenced by values, ideas, and resources prevalent in society at any given time. She uses an historical approach to introduce an important concept in life science. She provokes an interest in the topic by purposely showing an overhead beyond what is developmentally appropriate for high-school students. Her lecture is interrupted with questions that encourage discussion among students. The research activity, primarily using print material which she has been collecting for a long time, includes discussion. The questions about factors that might influence contemporary research return the students to issues that are of immediate concern to them.

[This example highlights some elements of Teaching Standards A and B; 9-12 Content Standards A, C, F and G; and Program Standard B.]

Ms.M. was beginning the second round of planning for the high-school biology class. She had set aside three weeks for a unit on green plants. Now it was time to decide what would happen during those three weeks. Students came to the class with some knowledge and understanding about green plants, but they still had many questions. As a way to get students to focus some of their questions, and to highlight the interdependence of science and civilization, she was going to begin the unit with a lecture on photosynthesis. Lecturing was something she seldom did. However, the purpose here was not to lay out the details of the photosynthetic process, but to illustrate how the scientific community's knowledge of photosynthesis had changed over time.

She would begin the lecture by putting a transparency on the overhead projector of that detailed diagram of photosynthesis which had been sent to her free from one of the pharmaceutical companies. One of the high-school textbooks that she kept as a reference said that scientists now had described 80 separate but interdependent reactions that made up photosynthesis. The high-school students would not study these reactions. Rather, she wanted the students to observe the complexity of the current knowledge about photosynthesis, and this diagram was a useful introduction to her lecture. She would ask the students how long the scientific community had known about these many complex reactions; why this knowledge was important; how they had come to know so much; was there still more detail to be described?

Next she would ask the students to tell her what they already knew about photosynthesis. She expected most would recall that carbon dioxide,water, sugar, oxygen and sunlight were important and many would recall growing plants in dark cupboards and under boxes in middle school. The next two questions would have to be worded carefully: Why is photosynthesis so important or, put another way, what is the fundamental question that photosynthesis answers? And how long have scientists known about photosynthesis?

With this introduction, she would lecture about the seventeenth century experiment of van Helmont and his tree and his conclusion that the weight of the plants came from water. Ms.M. would pause. “Was van Helmont wrong?”, she would ask the students. She expected them to have difficulty conceiving that van Helmont had conducted an experiment, which they knew was essential to science, but that he had not obtained the answer they knew was correct. Ms.M. would help them analyze the experiment and the conclusions that could legitimately be drawn from it. She would then introduce more of the context of van Helmont’s investigation: the prevailing belief about plants as a combination of fire and earth and how van Helmont’s study was designed to refute this belief. She would comment that many researchers chose to repeat the tree study, and then she would allow students to discuss how (or whether) van Helmont’s study had contributed to the science of photosynthesis.

She would then continue her historical lecture using similar details from several other episodes. She would describe how chemists had learned to collect gases from chemical reactions, how Priestley used these new techniques, and how he then observed the effect that gases from plants produced on burning candles. She would note that Priestley did not know about oxygen, but viewed it as a purer form of air. She would mention how Ingenhousz expanded Priestley’s finding by showing that the air was changed only when the plants were kept in sunlight,and how de Saussure confirmed that carbon dioxide was a gas needed for the same effect. She would detail how James Hutton had been involved in industrial debates about the quality of coal and was interested in why coal burned. He had interpreted plant imprints in coal as a clue that something from the sun was being stored in

plants and then fossilized as coal. The "something" would later be released again as light and heat as the coal burned. But Hutton had no concept of chemical or light energy—concepts introduced only decades later by Julius Mayer. Ms. M. would stop her history here. Students would review how various factors had shaped the development of early knowledge about photosynthesis. She would record and organize their views on the chalkboard. From this they would develop a set of questions for continuing the history on their own.

Ms. M. had collected a number of textbooks from different periods in the century. She would introduce them as a resource for sketching the changing status of knowledge about photosynthesis.She would have the students work in groups of five.Each group would prepare a brief presentation on ideas of photosynthesis during a particular historical period. After two days to gather information,each group would share the result of their research and together they would identify or infer what discoveries had been made in each period. Then, using the questions they had formulated earlier, the students would return to their groups to determine how each discovery had occurred. They would identify factors such as new technologies that were relevant to conducting investigations, the sources of funding for various research projects, the personal interests of researchers, occasions of luck or chance, and the theories that had guided research. Finally, each group would share two patterns that they had uncovered and how they had reached their conclusion.

Through this activity, students would come to realize that scientific understanding does not emerge all at once or fully formed. Further, the students recognized that each new concept reflected the personal backgrounds, time, and place of its discoverers. At the very end of the period Ms.M would ask the students to speculate on what scientists might ask about photosynthesis today or in the future, and what factors might shape their research.

and express the misconception that matter is created and destroyed at each step of the cycle rather than undergoing continuous transformation. Instruction using charts of the flow of matter through an ecosystem and emphasizing the reasoning involved with the entire process may enable students to develop more accurate conceptions.

Many high-school students hold the view that science should inform society about various issues and society should set policy about what research is important. In general, students have rather simple and naive ideas about the interactions between science and society. There is some research supporting the idea that S-T-S (science, technology, and society) curriculum helps improve student understanding of various aspects of science- and technology-related societal challenges.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

PERSONAL AND COMMUNITY HEALTH

See Content Standard C (grades 9-12)

- Hazards and the potential for accidents exist. Regardless of the environment, the possibility of injury, illness, disability, or death may be present. Humans have a variety of mechanisms—sensory, motor, emotional, social, and technological—that can reduce and modify hazards.
- The severity of disease symptoms is dependent on many factors, such as human resistance and the virulence of the disease-producing organism. Many diseases can be prevented, controlled, or cured. Some diseases, such as cancer, result from specific body dysfunctions and cannot be transmitted.
- Personal choice concerning fitness and health involves multiple factors. Personal goals, peer and social pressures, ethnic and religious beliefs, and understanding of biological consequences can all influence decisions about health practices.
- An individual's mood and behavior may be modified by substances. The modification may be beneficial or detrimental depending on the motives, type of substance, duration of use, pattern of use, level of influence, and short- and long-term effects. Students should understand that 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. Nutritional balance has a direct effect on growth and development and personal well-being. Personal and social factors—such as habits, family income, ethnic heritage, body size, advertising, and peer pressure—influence nutritional choices.
- Families serve basic health needs, especially for young children. Regardless of the family structure, individuals have families that involve a variety of physical, mental,and social relationships that influence the maintenance and improvement of health.
- Sexuality is basic to the physical, mental, and social development of humans. Students should understand that human sexuality involves biological functions,psychological motives, and cultural, ethnic, religious, and technological influences. Sex

is a basic and powerful force that has consequences to individuals' health and to society. Students should understand various methods of controlling the reproduction process and that each method has a different type of effectiveness and different health and social consequences.

POPULATION GROWTH

- Populations grow or decline through the combined effects of births and deaths,and through emigration and immigration. Populations can increase through linear or exponential growth, with effects on resource use and environmental pollution.
- Various factors influence birth rates and fertility rates, such as average levels of affluence and education,importance of children in the labor force, education and employment of women, infant mortality rates, costs of raising children, availability and reliability of birth control methods, and religious beliefs and cultural norms that influence personal decisions about family size.
- Populations can reach limits to growth. Carrying capacity is the maximum number of individuals that can be supported in a given environment. The limitation is not the availability of space, but the number of people in relation to resources and the capacity of earth systems to support human beings. Changes in technology can cause significant changes, either positive or negative, in carrying capacity.

NATURAL RESOURCES

- Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations.
- 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 have the capacity to reuse waste, but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

ENVIRONMENTAL QUALITY

See Content Standard C (grades 9-12)

- Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle,disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.
- Materials from human societies affect both physical and chemical cycles of the earth.
- Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views,and different ways humans view the earth.

NATURAL AND HUMAN-INDUCED HAZARDS

See Content Standard D (grades 9-12)

- 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. As societies have grown, become stable, and come to value aspects of the environment, vulnerability to natural processes of change has increased.

- Human activities can enhance potential for hazards. Acquisition of resources, urban growth,and waste disposal can accelerate rates of natural change.
- Some hazards, such as earthquakes, volcanic eruptions, and severe weather, are rapid and spectacular. But there are slow and progressive changes that also result in problems for individuals and societies. For example, change in stream channel position, erosion of bridge foundations, sedimentation in lakes and harbors, coastal erosions,and continuing erosion and wasting of soil and landscapes can all negatively affect society.
- Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards—ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and the accuracy with which scientists and engineers can (and cannot) predict events are important considerations.

SCIENCE AND TECHNOLOGY IN LOCAL, NATIONAL, AND GLOBAL CHALLENGES

See Content Standard E (grades 9-12)

- Science and technology are essential social enterprises, but alone they can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge.
- Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges.
- Progress in science and technology can be affected by social issues and challenges. Funding priorities for specific health problems serve as examples of ways that social issues influence science and technology.
- Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions—"What can happen?"—"What are the odds?"—and "How do scientists and engineers know what will happen?"
- 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.

History and Nature of Science

CONTENT STANDARD G:
As a result of activities in grades 9-12, all students should develop understanding of

- **Science as a human endeavor**
- **Nature of scientific knowledge**
- **Historical perspectives**

DEVELOPING STUDENT UNDERSTANDING

The *National Science Education Standards* use history to elaborate various aspects of scientific inquiry, the nature of science, and science in different historical and cultural perspectives. The standards on the history and nature of science are closely aligned with the nature of science and historical episodes described in the American Association for the Advancement of Science *Benchmarks for Scientific Literacy*. Teachers

Scientists have ethical traditions. Scientists value peer review, truthful reporting about the methods and outcomes of investigations, and making public the results of work.

of science can incorporate other historical examples that may accommodate different interests, topics, disciplines, and cultures—as the intention of the standard is to develop an understanding of the human dimensions of science, the nature of scientific knowledge, and the enterprise of science in society—and not to develop a comprehensive understanding of history.

Little research has been reported on the use of history in teaching about the nature of science. But learning about the history of science might help students to improve their general understanding of science. Teachers should be sensitive to the students' lack of knowledge and perspective on time, duration, and succession when it comes to historical study. High school students may have difficulties understanding the views of historical figures. For example, students may think of historical figures as inferior because they did not understand what we do today. This "Whiggish perspective" seems to hold for some students with regard to scientists whose theories have been displaced.

GUIDE TO THE CONTENT STANDARD

Fundamental concepts and principles that underlie this standard include

SCIENCE AS A HUMAN ENDEAVOR

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.
- Scientists have ethical traditions. Scientists value peer review, truthful reporting about the methods and outcomes of investigations, and making

public the results of work. Violations of such norms do occur, but scientists responsible for such violations are censured by their peers.

- Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.

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, as scientists strive for the best possible explanations about the natural world.
- Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.
- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism.

HISTORICAL PERSPECTIVES

- In history, diverse cultures have contributed scientific knowledge and technologic inventions. Modern science began to evolve rapidly in Europe several hundred years ago. During the past two centuries, it has contributed significantly to the industrialization of Western and non-Western cultures. However, other, non-European cultures have developed scientific ideas and solved human problems through technology.
- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our

An Analysis of a Scientific Inquiry

By the "header titles" this example emphasizes some important components of the assessment process. Any boundary between assessment and teaching is lost in this example. Students engage in an analytic activity that requires them to use their understanding of all the science content standards. The activity assumes that they have maintained journals throughout their high school career and have had much previous experience with analyzing scientific inquiry. It would be unreasonable to expect them to successfully complete such an analysis without prior experience. The assessment task requires the use of criteria developed by the class and the teacher together for self assessment and peer assessment. Students may elect to improve the analysis or do another. The teacher uses the data to decide what further inquiries, analyses, or evaluations students might do.

[This example highlights Teaching Standards A, C, and E; Assessments Standards A, B, and E; and 9-12 Content Standard G.]

SCIENCE CONTENT: This activity focuses on all aspects of the Content Standard on the History and Nature of Science: Science as a human endeavor, nature of scientific knowledge, and historical perspectives on science.

ASSESSMENT ACTIVITY: Students read an account of an historical or contemporary scientific study and report on it.

ASSESSMENT TYPE: Performance, individual, group, public.

ASSESSMENT PURPOSE: The teacher uses the information gathered in this activity for assigning grades and for planning further activities involving analysis or inquiry.

DATA: Students' individual reports; student reviews of their peers' work; and teacher's observations.

CONTEXT: This assessment activity is appropriate at the end of 12th grade. Throughout the high school science program, students have read accounts of scientific studies and the social context in which the studies were conducted. Students sometimes read the scientist's own account of the investigation and sometimes an account of the investigation written by another person. The earlier the investigation, the more likely that the high school students are able to read and understand the scientist's original account. Reports by scientists on contemporary studies are likely to be too technical for students to understand, but accounts in popular science books or magazines should be accessible to high school students. Examples of contemporary and historical accounts appropriate to this activity include

Goodfield's *An Imagined World*

Weiner's *The Beak of the Finch*

Watson's *The Double Helix*

Darwin's *Voyage of the Beagle*

Project Physics Readers

In each student's science journal are notes on his or her own inquiries and the inquiries read about throughout the school science career, including an analysis of historical context in which the study was conducted. After completing each analysis, the science teacher had reviewed and commented on the analysis as well as on the student's developing sophistication in doing analysis.Questions that guided each student's analysis include

What factors—personal, technological, cultural, and/or scientific—led this person to the investigation?

How was the investigation designed and why was it designed as it was?

What data did the investigator collect?

How did the investigator interpret the data?

How were the investigator's conclusions related to the design of the investigation and to major theoretical or cultural assumptions, if any?

How did the investigator try to persuade others? Were the ideas accepted by contemporaries? Are they accepted today? Why or why not?

How did the results of this investigation influence the investigator, fellow investigators, and society more broadly?

Were there ethical dimensions to this investigation? If so, how were they resolved?

What element of this episode seems to you most characteristic or most revealing about the process of science? Why?

ASSESSMENT EXERCISE

Each student in the class selects an account of one scientific investigation and analyzes it using the questions above. When the analyses are completed,they are handed in to the teacher who passes them out to other members of the class for peer review. Prior to the peer reviews, the teacher and the class have reviewed the framework for analysis and established criteria for evaluating the quality of the analyses. The teacher reviews the peer reviews and, if appropriate, returns them to the author. The author will have the opportunity to revise the analysis on the basis of the peer review before submitting it to the teacher for a grade.

EVALUATION OF STUDENT RESPONSES

The teacher's grade will be based both on the student's progress in conducting such analyses and on how well the analysis meets the criteria set by the teacher in consultation with the class.

ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

- Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. Examples of such advances include the following

  Copernican revolution

  Newtonian mechanics

  Relativity

  Geologic time scale

  Plate tectonics

  Atomic theory

  Nuclear physics

  Biological evolution

  Germ theory

  Industrial revolution

  Molecular biology

  Information and communication

  Quantum theory

  Galactic universe

  Medical and health technology

- The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.

References for Further Reading

SCIENCE AS INQUIRY

AAAS (American Association for the Advancement of Science).1993. Benchmarks for Science Literacy. New York: Oxford University Press.

AAAS (American Association for the Advancement of Science). 1989.Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics, and Technology. Washington DC.:AAAS.

Bechtel, W. 1988.Philosophy of Science: An Overview for Cognitive Science. Hillsdale,NJ: Lawrence Earlbaum.

Bingman, R.1969. Inquiry Objectives in the Teaching of Biology. Boulder, CO and Kansas City, MO: Biological Sciences Curriculum Study and Mid-Continent Regional Educational Laboratory.

Carey, S.,R. Evans,M. Honda,E. Jay, and C. Unger. 1989. An experiment is when you try it and see if it works:A study of grade 7 students' understanding of the construction of scientific knowledge. International Journal of Science Education, 11(5): 514-529.

Chinn,C.A.,and W.F. Brewer. 1993. The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. Review of Educational Research,63(1): 1-49.

Connelly, F.M.,M.W. Wahlstrom, M.Finegold, and F. Elbaz.1977.Enquiry Teaching in Science:A Handbook for Secondary School Teachers. Toronto, Ontario: Ontario Institute for Studies in Education.

Driver, R.1989.Students' conceptions and the learning of science: Introduction. International Journal of Science Education,11(5):481-490.

Duschl, R.A.1990. Restructuring Science Education: The Importance of Theories and Their Development. New York: Teachers College Press.

Duschl,R.A.,and R.J. Hamilton, eds.1992. Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice. Albany, NY: State University of New York Press.

Glaser, R.1984.Education and thinking: The role of knowledge. American Psychologist, 39(2): 93-104.

Grosslight,L., C. Unger, E. Jay, and C.L. Smith. 1991. Understanding models and their use in science: Conceptions of middle and high school students and experts. [Special issue] Journal of Research in Science Teaching, 28(9): 799-822.

Hewson, P.W.,and N.R. Thorley. 1989. The conditions of conceptual change in the classroom. International Journal of Science Education, 11(5):541-553.

Hodson, D. 1992. Assessment of practical work: Some considerations in philosophy of science. Science & Education,1(2): 115-134.

Hodson, D. 1985.Philosophy of science, science and science education.Studies in Science Education,12: 25-57.

Kyle, W. C. Jr. 1980. The distinction between inquiry and scientific inquiry and why high school students should be cognizant of the distinction. Journal of Research in Science Teaching, 17(2): 123-130.

Longino, H.E.1990.Science as Social Knowledge: Values and Objectivity in Scientific Inquiry. Princeton, NJ: Princeton University Press.

Mayer, W.V., ed.1978.BSCS Biology Teachers' Handbook,third edition. New York: John Wiley and Sons.

Metz,K.E.1991. Development of explanation: Incremental and fundamental change in children's physics knowledge.[Special issue] Journal of Research in Science Teaching, 28(9): 785-797.

NRC (National Research Council).1988. Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12. R.J. Murnane,and S.A. Raizen, eds. Washington, DC: National Academy Press.

NSRC (National Science Resources Center). 1996. Resources for Teaching Elementary School Science. Washington, DC: National Academy Press.

Ohlsson,S. 1992. The cognitive skill of theory articulation:A neglected aspect of science education.Science & Education, 1(2): 181-192.

Roth, K.J. 1989.Science education: It's not enough to 'do' or 'relate.' The American Educator, 13(4): 16-22; 46-48.

Rutherford, F.J. 1964. The role of inquiry in science teaching. Journal of Research in Science Teaching, 2: 80-84.

Schauble,L.,L.E. Klopfer, and K. Raghavan. 1991.Students' transition from an engineering model to a science model of experimentation. [Special issue] Journal of Research in Science Teaching, 28(9): 859-882.

Schwab, J.J. 1958. The teaching of science as inquiry. Bulletin of the Atomic Scientists, 14: 374-379.

Schwab, J.J. 1964. The teaching of science as enquiry. In The Teaching of Science, J.J. Schwab and P.F. Brandwein, eds.:3-103. Cambridge,MA: Harvard University Press.

Welch, W.W.,L.E. Klopfer, G.S. Aikenhead,and J.T. Robinson.1981. The role of inquiry in science education: Analysis and recommendations.Science Education, 65(1): 33-50.

PHYSICAL SCIENCE, LIFE SCIENCE, AND EARTH AND SPACE SCIENCE

AAAS (American Association for the Advancement of Science). 1993. Benchmarks for Science Literacy. New York: Oxford University Press.

AAAS (American Association for the Advancement of Science).1989.Science for All Americans:A Project 2061 Report on Literacy Goals in Science, Mathematics,and Technology. Washington, DC:AAAS.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. Making Sense of Secondary Science: Research into Children's Ideas. London: Routledge.

Driver, R., E. Guesne, and A. Tiberghien, eds. 1985. Children's Ideas in Science. Philadelphia, PA.: Open University Press.

Fensham, P. J., R. F. Gunstone, and R. T. White, eds. 1994. The Content of Science: A Constructivist Approach to Its Teaching and Learning. Bristol, PA: Falmer Press.

Harlen, W. 1988. The Teaching of Science. London: Fulton.

NSTA (National Science Teachers Association). 1992. Scope, Sequence, Coordination. The Content Core: A Guide for Curriculum Designers. Washington, DC: NSTA.

Osborne, R.J., and P. Freyberg. 1985. Learning in Science: The Implications of 'Children's Science.' New Zealand: Heinemann.

PHYSICAL SCIENCE

AAPT (American Association of Physics Teachers). 1988. Course Content in High School Physics. High School Physics: Views from AAPT. College Park, MD: AAPT.

AAPT (American Association of Physics Teachers). 1986. Guidelines for High School Physics Programs. Washington, DC: AAPT.

ACS (American Chemical Society). 1996. FACETS Foundations and Challenges to Encourage Technology-based Science. Dubuque, Iowa: Kendall/Hunt.

ACS (American Chemical Society). 1993. ChemCom: Chemistry in the Community, second ed. Dubuque, Iowa: Kendall/Hunt.

LIFE SCIENCE

BSCS (Biological Sciences Curriculum Study). 1993. Developing Biological Literacy: A Guide to Developing Secondary and Post-Secondary Biology Curricula. Colorado Springs, CO: BSCS.

Jacob, F. 1982. The Possible and the Actual. Seattle: University of Washington Press.

Medawar, P.B., and J.S. Medawar. 1977. The Life Science: Current Ideas of Biology. New York: Harper and Row.

Moore, J.A. 1993. Science as a Way of Knowing: The Foundations of Modern Biology. Cambridge, MA: Harvard University Press.

Morowitz, H.J. 1979. Biological Generalizations and Equilibrium Organic Chemistry. In Energy Flow in Biology: Biological Organization as a Problem in Thermal Physics. Woodbridge, CT: Oxbow Press.

NRC (National Research Council). 1990. Fulfilling the Promise: Biology Education in Our Nation's Schools. Washington, DC: National Academy Press.

NRC (National Research Council). 1989. High-School Biology Today and Tomorrow. Washington, DC: National Academy Press.

EARTH AND SPACE SCIENCE

AGI (American Geological Institute). 1991. Earth Science Content Guidelines Grades K-12. Alexandria, VA: AGI.

AGI (American Geological Institute). 1991. Earth Science Education for the 21st Century: A Planning Guide. Alexandria, VA: AGI.

NRC (National Research Council). 1993. Solid-Earth Sciences and Society: A Critical Assessment. Washington, DC: National Academy Press.

SCIENCE AND TECHNOLOGY

AAAS (American Association for the Advancement of Science). 1993. Benchmarks for Science Literacy. New York: Oxford University Press.

AAAS (American Association for the Advancement of Science). 1989. Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics, and Technology. New York: Oxford University Press.

Johnson, J. 1989. Technology: A Report of the Project 2061 Phase I Technology Panel. Washington, DC: American Association for the Advancement of Science.

Selby, C.C.1993. Technology: From myths to realities. Phi Delta Kappan,74(9):684-689.

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

AAAS (American Association for the Advancement of Science). 1993. Benchmarks for Science Literacy. New York: Oxford University Press.

Gore,A.1992.Earth in the Balance:Ecology and the Human Spirit. Boston: Houghton Mifflin.

Meadows, D.H., D.L. Meadows,and J. Randers. 1992. Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future. Post Mills,VT: Chelsea Green.

Miller, G.T. 1992.Living in the Environment: An Introduction to Environmental Science,7th ed. Belmont,CA: Wadsworth.

Moore, J. 1985. Science as a Way of Knowing II: Human Ecology. Baltimore,MD: American Society of Zoologists.

NRC (National Research Council).1993. Solid-Earth Sciences and Society. Washington, DC: National Academy Press.

Silver, C.S., and R.S. DeFries.1990.One Earth, One Future: Our Changing Global Enviroment. Washington, DC: National Academy Press.

HISTORY AND NATURE OF SCIENCE

In addition to references for Science as Inquiry, the following references are suggested.

AAAS (American Association for the Advancement of Science). 1993. Benchmarks for Science Literacy. New York: Oxford University Press.

Bakker, G., and L. Clark.1988. Explanation: An Introduction to the Philosophy of Science. Mountain View, CA: Mayfield.

Cohen,I.B. 1985. Revolution in Science. Cambridge, MA: The Belknap Press of Harvard University Press.

Hacking, I.1983. Representing and Intervening: Introductory Topics in the Philosophy of Natural Science. New York: Cambridge University Press.

Hoyingen-Huene, P. 1987. Context of discovery and context of justification. Studies in History and Philosophy of Science,18(4): 501-515.

Klopfer, L. 1992.A historical perspective on the history and nature of science on school science programs. In Teaching About the History and Nature of Science and Technology: Background Papers, Biological Sciences Curriculum Study and Social Science Education Consortium: 105-129. Colorado Springs, CO: Biological Sciences Curriculum Study.

Machamer, P. 1992.Philosophy of science: An overview for educators. In Teaching About the History and Nature of Science and Technology: Background Papers, Biological Sciences Curriculum Study and Social Science Education Consortium: 9-17. Colorado Springs,CO: Biological Sciences Curriculum Study.

Malley, M.1992. The Nature and History of Science. In Teaching About the History and Nature of Science and Technology: Background Papers, Biological Sciences Curriculum Study and Social Science Education Consortium:67-79. Colorado Springs,CO: Biological Sciences Curriculum Study.

Moore, J.A.1993.Science as a Way of Knowing: The Foundations of Modern Biology. Cambridge,MA.: Harvard University Press.

NRC (National Research Council).1995.On Being a Scientist: Responsible Conduct in Research.2nd ed. Washington, DC: National Academy Press.

Russell, T.L. 1981. What history of science,how much,and why? Science Education 65 (1): 51-64.