



The Science
Content
Standards for
Grades Nine
Through
Twelve



The Science Content Standards for Grades Nine Through Twelve

The science content standards for kindergarten through grade eight provide the background for students to succeed with the science content standards for grades nine through twelve. Aligning the high school curriculum to offer standards-based courses for every student will put new demands on schools and science departments. However, the reward for successfully meeting the challenge will be that high school graduates can attain the highest level of science literacy achieved by students in more than two decades.

Changing to a program based on the science content standards will require a restructuring of the high school curriculum, although the science that was generally taught in California before the *Science Content Standards for California Public Schools* was published is mostly included in the standards.¹ The successful implementation of standards-based kindergarten through grade eight programs aligned to this *Science Framework* should enable more students to take standards-based courses in high school. This chapter provides guidance for teaching students who have mastered the kindergarten through grade eight materials. To achieve this mastery will require many years of effort, and school districts should adjust their programs appropri-

ately as their students have the opportunity to learn the prerequisite material in the earlier grades.

School districts are responsible for their curriculum and must decide how to structure their courses to teach the science standards. Traditionally, biology has been taught in the tenth grade, followed by chemistry and then possibly by physics. However, this sequence dates from a time when the content of the biology course was descriptive and that of the physics course was the most quantitative among the science disciplines. The high school science standards allow for other structures. Because districts need flexibility to design their own course structure, this chapter is presented in modular format—no sequence or emphasis is prescribed.

Appropriate to the rigor of the standards, each section covers a particular scientific discipline: physics, chemistry, biology/life sciences, and earth sciences. Along with meeting the subject-matter requirements for science, every student should learn the content in the full set of Investigation and Experimentation standards and have an opportunity to learn the slightly more advanced material in the standards that are marked with an asterisk.

In 1997 California established the Digital High School program, ensuring that all high schools throughout the

state would have access to technology to improve student achievement in science and other academic subjects. Many schools purchased materials for scientific-based technology, and their use should be integrated into science programs. Technology can be used to teach some science standards and to assess students' understanding. Science education provides an opportunity to instruct students in gathering, graphing, tracking, and interpreting data through the use of technological tools, such as word processing, spreadsheets, and database development. Related concepts from science, mathematics, and language arts can be merged in the development of a science experiment and its subsequent analysis.

Safety is always the foremost consideration in the design of demonstrations, laboratories, and science experiments. The importance of safety is evident because scientists and engineers in universities and industries are required to follow strict health and safety regulations. Safety needs to be taught. Teachers should be familiar with the *Science Safety Handbook for California Public Schools*.² It contains specific, useful information relevant to classroom science teachers. School administrators, teachers, parents/guardians, and students have a legal and moral obligation to promote safety in science education. Knowing and following safe practices in science are a part of understanding the nature of science and scientific enterprise.

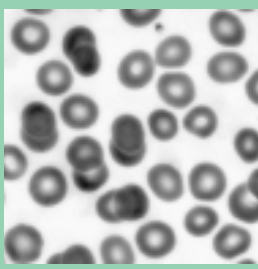
Biology/Life Sciences

Living organisms appear in many variations, yet there are basic similarities among their forms and functions. For example, all organisms require an outside source of energy to sustain life processes; all organisms demonstrate patterns of growth and, in many cases, senescence, the process of becoming old; and the continuity of all species requires reproduction. All organisms are constructed from the same types of macromolecules (proteins, nucleic acids, lipids) and inherit a deoxyribonucleic acid (DNA) genome from a parent or parents. DNA is always transcribed to yield ribonucleic acid (RNA), which is translated through the use of a nearly universal genetic code. Environmental factors frequently regulate and influence the expression of specific genes.

Biologists study life at many levels, and the biology standards for grades nine through twelve reflect these studies. *Organisms* are part of an ecosystem and have complex relationships with other organisms and the physical environment. Ecologists study these populations and communities, and many are deeply interested in the physical and behavioral adaptations of organisms. Evolutionary biologists share these interests because the fitness of an organism is a manifestation of these adaptations. *Adaptations* are traits subject to the rules of inheritance; therefore, genetics and evolutionary biology are closely allied fields.

Physiologists study whole body systems or organs. For example, a neurophysiologist focuses primarily on the nervous system. Cell biologists study the details of how cells and organelles work, considering such weighty matters as how cytoskeletal elements segregate chromosomes during mitosis, how proteins are sorted to different compartments of the cell, and how receptors in the cell membrane communicate with factors that regulate gene expression. Many cell biologists also consider themselves to be developmental biologists, molecular geneticists, or biochemists. There are many connections between all the fields and different ways of viewing life.

Biology textbooks typically start with a review of chemistry and energetics; therefore, California students will be able to make good use of their study of the content standards for “Chemistry of Living Systems” in the eighth grade. The principles of cellular biology, including respiration and photosynthesis, are usually taught next, followed by instruction in molecular and Mendelian genetics. Population genetics and evolution follow naturally from the study of genetics and lead to a discussion of diversity of form and physiology. The teaching culminates with ecology, a subject that draws on each of the preceding topics. The teaching comes full circle because ecology is also a starting point for students in lower elementary school grade levels.



STANDARD SET I. Cell Biology

The first knowledge of cells came from the work of an English scientist, Robert Hooke, who in 1665 used a primitive microscope to study thin sections of cork and called the boxlike cavities he saw “cells.” Antony van Leeuwenhoek later observed one-celled “animalcules” in pond water, but not until the 1830s did Theodor Schwann view cartilage tissue in which he discovered cells resembling plant cells. He published the theory that cells are the basic unit of life. Rudolf Virchow used the work of Schwann and Matthias Schleiden to advance the cell theory, presenting the concept that plants and animals are made of cells that contain fluid and nuclei and arise from preexisting cells.

After the cell theory was established, detailed study of cell structure and function depended on the improvement of microscopes and on techniques for preparing specimens for observation. It is now understood that cells in plants and animals contain genes to control chemical reactions needed for survival and organelles to perform those reactions. Living organisms may consist of one cell, as in bacteria, or of many cells acting in a coordinated and cooperative manner, as in plants, animals, and fungi. All cells have at least three structures in common: genetic material, a cell or plasma membrane, and cytoplasm.

I. The fundamental life processes of plants and animals depend on a variety of chemical reactions that occur in specialized areas of the organism’s cells. As a basis for understanding this concept:

- a.** *Students know* cells are enclosed within semipermeable membranes that regulate their interaction with their surroundings.

The plasma membrane consists of two layers of lipid molecules organized with the polar (globular) heads of the molecules forming the outside of the membrane and the nonpolar (straight) tails forming the interior of the membrane. Protein molecules embedded within the membrane move about relative to one another in a fluid fashion. Because of its dynamic nature the membrane is sometimes referred to as *the fluid mosaic model* of membrane structure.

Cell membranes have three major ways of taking in or of regulating the passage of materials into and out of the cell: simple diffusion, carrier-facilitated diffusion, and active transport. Osmosis of water is a form of diffusion. Simple diffusion and carrier-facilitated diffusion do not require the expenditure of chemical bond energy, and the net movement of materials reflects a concentration gradient or a voltage gradient or both. Active transport requires free energy, in the form of either chemical bond energy or a coupled concentration gradient, and permits the net transport or “pumping” of materials against a concentration gradient.

- I. b.** *Students know* enzymes are proteins that catalyze biochemical reactions without altering the reaction equilibrium and the activities of enzymes depend on the temperature, ionic conditions, and the pH of the surroundings.

Almost all *enzymes* are protein catalysts made by living organisms. Enzymes speed up favorable (spontaneous) reactions by reducing the activation energy required for the reaction, but they are not consumed in the reactions they promote. To demonstrate the action of enzymes on a substrate, the teacher can use liver homogenate or yeast as a source of the enzyme catalase and hydrogen peroxide as the substrate. The effect of various environmental factors, such as pH, temperature, and substrate concentration, on the rate of reaction can be investigated. These investigations should encourage student observation, recording of qualitative and quantitative data, and graphing and interpretation of data.

- I. c.** *Students know* how prokaryotic cells, eukaryotic cells (including those from plants and animals), and viruses differ in complexity and general structure.

All living cells are divided into one of two groups according to their cellular structure. *Prokaryotes* have no membrane-bound organelles and are represented by the Kingdom Monera, which in modern nomenclature is subdivided into the Eubacteria and Archaea. *Eukaryotes* have a complex internal structure that allows thousands of chemical reactions to proceed simultaneously in various organelles. *Viruses* are not cells; they consist of only a protein coat surrounding a strand of genetic material, either RNA or DNA.

- I. d.** *Students know* the central dogma of molecular biology outlines the flow of information from transcription of ribonucleic acid (RNA) in the nucleus to translation of proteins on ribosomes in the cytoplasm.

DNA, which is found in the nucleus of eukaryotes, contains the genetic information for encoding proteins. The DNA sequence specifying a specific protein is copied (transcribed) into messenger RNA (mRNA), which then carries this message out of the nucleus to the ribosomes located in the cytoplasm. The mRNA message is then translated, or converted, into the protein originally coded for by the DNA.

- I. e.** *Students know* the role of the endoplasmic reticulum and Golgi apparatus in the secretion of proteins.

There are two types—rough and smooth—of endoplasmic reticulum (ER), both of which are systems of folded sacs and interconnected channels. *Rough ER* synthesizes proteins, and *smooth ER* modifies or detoxifies lipids. Rough ER produces new proteins, including membrane proteins. The proteins to be exported from the cell are moved to the Golgi apparatus for modification, packaged in vesicles, and transported to the plasma membrane for secretion.

I. f. Students know usable energy is captured from sunlight by chloroplasts and is stored through the synthesis of sugar from carbon dioxide.

Photosynthesis is a complex process in which visible sunlight is converted into chemical energy in carbohydrate molecules. This process occurs within chloroplasts and specifically within the thylakoid membrane (light-dependent reaction) and the stroma (light-independent reaction). During the light-dependent reaction, water is oxidized and light energy is converted into chemical bond energy generating ATP, NADPH + H⁺, and oxygen gas.[†] During the light-independent reaction (Calvin cycle), carbon dioxide, ATP, and NADPH + H⁺ react, forming phosphoglyceraldehyde, which is then converted into sugars. By using a microscope with appropriate magnification, students can see the chloroplasts in plant cells (e.g., lettuce, onion) and photosynthetic protists (e.g., euglena).

Students can prepare slides of these cells themselves, an activity that provides a good opportunity to see the necessity for well-made thin sections of specimens and for correct staining procedures. Commercially prepared slides are also available. By observing prepared cross sections of a leaf under a microscope, students can see how a leaf is organized structurally and think about the access of cells to light and carbon dioxide during photosynthesis. The production of oxygen from photosynthesis can be demonstrated and measured quantitatively with a volumeter, which can collect oxygen gas from the illuminated leaves of an aquatic plant, such as elodea. By varying the distance between the light source and the plant, teachers can demonstrate intensities of the effects of various illumination. To eliminate heat as a factor, the teacher can place a heat sink, such as a flat-sided bottle of water, between the plant and light source to absorb or dissipate unwanted heat.

I. g. Students know the role of the mitochondria in making stored chemical-bond energy available to cells by completing the breakdown of glucose to carbon dioxide.

Mitochondria consist of a matrix where three-carbon fragments originating from carbohydrates are broken down (to CO₂ and water) and of the cristae where ATP is produced. Cell respiration occurs in a series of reactions in which fats, proteins, and carbohydrates, mostly glucose, are broken down to produce carbon dioxide, water, and energy. Most of the energy from cell respiration is converted into ATP, a substance that powers most cell activities.

I. h. Students know most macromolecules (polysaccharides, nucleic acids, proteins, lipids) in cells and organisms are synthesized from a small collection of simple precursors.

Many of the large carbon compound molecules necessary for life (e.g., polysaccharides, nucleic acids, proteins, and lipids) are polymers of smaller monomers. Polysaccharides are composed of monosaccharides; proteins are composed of amino

[†]ATP is adenosine triphosphate, and NADPH is reduced nicotinamide adenine dinucleotide phosphate.

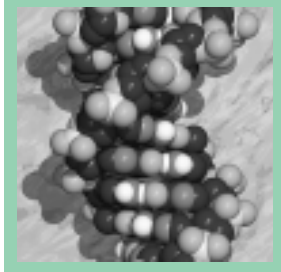
acids; lipids are composed of fatty acids, glycerol, and other components; and nucleic acids are composed of nucleotides.

I. i.* *Students know how chemiosmotic gradients in the mitochondria and chloroplast store energy for ATP production.*

Enzymes called *ATP synthase*, located within the thylakoid membranes in chloroplasts and cristae membranes in mitochondria, synthesize most ATP within cells. The thylakoid and cristae membranes are impermeable to protons except at pores that are coupled with the ATP synthase. The potential energy of the proton concentration gradient drives ATP synthesis as the protons move through the ATP synthase pores. The proton gradient is established by energy furnished by a flow of electrons passing through the electron transport system located within these membranes.

I. j.* *Students know how eukaryotic cells are given shape and internal organization by a cytoskeleton or cell wall or both.*

The *cytoskeleton*, which gives shape to and organizes eukaryotic cells, is composed of fine protein threads called *microfilaments* and thin protein tubes called *microtubules*. *Cilia* and *flagella* are composed of microtubules arranged in the 9 + 2 arrangement, in which nine pairs of microtubules surround two single microtubules. The rapid assembly and disassembly of microtubules and microfilaments and their capacity to slide past one another enable cells to move, as observed in white blood cells and amoebae, and also account for movement of organelles within the cell. Students can observe prepared slides of plant mitosis in an onion root tip to see the microtubules that make up the spindle apparatus. Prepared slides of white fish blastula reveal animal spindle apparatus and centrioles, both of which are composed of microtubules.



STANDARD SET 2. Genetics (Meiosis and Fertilization)

Students should know that organisms reproduce offspring of their own kind and that organisms of the same species resemble each other. Students have been introduced to the idea that some characteristics can be passed from parents to offspring and that individual variations appear among offspring and in the broader population. Understanding genetic variation requires mastery of the fundamentals of sex cell formation and the steps to reorganize and redistribute genetic material during defined stages in the cell cycle.

Students should understand the difference between asexual cell reproduction (*mitosis*) and the formation of male or female gamete cells (*meiosis*). Sexual reproduction initially requires the production of haploid eggs and haploid sperm, a process occurring in humans within the female ovary and the male testis. These haploid cells unite in fertilization and produce the *diploid zygote*, or fertilized cell.

The mechanisms involved in synapsis and movement of chromosomes during meiosis bring about the halving of the chromosome numbers for the production of the haploid male or female gamete cells from the original diploid parent cell and different combinations of parental genes. The exchange of chromosomal segments between homologous chromosomes (crossing over) revises the association of genes on the chromosomes and contributes to increased diversity. Any change in genetic constitution through mutation, crossing over, or chromosome assortment during meiosis promotes genetic variation in a population.

2. Mutation and sexual reproduction lead to genetic variation in a population. As a basis for understanding this concept:

- a. *Students know* meiosis is an early step in sexual reproduction in which the pairs of chromosomes separate and segregate randomly during cell division to produce gametes containing one chromosome of each type.

Haploid gamete production through meiosis involves two cell divisions. During meiosis prophase I, the homologous chromosomes are paired, a process that abets the exchange of chromosome parts through breakage and reunion. The second meiotic division parallels the mechanics of mitosis except that this division is not preceded by a round of DNA replication; therefore, the cells end up with the haploid number of chromosomes. (The nucleus in a haploid cell contains one set of chromosomes.) Four haploid nuclei are produced from the two divisions that characterize meiosis, and each of the four resulting cells has different chromosomal constituents (components). In the male all four become sperm cells. In the female only one becomes an egg, while the other three remain small degenerate polar bodies and cannot be fertilized.

Chromosome models can be constructed and used to illustrate the segregation taking place during the phases of mitosis (covered initially in Standard 1.e for grade seven in Chapter 4) and meiosis. Commercially available optical microscope slides also show cells captured in mitosis (onion root tip) or meiosis (*Ascaris* blastocyst cells), and computer and video animations are also available.

- 2. b.** *Students know* only certain cells in a multicellular organism undergo meiosis.

Only special diploid cells, called *spermatogonia* in the testis of the male and *oogonia* in the female ovary, undergo meiotic divisions to produce the haploid sperm and haploid eggs.

- 2. c.** *Students know* how random chromosome segregation explains the probability that a particular allele will be in a gamete.

The steps in meiosis involve random chromosome segregation, a process that accounts for the probability that a particular allele will be packaged in any given gamete. This process allows for genetic predictions based on laws of probability

that pertain to genetic sortings. Students can create a genetic chart and mark alternate traits on chromosomes, one expression coming from the mother and another expression coming from the father. Students can be shown that partitions of the chromosomes are controlled by chance (are random) and that separation (segregation) of chromosomes during *karyokinesis* (division of the nucleus) leads to the random sequestering of different combinations of chromosomes.

2. d. *Students know new combinations of alleles may be generated in a zygote through the fusion of male and female gametes (fertilization).*

Once gametes are formed, the second half of sexual reproduction can take place. In this process a diploid organism is reconstituted from two haploid parts. When a sperm is coupled with an egg, a fertilized egg (zygote) is produced that contains the combined genotypes of the parents to produce a new allelic composition for the progeny. Genetic charts can be used to illustrate how new combinations of alleles may be present in a zygote through the events of meiosis and the chance union of gametes. Students should be able to read the genetic diploid karyotype, or chromosomal makeup, of a fertilized egg and compare the allelic composition of progeny with the genotypes and phenotypes of the parents.

2. e. *Students know why approximately half of an individual's DNA sequence comes from each parent.*

Chromosomes are composed of a single, very long molecule of double-stranded DNA and proteins. Genes are defined as segments of DNA that code for polypeptides (proteins). During fertilization half the DNA of the progeny comes from the gamete of one parent, and the other half comes from the gamete of the other parent.

2. f. *Students know the role of chromosomes in determining an individual's sex.*

The normal human somatic cell contains 46 chromosomes, of which 44 are pairs of homologous chromosomes and 2 are sex chromosomes. Females usually carry two X chromosomes, and males possess one X and a smaller Y chromosome. Combinations of these two sex chromosomes determine the sex of the progeny.

2. g. *Students know how to predict possible combinations of alleles in a zygote from the genetic makeup of the parents.*

When the genetic makeups of potential parents are known, the possible assortments of alleles in their gametes can be determined for each genetic locus. Two parental gametes will fuse during fertilization, and with all pair-wise combinations of their gametes considered, the possible genetic makeups of progeny can then be predicted.



STANDARD SET 3. Genetics (Mendel's Laws)

Breeding of plants and animals has been an active technology for thousands of years, but the science of heredity is linked to the genetics pioneer Gregor Mendel. He studied phenotypic traits of various plants, especially those of peas.

(A *phenotypic trait* is the physical appearance of a trait in an organism). From the appearance of these traits in different generations of growth, he was able to infer their *genotypes* (the genetic makeup of an organism with respect to a trait) and to speculate about the genetic makeup and method of transfer of the hereditary units from one generation to the next. (Probability analysis is now used to predict probable progeny phenotypes from various parental genetic crosses.) The genetic basis for Mendel's laws of segregation and independent assortment is apparent from genetic outcomes of crosses.

3. A multicellular organism develops from a single zygote, and its phenotype depends on its genotype, which is established at fertilization. As a basis for understanding this concept:

- a. *Students know* how to predict the probable outcome of phenotypes in a genetic cross from the genotypes of the parents and mode of inheritance (autosomal or X-linked, dominant or recessive).

Monohybrid crosses, including autosomal dominant alleles, autosomal recessive alleles, incomplete dominant alleles, and X-linked alleles, can be used to indicate the parental genotypes and phenotypes. The possible gametes derived from each parent are based on genotypic ratios and can be used to predict possible progeny. The predictive (probabilistic) methods for determining the outcome of genotypes and phenotypes in a genetic cross can be introduced by using Punnett Squares and probability mathematics.

Teachers should review the process of writing genotypes and help students translate genotypes into phenotypes. Teachers should emphasize dominant, recessive, and incomplete dominance as the students advance to an explanation of monohybrid crosses illustrating human conditions characterized by autosomal recessive alleles, such as albinism, cystic fibrosis, Tay-Sachs, and phenylketonuria (PKU). These disorders can be contrasted with those produced by possession of just one autosomal dominant allele, conditions such as Huntington disease, dwarfism, and neurofibromatosis. This basic introduction can be followed with examples of incomplete dominance, such as seen in the comparisons of straight, curly, and wavy hair or in the expression of intermediate flower colors in snapdragon plants.

Sex-linked characteristics that are found only on the X chromosome should also be considered, and students should reflect on how this mode of transmission can cause the exclusive or near-exclusive appearance in males of color blindness, hemophilia, fragile-X syndrome, and sex-linked muscular dystrophy.

3. b. *Students know the genetic basis for Mendel’s laws of segregation and independent assortment.*

Mendel deduced that for each characteristic, an organism inherits two genes, one from each parent. When the two alleles differ, the dominant allele is expressed, and the recessive allele remains hidden. Two genes or alleles separate (segregate) during gamete production in meiosis, resulting in the sorting of alleles into separate gametes (the law of segregation). Students can be shown how to diagram Mendel’s explanation for how a trait present in the parental generation can appear to vanish in the first filial (F1) generation of a monohybrid cross and then reappear in the following second filial (F2) generation.

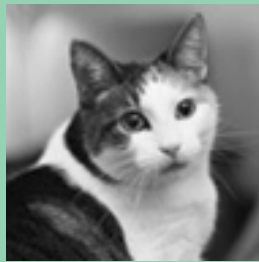
Students should be told that alternate versions of a gene at a single locus are called *alleles*. Students should understand Mendel’s deduction that for each character, an organism inherits two genes, one from each parent. From this point students should realize that if the two alleles differ, the dominant allele, if there is one, is expressed, and the recessive allele remains hidden. Students should recall that the two genes, or alleles, separate (segregate) during gamete production in meiosis and that this sorting of alleles into separate gametes is the basis for the law of segregation. This law applies most accurately when genes reside on separate chromosomes that segregate out at random, and it often does not apply or is a poor predictor for combinations and frequencies of genes that reside on the same chromosome. Students can study various resources that describe Mendel’s logic and build models to illustrate the laws of segregation and independent assortment.

3. c.* *Students know how to predict the probable mode of inheritance from a pedigree diagram showing phenotypes.*

Students should be taught how to use a pedigree diagram showing phenotypes to predict the mode of inheritance.

3. d.* *Students know how to use data on frequency of recombination at meiosis to estimate genetic distances between loci and to interpret genetic maps of chromosomes.*

Students should be able to interpret genetic maps of chromosomes and manipulate genetic data by using standard techniques to relate recombination at meiosis to estimate genetic distances between loci.



**STANDARD SET 4. Genetics
(Molecular Biology)**

All cells contain DNA as their genetic material. The role of DNA in organisms is twofold: first, to store and transfer genetic information from one generation to the next, and second, to express that genetic information in the synthesis

of proteins. By controlling protein synthesis, DNA controls the structure and function of all cells. The complexity of an organism determines whether it may have several hundred to more than twenty thousand proteins as a part of its makeup.

Proteins are composed of a sequence of amino acids linked by peptide bonds (see Standard 10.c for chemistry in this chapter). The identity, number, and sequence of the amino acids in a protein give each protein its unique structure and function. Twenty types of amino acids are commonly employed in proteins, and each can appear many times in a single protein molecule. The proper sequence of amino acids in a protein is translated from an RNA sequence that is itself encoded in the DNA.

4. Genes are a set of instructions encoded in the DNA sequence of each organism that specify the sequence of amino acids in proteins characteristic of that organism. As a basis for understanding this concept:

- a. *Students know* the general pathway by which ribosomes synthesize proteins, using tRNAs to translate genetic information in mRNA.

DNA does not leave the cell nucleus, but messenger RNA (mRNA), complementary to DNA, carries encoded information from DNA to the ribosomes (transcription) in the cytoplasm. (The *ribosomes* translate mRNAs to make protein.) Freely floating amino acids within the cytoplasm are bonded to specific transfer RNAs (tRNAs) that then transport the amino acid to the mRNA now located on the ribosome. As a ribosome moves along the mRNA strand, each mRNA codon, or sequence of three nucleotides specifying the insertion of a particular amino acid, is paired in sequence with the anticodon of the tRNA that recognizes the sequence. Each amino acid is added, in turn, to the growing polypeptide at the specified position.

After learning about transcription and translation through careful study of expository texts, students can simulate the processes on paper or with representative models. Computer software and commercial videos are available that illustrate animated sequences of transcription and translation.

- 4. b.** *Students know* how to apply the genetic coding rules to predict the sequence of amino acids from a sequence of codons in RNA.

The sequence of amino acids in protein is provided by the genetic information found in DNA. In prokaryotes, mRNA transcripts of a coding sequence are copied from the DNA as a single contiguous sequence. In eukaryotes, the initial RNA transcript, while in the nucleus, is composed of *exons*, sequences of nucleotides that carry useful information for protein synthesis, and *introns*, sequences that do not. Before leaving the nucleus, the initial transcript is processed to remove introns and splice exons together. The processed transcript, then properly called mRNA and carrying the appropriate codon sequence for a protein, is transported from the nucleus to the ribosome for translation.

Each mRNA has sequences, called *codons*, that are decoded three nucleotides at a time. Each codon specifies the addition of a single amino acid to a growing polypeptide chain. A *start codon* signals the beginning of the sequence of codons to be translated, and a *stop codon* ends the sequence to be translated into protein. Students can write out mRNA sequences with start and stop codons from a given DNA sequence and use a table of the genetic code to predict the primary sequences of proteins.

4. c. *Students know* how mutations in the DNA sequence of a gene may or may not affect the expression of the gene or the sequence of amino acids in the encoded protein.

Mutations are permanent changes in the sequence of nitrogen-containing bases in DNA (see Standard 5.a in this section for details on DNA structure and nitrogen bases). Mutations occur when base pairs are incorrectly matched (e.g., *A* bonded to *C* rather than *A* bonded to *T*) and can, but usually do not, improve the product coded by the gene. Inserting or deleting base pairs in an existing gene can cause a mutation by changing the codon reading frame used by a ribosome. Mutations that occur in somatic, or nongerm, cells are often not detected because they cannot be passed on to offspring. They may, however, give rise to cancer or other undesirable cellular changes. Mutations in the germline can produce functionally different proteins that cause such genetic diseases as Tay-Sachs, sickle cell anemia, and Duchenne muscular dystrophy.

4. d. *Students know* specialization of cells in multicellular organisms is usually due to different patterns of gene expression rather than to differences of the genes themselves.

Gene expression is a process in which a gene codes for a product, usually a protein, through transcription and translation. Nearly all cells in an organism contain the same DNA, but each cell transcribes only that portion of DNA containing the genetic information for proteins required at that specific time by that specific cell. The remainder of the DNA is not expressed. Specific types of cells may produce specific proteins unique to that type of cell.

4. e. *Students know* proteins can differ from one another in the number and sequence of amino acids.

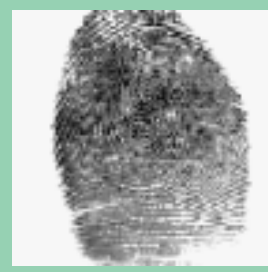
Protein molecules vary from about 50 to 3,000 amino acids in length. The types, sequences, and numbers of amino acids used determine the type of protein produced.

4. f.* *Students know* why proteins having different amino acid sequences typically have different shapes and chemical properties.

The 20 different protein-making amino acids have the same basic structure: an amino group; an acidic (carboxyl) group; and an R, or radical group (see Standard

Set 10, “Organic and Biochemistry,” in the chemistry section of this chapter). The protein is formed by the amino group of one amino acid linking to the carboxyl group of another amino acid. This bond, called the *peptide bond*, is repeated to form long molecular chains with the R groups attached along the polymer backbone.

The properties of these amino acids vary from one another because of both the order and the chemical properties of these R groups. Typically, the long protein molecule folds on itself, creating a three-dimensional structure related to its function. Structure, for example, may allow a protein to be a highly specific catalyst, or enzyme, able to position and hold other molecules. The R group of an amino acid consists of atoms that may include carbon, hydrogen, nitrogen, oxygen, and sulfur, depending on the amino acid. Amino acids containing sulfur sometimes play an important role of cross-linking and stabilizing polymer chains. Because of their various R groups, different amino acids vary in their chemical and physical properties, such as solubility in water, electrical charge, and size. These differences are reflected in the unique structure and function of each type of protein.



STANDARD SET 5. Genetics (Biotechnology)

Long before scientists identified DNA as the genetic material of cells, much was known about inheritance and the relationships between various characteristics likely to appear from one generation to the next. However, to comprehend clearly how the genetic composition of cells changes, students need to understand the structure and activity of nucleic acids.

Genetic recombination occurs naturally in sexual reproduction, viral infection, and bacterial transformation. These natural events change the genetic makeup of organisms and provide the raw materials for evolution. Natural selection determines the usefulness of the recombinants. In recombinant DNA technology specific pieces of DNA are recombined in the laboratory to achieve a specific goal. The scientist, rather than natural selection, then determines the usefulness of the recombinant DNA created.

5. The genetic composition of cells can be altered by incorporation of exogenous DNA into the cells. As a basis for understanding this concept:

- a. Students know the general structures and functions of DNA, RNA, and protein.

Nucleic acids are polymers composed of monomers called *nucleotides*. Each nucleotide consists of three subunits: a five-carbon pentose sugar, a phosphoric acid group, and one of four nitrogen bases. (For DNA these nitrogen bases are adenine, guanine, cytosine, or thymine.) DNA and RNA differ in a number of major ways. A DNA nucleotide contains a deoxyribose sugar, but RNA contains ribose sugar.

The nitrogen bases in RNA are the same as those in DNA except that thymine is replaced by uracil. RNA consists of only one strand of nucleotides instead of two as in DNA.

The DNA molecule consists of two strands twisted around each other into a double helix resembling a ladder twisted around its long axis. The outside, or uprights, of the ladder are formed by the two sugar-phosphate backbones. The rungs of the ladder are composed of pairs of nitrogen bases, one extending from each upright. In DNA these nitrogen bases always pair so that *T* pairs with *A*, and *G* pairs with *C*. This pairing is the reason DNA acts as a template for its own replication. RNA exists in many structural forms, many of which play different roles in protein synthesis. The mRNA form serves as a template during protein synthesis, and its codons are recognized by aminoacylated tRNAs. Protein and rRNA make up the structure of the ribosome.

Proteins are polymers composed of amino acid monomers (see Standard Set 10 for chemistry in this chapter). Different types of proteins function as enzymes and transport molecules, hormones, structural components of cells, and antibodies that fight infection. Most cells in an individual organism carry the same set of DNA instructions but do not use the entire DNA set all the time. Only a small amount of the DNA appropriate to the function of that cell is expressed. Genes are, therefore, turned on or turned off as needed by the cell, and the products coded by these genes are produced only when required.

5. b. *Students know how to apply base-pairing rules to explain precise copying of DNA during semiconservative replication and transcription of information from DNA into mRNA.*

Enzymes initiate DNA replication by unzipping, or unwinding, the double helix to separate the two parental strands. Each strand acts as a template to form a complementary daughter strand of DNA. The new daughter strands are formed when complementary new nucleotides are added to the bases of the nucleotides on the parental strands. The nucleotide sequence of the parental strand dictates the order of the nucleotides in the daughter strands. One parental strand is conserved and joins a newly synthesized complementary strand to form the new double helix; this process is called *semiconservative replication*.

DNA replication is usually initiated by the separation of DNA strands in a small region to make a “replication bubble” in which DNA synthesis is primed. The DNA strands progressively unwind and are replicated as the replication bubble expands, and the two forks of replication move in opposite directions along the chromosome. At each of the diverging replication forks, the strand that is conserved remains a single, continuous “leading” strand, and the other “lagging” complementary strand is made as a series of short fragments that are subsequently repaired and ligated together.

Students may visualize DNA by constructing models, and they can simulate semiconservative replication by tracing the synthesis of the leading and lagging

strands. The critical principles to teach with this activity are that two double-stranded DNA strands are the product of synthesis, that the process is semiconservative, that the antiparallel orientation of the strands requires repeated reinitiation on the lagging strand, and that the only information used during synthesis is specified by the base-pairing rules.

RNA is produced from DNA when a section of DNA (containing the nucleotide sequence required for the production of a specific protein) is transcribed. Only the template side of the DNA is copied. RNA then leaves the nucleus and travels to the cytoplasm, where protein synthesis takes place.

5. c. *Students know how genetic engineering (biotechnology) is used to produce novel biomedical and agricultural products.*

Recombinant DNA contains DNA from two or more different sources. Bacterial plasmids and viruses are the two most common vectors, or carriers, by which recombinant DNA is introduced into a host cell. Restriction enzymes provide the means by which researchers cut DNA at desired locations to provide DNA fragments with “sticky ends.” Genes, once identified, can be amplified either by cloning or by polymerase chain reactions, both of which produce large numbers of copies. The recombinant cells are then grown in large fermentation vessels, and their products are extracted from the cells (or from the medium if the products are secreted) and purified. Genes for human insulin, human growth hormone, blood clotting factors, and many other products have been identified and introduced into bacteria or other microorganisms that are then cultured for commercial production. Some agricultural applications of this technology are the identification and insertion of genes to increase the productivity of food crops and animals and to promote resistance to certain pests and herbicides, robustness in the face of harsh environmental conditions, and resistance to various viruses.

Students can model the recombinant DNA process by using paper models to represent eukaryotic complementary DNA (cDNA), the activity of different restriction enzymes, and ligation into plasmid DNA containing an antibiotic resistance gene and origin of DNA replication. To manipulate the modeled DNA sequences, students can use scissors (representing the activity of restriction enzymes) and tape (representing DNA ligase). If both strands are modeled on a paper tape, students can visualize how, in many cases, restriction enzymes make staggered cuts that generate “sticky ends” and how the ends must be matched during ligation.

5. d.* *Students know how basic DNA technology (restriction digestion by endonucleases, gel electrophoresis, ligation, and transformation) is used to construct recombinant DNA molecules.*

In recombinant DNA technology DNA is isolated and exchanged between organisms to fulfill a specific human purpose. The desired gene is usually identified and extracted by using restriction enzymes, or *endonucleases*, to cut the DNA into fragments. Restriction enzymes typically cut *palindromic* portions of DNA, which

read the same forward and backward, in ways that form sticky complementary ends. DNA from different sources, but with complementary sticky ends, can be joined by the enzyme DNA ligase, thus forming recombinant DNA.

DNA fragments of varying lengths can be separated from one another by *gel electrophoresis*. In this process the particles, propelled by an electric current, are moved through an agarose gel. Depending on the size, shape, and electrical charge of the particles, they will move at different rates through the gel and thus form bands of particles of similar size and charge. With appropriate staining, the various DNA fragments can then be visualized and removed for further analysis or recombination.

5. e.* *Students know how exogenous DNA can be inserted into bacterial cells to alter their genetic makeup and support expression of new protein products.*

Bacteria can be induced to take up recombinant plasmids, a process called DNA transformation, and the plasmid is replicated as the bacteria reproduce. Recombinant bacteria can be grown to obtain billions of copies of the recombinant DNA. Commercially available kits containing all the necessary reagents, restriction enzymes, and bacteria are available for experiments in plasmid DNA transformation. Although the reagents and equipment can be expensive, various California corporations and universities have programs to make the cost more affordable, sometimes providing reagents and lending equipment.

Students should know that DNA transformation is a natural process and that horizontal DNA transfer is common in the wild. An example of how humans have manipulated genetic makeup is through the selective breeding of pets and of agricultural crops.



STANDARD SET 6. Ecology

Ecology is the study of relationships among living organisms and their interactions with the physical environment. These relationships are in a constant state of flux, and even small changes can cause effects throughout the ecosystem.

Students in grades nine through twelve can be taught to think of ecology as changing relationships among the components of an ecosystem. Students also need to recognize that humans are participants in these ecosystem relationships, not just observers. A goal of classroom teaching should be to develop a strong scientific understanding of ecology to establish the basis for making informed and valid decisions.

**6. Stability in an ecosystem is a balance between competing effects.
As a basis for understanding this concept:**

- a.** *Students know* biodiversity is the sum total of different kinds of organisms and is affected by alterations of habitats.

Biodiversity refers to the collective variety of living organisms in an ecosystem. This structure is influenced by alterations in habitat, including but not limited to climatic changes, fire, flood, and invasion by organisms from another system. The more biodiversity in an ecosystem, the greater its stability and resiliency. The best way for students to learn about ecology is to master the principles of the subject through careful study and then to make firsthand observations of ecosystems in action over time.

Although field trips are the ideal way to implement this process and should be encouraged, even career scientists often use models to study ecology. Local ecologists from government, private industry, or university programs may also be willing to serve as guest speakers in the classroom. Viewing the Internet's many virtual windows that show actual ecological experiments can also help students understand the scientific basis of ecology.

- 6. b.** *Students know* how to analyze changes in an ecosystem resulting from changes in climate, human activity, introduction of nonnative species, or changes in population size.

Analysis of change can help people to describe and understand what is happening in a natural system and, to some extent, to control or influence that system. Understanding different kinds of change can help to improve predictions of what will happen next. Changes in ecosystems often manifest themselves in predictable patterns of climate, seasonal reproductive cycles, population cycles, and migrations. However, unexpected disturbances caused by human intervention or the introduction of a new species, for example, may destabilize the often complex and delicate balance in an ecosystem.

Analyzing changes in an ecosystem can require complex methods and techniques because variation is not necessarily simple and may be interrelated with changes or trends in other factors. Rates and patterns of change, including trends, cycles, and irregularities, are essential features of the living world and are useful indicators of change that can provide data for analysis. Often it is important to analyze change over time, a process called *longitudinal analysis*.

- 6. c.** *Students know* how fluctuations in population size in an ecosystem are determined by the relative rates of birth, immigration, emigration, and death.

Fluctuations in the size of a population are often difficult to measure directly but may be estimated by measuring the relative rates of birth, death, immigration, and emigration in a population. The number of deaths and emigrations over time

will decrease a population's size, and the number of births and immigrations over time will increase it. Comparing rates for death and emigration with those for birth and immigration will determine whether the population shows a net growth or a decline over time.

6. d. *Students know* how water, carbon, and nitrogen cycle between abiotic resources and organic matter in the ecosystem and how oxygen cycles through photosynthesis and respiration.

Living things depend on nonliving things for life. At the organism level living things depend on natural resources, and at the molecular level, they depend on chemical cycles. Water, carbon, nitrogen, phosphorus, and other elements are recycled back and forth between organisms and their environments. Water, carbon, and nitrogen are necessary for life to exist. These chemicals are incorporated into plants (producers) by photosynthesis and nitrogen fixation and used by animals (consumers) for food and protein synthesis. Chemical recycling occurs through respiration, the excretion of waste products and, of course, the death of organisms.

6. e. *Students know* a vital part of an ecosystem is the stability of its producers and decomposers.

An ecosystem's producers (plants and photosynthetic microorganisms) and decomposers (fungi and microorganisms) are primarily responsible for the productivity and recycling of organic matter, respectively. Conditions that threaten the stability of producer and decomposer populations in an ecosystem jeopardize the availability of energy and the capability of matter to recycle in the rest of the biological community. To study the interaction between producers and decomposers, students can set up a closed or restricted ecosystem, such as a worm farm, a composting system, a terrarium, or an aquarium.

6. f. *Students know* at each link in a food web some energy is stored in newly made structures but much energy is dissipated into the environment as heat. This dissipation may be represented in an energy pyramid.

The energy pyramid illustrates how stored energy is passed from one organism to another. At every level in a food web, an organism uses energy metabolically to survive and grow, but much is released as heat, usually about 90 percent. At every link in a food web, energy is transferred to the next level, but typically only 10 percent of the energy from the previous level is passed on to the consumer.

6. g.* *Students know* how to distinguish between the accommodation of an individual organism to its environment and the gradual adaptation of a lineage of organisms through genetic change.

Living organisms may adapt to changing environments through nongenetic changes in their structure, metabolism, or behavior or through natural selection of

favorable combinations of alleles governing any or all of these processes. Genetic and behavioral adaptations are sometimes difficult to identify or to distinguish without studying the organism over a long time. Physical changes are slow to develop in most organisms, requiring careful measurements over many years. Examining fossil ancestors of an organism may help provide clues for detecting adaptation through genetic change. Genetic change can institute behavioral changes, making it all the more complicated to determine whether a change is solely a behavioral accommodation to environmental change.

Through the use of print and online resources in library-media centers, students can research the effects of encroaching urbanization on undeveloped land and consider the effects on specific species, such as the coyote (not endangered) and the California condor (endangered). Such examples can illustrate how some organisms adapt to their environments through learned changes in behavior, and others are unsuccessful in learning survival skills. Over a long time, organisms can also adapt to changing environments through genetic changes, some of which may include genetically determined changes in behavior. Such changes may be difficult to recognize because a long time must elapse before the changes become evident. Studies of the origins of desert pup fish or blind cave fish may help students understand how gradual genetic changes in an organism lead to adaptations to changes in its habitat.



STANDARD SET 7. Evolution (Population Genetics)

This discussion applies to Standard Sets 7 and 8. Students in grades nine through twelve should be ready to explore and understand the concept of biological evolution from its basis in genetics. The synthesis of genetics, and later of molecular biology, with the Darwin-Wallace theory of natural selection validated the mechanism of evolution and extended its scientific impact. Students need to understand that the same evolutionary mechanisms that have affected the rest of the living world have also affected the human species.

Students need to understand that a theory in science is not merely a hypothesis or a guess, but a unifying explanation of observed phenomena. Charles Darwin's theory of the origin of species by natural selection is such an explanation. Even though biologists continue to test the boundaries of this theory today, their investigations have not found credible evidence to refute the theory. Scientists have also had many opportunities to demonstrate the gradual evolution of populations in the wild and in controlled laboratory settings. As more populations of organisms are studied at the level of DNA sequence and as the fossil record improves, the understanding of species divergence has become clearer.

7. The frequency of an allele in a gene pool of a population depends on many factors and may be stable or unstable over time. As a basis for understanding this concept:

- a.** *Students know why natural selection acts on the phenotype rather than the genotype of an organism.*

Natural selection works directly on the expression or appearance of an inherited trait, the *phenotype*, rather than on the gene combination that produces that trait, the *genotype*. The influence of a dominant allele for a trait over a recessive one in the genotype determines the resulting phenotype on which natural selection acts.

- 7. b.** *Students know why alleles that are lethal in a homozygous individual may be carried in a heterozygote and thus maintained in a gene pool.*

Two types of allele pairings can occur in the genotype: *homozygous* (pairing two of the same alleles, whether dominant, codominant, or recessive) and *heterozygous* (pairing of two different alleles). Recessive lethal alleles (e.g., Tay-Sachs disease) will, by definition, cause the death of only the homozygous recessive individual. Healthy heterozygous individuals will also contribute the masked recessive gene to the population's gene pool, allowing the gene to persist.

- 7. c.** *Students know new mutations are constantly being generated in a gene pool.*

Mutation is an important source of genetic variation within a gene pool. These random changes take the form of additions, deletions, and substitutions of nucleotides and of rearrangements of chromosomes. The effect of many mutations is minor and neutral, being neither favorable nor unfavorable to survival and reproduction. Other mutations may be beneficial or harmful. The important principle is that culling, or selective breeding, cannot eliminate genetic diseases or unwanted traits from a population. The trait constantly reappears in the population in the form of new, spontaneous mutations.

- 7. d.** *Students know variation within a species increases the likelihood that at least some members of a species will survive under changed environmental conditions.*

As environmental factors change, natural selection of adaptive traits must also be realigned. Variation within a species stemming either from mutation or from genetic recombination broadens the opportunity for that species to adapt to change, increasing the probability that at least some members of the species will be suitably adapted to the new conditions. Genetic diversity promotes survival of a species should the environment change significantly, and sameness can mean vulnerability that could lead to extinction.

7. e.* *Students know the conditions for Hardy-Weinberg equilibrium in a population and why these conditions are not likely to appear in nature.*

The principle of Hardy-Weinberg equilibrium, derived in 1908, asserts that the genetic structure of a nonevolving population remains constant over the generations. If mating in a large population occurs randomly without the influence of natural selection, the migration of genes from neighboring populations, or the occurrence of mutations, the frequency of alleles and of genotypes will remain constant over time. Such conditions are so restrictive that they are not likely to occur in nature precisely as predicted, but the Hardy-Weinberg equilibrium equation often gives an excellent approximation for a limited number of generations in sizeable, randomly mating populations. Even though genetic recombination is taken into account, mutations, gene flow between populations, and environmental changes influencing pressures of selection on a population do not cease to occur in the natural world.

7. f.* *Students know how to solve the Hardy-Weinberg equation to predict the frequency of genotypes in a population, given the frequency of phenotypes.*

The Hardy-Weinberg equilibrium equation can be used to calculate the frequency of alleles and genotypes in a population's gene pool. When only two alleles for a trait occur in a population, the letter p is used to represent the frequency of one allele, and the letter q is used to represent the frequency of the other. Students should agree first that the sum of the frequencies of the two alleles is 1, and this equation is written $p + q = 1$. That is, the combined frequencies of the alleles account for all the genes for a given trait.

Students should then consider the possible combinations of alleles in a *diploid organism* (the genome of a diploid organism consists of two copies of each chromosome). An individual could be homozygous for one allele (pp) or homozygous for the other (qq) or heterozygous (either pq or qp). These diploid genotypes will appear at frequencies that are the product of the allele frequencies (e.g., the frequency of a diploid pp individual is p^2 , and the frequency of a diploid qq individual is q^2).

The heterozygotes are of two varieties, pq and qp (because the p allele might have been inherited from either parent), but the products of frequency pq and qp are the same. Therefore, the frequency of heterozygotes can simply be expressed as $2pq$. The sum of the frequencies of the homozygous and heterozygous individuals must equal 1, since all individuals have been accounted for. These principles are usually expressed as the equation $p^2 + 2pq + q^2 = 1$. Both equations represent different statements. The first ($p + q = 1$) is an accounting of the two types of alleles in the population, and the second ($p^2 + 2pq + q^2 = 1$) is an accounting of the three distinguishable genotypes.

If the allele frequencies are known (e.g., if $p = 0.1$ and $q = 0.9$) and Hardy-Weinberg equilibrium is assumed, then the frequencies p^2 , $2pq$, and q^2 are

respectively 0.01, 0.18, and 0.81. That is, 81 percent of individuals would be homozygous qq . If p were a dominant (but nonselective) allele, then $p^2 + 2pq$, or 19 percent of the population, would express the dominant phenotype of the p allele.

The calculation can be used in reverse as well. If Hardy-Weinberg equilibrium conditions exist and 81 percent of the population expresses the qq recessive phenotype, then the allele frequency q is the square root of 0.81, and the rest of the terms can be calculated in a straightforward fashion.

Students can convince themselves of the state of equilibrium by constructing a Punnett Square that assumes random mating. The scenario might be a mass spawning of fish, in which 100,000 eggs and sperm are mixed in a stream and meet with each other randomly to form zygotes. Students can calculate the fraction of p and q type gametes in the stream by thinking through the types of gametes produced by heterozygous and homozygous adult fish. (For this exercise to work, the genotype distribution of adults must agree with Hardy-Weinberg equilibrium.) With the frequencies or numbers of each type of zygote calculated in the cells of a Punnett Square, students will see that equilibrium is preserved. Frequencies of alleles and genotypes, which are the genetic structure of the study population, would remain constant for generations under the premise of Hardy-Weinberg equilibrium.



STANDARD SET 8. Evolution (Speciation)

See the discussion introducing the concept of biological evolution that appears under Standard Set 7, “Evolution (Population Genetics),” on page 237.

8. Evolution is the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept:

- a. Students know how natural selection determines the differential survival of groups of organisms.

Genetic changes can result from gene recombination during gamete formation and from mutations. These events are responsible for variety and diversity within each species. Natural selection favors the organisms that are better suited to survive in a given environment. Those not well suited to the environment may die before they can pass on their traits to the next generation. As the environment changes, selection for adaptive traits is realigned with the change. Traits that were once adaptive may become disadvantageous because of change.

Students can explore the process of natural selection further with an activity based on predator-prey relationships. The main purpose of these activities is to simulate survival in predator or prey species as they struggle to find food or to escape being consumed themselves. The traits of predator and prey individuals can be varied to test their selective fitness in different environmental settings.

An example of natural selection is the effect of industrial “melanism,” or darkness of pigmentation, on the peppered moths of Manchester, England. These moths come in two varieties, one darker than the other. Before the industrial revolution, the dark moth was rare; however, during the industrial revolution the light moth seldom appeared. Throughout the industrial revolution, much coal was burned in the region, emitting soot and sulfur dioxide. For reasons not completely understood, the light-colored moth had successfully adapted to the cleaner air conditions that existed in preindustrial times and that exist in the region today.

However, the light-colored moth appears to have lost its survival advantage during times of heavy industrial air pollution. One early explanation is that when soot covered tree bark, light moths became highly visible to predatory birds. Once this change happened, the dark-peppered moth had an inherited survival advantage because it was harder to see against the sooty background. This explanation may not have been the cause, and an alternative one is that the white-peppered moth was more susceptible to the sulfur dioxide emissions of the industrial revolution. In any case, in the evolution of the moth, mutations of the genes produced light and dark moths. Through natural selection the light moth had an adaptive advantage until environmental conditions changed, increasing the population of the dark moths and depleting that of the light moths.

8. b. *Students know a great diversity of species increases the chance that at least some organisms survive major changes in the environment.*

This standard is similar to the previous standard set on diversity within a species but takes student understanding one step further by addressing diversity among and between species. For the same reasons pertinent to those for intraspecies diversity, increased diversity among species increases the chances that some species will adapt to survive future environmental changes.

8. c. *Students know the effects of genetic drift on the diversity of organisms in a population.*

If a small random sample of individuals is separated from a larger population, the gene frequencies in the sample may differ significantly from those in the population as a whole. The shifts in frequency depend only on which individuals fall in the sample (and so are themselves random). Because a random shift in gene frequency is not guaranteed to make the next generation better adapted, the shift—or genetic drift—with respect to the original gene pool is not necessarily an adaptive change. The *bottleneck effect* (i.e., nonselective population reductions due to disasters) and the *founder effect* (i.e., the colonization of a new habitat by a few individuals) describe situations that can lead to genetic drift of small populations.

8. d. *Students know reproductive or geographic isolation affects speciation.*

Events that lead to reproductive isolation of populations of the same species cause new species to appear. Barriers to reproduction that prevent mating between

populations are called *prezygotic* (before fertilization) if they involve such factors as the isolation of habitats, a difference in breeding season or mating behavior, or an incompatibility of genitalia or gametes. *Postzygotic* (after fertilization) barriers that prevent the development of viable, fertile hybrids exist because of genetic incompatibility between the populations, hybrid sterility, and hybrid breakdown.

These isolation events can occur within the geographic range of a parent population (*sympatric speciation*) or through the geographic isolation of a small population from its parent population (*allopatric speciation*). Sympatric speciation is much more common in plants than in animals. Extra sets of chromosomes, or *polypoidy*, that result from mistakes in cell division produce plants still capable of long-term reproduction but animals that are incapable of that process because polypoidy interferes with sex determination and because animals, unlike most plants, are usually of one sex or the other. Allopatric speciation occurs in animal evolution when geographically isolated populations adapt to different environmental conditions. In addition, the rate of allopatric speciation is faster in small populations than in large ones because of greater genetic drift.

8. e. *Students know how to analyze fossil evidence with regard to biological diversity, episodic speciation, and mass extinction.*

Analysis of the fossil record reveals the story of major events in the history of life on earth, sometimes called *macroevolution*, as opposed to the small changes in genes and chromosomes that occur within a single population, or *microevolution*. Explosive radiations of life following mass extinctions are marked by the four eras in the geologic time scale: the Precambrian, Paleozoic, Mesozoic, and Cenozoic. The study of biological diversity from the fossil record is generally limited to the study of the differences among species instead of the differences within a species. Biological diversity within a species is difficult to study because preserved organic material is rare as a source of DNA in fossils.

Episodes of speciation are the most dramatic after the appearance of novel characteristics, such as feathers and wings, or in the aftermath of a mass extinction that has cleared the way for new species to inhabit recently vacated adaptive zones. Extinction is inevitable in a changing world, but examples of mass extinction from the fossil record coincide with rapid global environmental changes. During the formation of the supercontinent Pangaea during the Permian period, most marine invertebrate species disappeared with the loss of their coastal habitats. During the Cretaceous period a climatic shift to cooler temperatures because of diminished solar energy coincided with the extinction of dinosaurs.

8. f.* *Students know how to use comparative embryology, DNA or protein sequence comparisons, and other independent sources of data to create a branching diagram (cladogram) that shows probable evolutionary relationships.*

The area of study that connects biological diversity to *phylogeny*, or the evolutionary history of a species, is called *systematics*. Systematic classification is based on

the degree of similarity between species. Thus, comparisons of embryology, anatomy, proteins, and DNA are used to establish the extent of similarities. Embryological studies reveal that *ontogeny*, development of the embryo, provides clues to phylogeny. In contrast to the old assertion that “ontogeny recapitulates phylogeny” (i.e., that it replays the entire evolutionary history of a species), new findings indicate that structures, such as gill pouches, that appear during embryonic development but are less obvious in many adult life forms may establish *homologies* between species (similarities attributable to a common origin). These homologies are evidence of common ancestry. Likewise, homologous anatomical structures, such as the forelimbs of humans, cats, whales, and bats, are also evidence of a common ancestor. Similarity between species can be evaluated at the molecular level by comparing the amino acid sequences of proteins or the nucleotide sequences of DNA strands. DNA-DNA hybridization, restriction mapping, and DNA sequencing are powerful new tools in systematics.

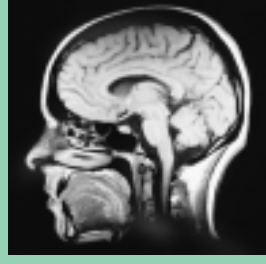
Approaches for using comparison information to classify organisms on the basis of evolutionary history differ greatly. *Cladistics* uses a branching pattern, or *cladogram*, based on shared derived characteristics to map the sequence of evolutionary change. The cladogram is a dichotomous tree that branches to separate those species that share a derived characteristic, such as hair or fur, from those species that lack the characteristic. Each new branch of the cladogram helps to establish a sequence of evolutionary history; however, the extent of divergence between species is unclear from the sequence alone.

Phenetics classifies species entirely on the basis of measurable similarities and differences with no attempt to sort homology from analogy. In recent years phenetic studies have been helped by the use of computer programs to compare species automatically across large numbers of traits. Striking a balance between these two approaches to classification has often involved subjective judgments in the final decision of taxonomic placement. Students can study examples of cladograms and create new ones to understand how a sequence of evolutionary change based on shared derived characteristics is developed.

8. g.* *Students know* how several independent molecular clocks, calibrated against each other and combined with evidence from the fossil record, can help to estimate how long ago various groups of organisms diverged evolutionarily from one other.

Molecular clocks are another tool to establish phylogenetic sequences and the relative dates of phylogenetic branching. Homologous proteins, such as cytochrome c, of different *taxa* (plants and animals classified according to their presumed natural relationships) and the genes that produce those proteins are assumed to evolve at relatively constant rates. On the basis of that assumption, the number of amino acid or nucleotide substitutions provides a record of change proportional to the time between evolutionary branches. The estimates of rate of change derived from these molecular clocks generally agree with parallel data from the fossil record; however, the branching orders and times between branches are more reliably determined by

measuring the degree of molecular change than by comparing qualitative features of morphology. When gaps in the fossil record exist, phylogenetic branching dates can be estimated by calibrating molecular change against the timeline determined from the fossil record.



STANDARD SET 9. Physiology (Homeostasis)

From the individual cell to the total organism, each functioning unit is organized according to *homeostasis*, or how the body and its parts deal with changing demands while maintaining a constant internal environment. In 1859 noted French physiologist Claude Bernard described the difference between the internal environment of the cells and the external environment in which the organism lives. Organisms are shielded from the variations of the external environment by the “constancy of the internal milieu.” This “steady state” refers to the dynamic equilibrium achieved by the integrated functioning of all the parts of the organism.

American physiologist Walter Cannon called this phenomenon *homeostasis*, which means “standing still.” All organ systems of the human body contribute to homeostasis so that blood and tissue constituents and values stay within a normal range. Students will need supportive review of the major systems of the body and of the organ components of those systems (see Standard Set 2, “Life Sciences,” for grade five in Chapter 3 and Standard Set 5, “Structure and Function in Living Systems,” for grade seven in Chapter 4). As the prime coordinators of the body’s activities, the nervous and endocrine systems must be examined and their interactive roles clearly defined.

9. As a result of the coordinated structures and functions of organ systems, the internal environment of the human body remains relatively stable (homeostatic) despite changes in the outside environment. As a basis for understanding this concept:

- a. *Students know* how the complementary activity of major body systems provides cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide.

The digestive system delivers nutrients (e.g., glucose) to the circulatory system. Oxygen molecules move from the air to the alveoli of the lungs and then to the circulatory system. From the circulatory system glucose and oxygen molecules move from the capillaries into the cells of the body where cellular respiration occurs. During cellular respiration these molecules are oxidized into carbon dioxide and water, and energy is trapped in the form of ATP. The gas exchange process is reversed for the removal of carbon dioxide from its higher concentration in the cells to the circulatory system and, finally, to its elimination by exhalation from the lungs.

The concentration of sugar in the blood is monitored, and students should know that sugar can be stored or pulled from reserves (glycogen) in the liver and

muscles to maintain a constant blood sugar level. Amino acids contained in proteins can also serve as an energy source, but first the amino acids must be deaminated, or chemically converted, in the liver, producing ammonia (a toxic product), which is converted to water-soluble urea and excreted by the kidneys. Teachers should emphasize that all these chemicals are transported by the circulatory system and the cells. Organs at the final destination direct these chemicals to their exit from the circulatory system.

9. b. *Students know how the nervous system mediates communication between different parts of the body and the body's interactions with the environment.*

An individual becomes aware of the environment through the sense organs and other body receptors (e.g., by allowing for touch, taste, and smell and by collecting information about temperature, light, and sound). The body reflexively responds to external stimuli through a reflex arc (see Standard 9.e in this section). (*A reflex arc* is the pathway along the central nervous system where an impulse must travel to bring about a reflex; e.g., sneezing or coughing.) Students can examine the sense organs, identify other body receptors that make them aware of their environment, and see ways in which the body reflexively responds to an external stimulus through a reflex arc.

Hormones work in conjunction with the nervous system, as shown, for example, in the digestive system, where insulin released from the pancreas into the blood regulates the uptake of glucose by muscle cells. The pituitary master gland produces growth hormone for controlling height. Other pituitary hormones have specialized roles (e.g., follicle-stimulating hormone [FSH] and luteinizing hormone [LH] control the gonads, thyroid-stimulating hormone [TSH] controls the thyroid, and adrenocorticotrophic hormone [ACTH] regulates the formation of glucocorticoids by the adrenal cortex). This master gland is itself controlled by the hypothalamus of the brain.

9. c. *Students know how feedback loops in the nervous and endocrine systems regulate conditions in the body.*

Feedback loops are the means through which the nervous system uses the endocrine system to regulate body conditions. The presence or absence of hormones in blood brought to the brain by the circulatory system will trigger an attempt to regulate conditions in the body. To make feedback loops relevant to students, teachers can discuss the hormone leptin, which fat cells produce as they become filled with storage reserves. Leptin is carried by the blood to the brain, where it normally acts to inhibit the appetite center, an example of negative feedback. When fat reserves diminish, the concentration of leptin decreases, a phenomenon that in turn causes the appetite center in the brain to start the hunger stimulus and activate the urge to eat.

9. d. *Students know the functions of the nervous system and the role of neurons in transmitting electrochemical impulses.*

Transmission of nerve impulses involves an electrochemical “action potential” generated by gated ion channels in the membrane that make use of the counter-vailing gradients of sodium and potassium ions across the membrane. Potassium ion concentration is high inside cells and low outside; sodium ion concentration is the opposite. The sodium and potassium ion concentration gradients are restored by an active transport system, a pump that exchanges sodium and potassium ions across the membrane and uses ATP hydrolysis as a source of free energy. The release of neurotransmitter chemicals from the axon terminal at the synapse may initiate an action potential in an adjacent neuron, propagating the impulse to a new cell.

9. e. *Students know the roles of sensory neurons, interneurons, and motor neurons in sensation, thought, and response.*

The pathways of impulses from dendrite to cell body to axon of sensory neurons, interneurons, and motor neurons link the chains of events that occur in a reflex action. Students should be able to diagram this pathway. Similar paths of neural connections lead to the brain, where the sensations become conscious and conscious actions are initiated in response to external stimuli. Students might also trace the path of the neural connections as the sensation becomes conscious and a response to the external stimulus is initiated. Students should also be able to identify gray and white matter in the central nervous system.

9. f.* *Students know the individual functions and sites of secretion of digestive enzymes (amylases, proteases, nucleases, lipases), stomach acid, and bile salts.*

To bring about digestion, secretions of enzymes are mixed with food (in the mouth and as the food proceeds from the mouth through the stomach and through the small intestines). For example, salivary glands and the pancreas secrete amylase enzymes that change starch into sugar. Stomach acid and gastric enzymes begin the breakdown of protein, a process that intestinal and pancreatic secretions continue.

Lipase enzymes secreted by the pancreas break down fat molecules (which contain three fatty acids) to free fatty acids plus diglycerides (which contain two fatty acids) and monoglycerides (which contain one fatty acid). Bile secreted by the liver furthers the process of digestion, emulsifying fats and facilitating digestion of lipids. Students might diagram the digestive tract, labeling important points of secretion and tracing the pathways from digestion of starches, proteins, and other foods. They can then outline the role of the kidney nephron in the formation of urine and the role of the liver in glucogenesis and glycogenolysis (glucose balance) and in blood detoxification.

9. g.* *Students know the homeostatic role of the kidneys in the removal of nitrogenous wastes and the role of the liver in blood detoxification and glucose balance.*

Microscopic nephrons within the kidney filter out body wastes, regulate water, and stabilize electrolyte levels in blood. The liver removes toxic materials from the blood, stores them, and excretes them into the bile. The liver also regulates blood glucose.

9. h.* *Students know the cellular and molecular basis of muscle contraction, including the roles of actin, myosin, Ca^{+2} , and ATP.*

Controlled by calcium ions and powered by hydrolysis of ATP, actin and myosin filaments in a sarcomere generate movement in stomach muscles. Striated muscle fibers reflect the filamentous makeup and contraction state evidenced by the banding patterns of those fibers. A sketch of the sarcomere can be used to indicate the functions of the actin and myosin filaments and the role of calcium ions and ATP in muscle contraction.

9. i.* *Students know how hormones (including digestive, reproductive, osmoregulatory) provide internal feedback mechanisms for homeostasis at the cellular level and in whole organisms.*

Hormones act as chemical messengers, affecting the activity of neighboring cells or other target organs. Their movement can be traced from their point of origin to the target site. The feedback mechanism works to regulate the activity of hormones and promotes homeostasis.



STANDARD SET 10. Physiology (Infection and Immunity)

Some bacteria, parasites, and viruses cause human diseases because they either rob the body of necessary sustenance or secrete toxins that cause injury. The human body has a variety of mechanisms to interfere with or destroy invading pathogens. Besides protection afforded by the skin, one of the most effective means of defending against agents that harm the body is the immune system with its cellular and chemical defenses. Students should develop a clear understanding of the components of the immune system and know how vaccines and antibiotics are used to combat disease. They should also know that acquired immune deficiency syndrome (AIDS) compromises the immune system, causing affected persons to succumb to other AIDS-associated infections that are harmless to people with an intact immune system.

10. Organisms have a variety of mechanisms to combat disease. As a basis for understanding the human immune response:

- a. *Students know* the role of the skin in providing nonspecific defenses against infection.

The skin serves as a physical barrier to prevent the passage of many disease-causing microorganisms. Cuts and abrasions compromise the skin's ability to act as a barrier. Teachers can use charts and overhead projections to show the dangers and physiologic responses of a break in the skin.

- 10. b.** *Students know* the role of antibodies in the body's response to infection.

Cells produce antibodies to oppose antigens, substances that are foreign to the body. An example of an antigen is a surface protein of a flu virus, a protein with a shape and structure unlike those of any human proteins. The immune system recognizes that the flu virus structure is different and generates proteins called *antibodies* that bind to the flu virus. Antibodies can inactivate pathogens directly or signal immune cells that pathogens are present.

- 10. c.** *Students know* how vaccination protects an individual from infectious diseases.

Several weeks are required before the immune system develops immunity to a new antigen. To overcome this problem, vaccinations safely give the body a look in advance at the foreign structures. Vaccines usually contain either weakened or killed pathogens that are responsible for a specific infectious disease, or they may contain a purified protein or subunit from the pathogen. Although the vaccine does not cause an infectious disease, the antigens in the mixture prompt the body to generate antibodies to oppose the pathogen. When the individual is exposed to the pathogenic agent, perhaps years later, the body still remembers having seen the antigens in the vaccine dose and can respond quickly. Students have been exposed to the practical aspects of immunization through their knowledge of the vaccinations they must receive before they can enter school. They have all experienced getting shots and may have seen their personal vaccination record in which dates and kinds of inoculations are recorded. The review of a typical vaccination record, focusing on the reason for the shots and ways in which they work, may serve as an effective entry to the subject.

Students should review the history of vaccine use. Early literature provides descriptions of vaccine use from pragmatic exposure, but the term *vaccine* is derived from the cowpox exudate that Edward Jenner used during the 1700s to inoculate villagers against the more pathogenic smallpox. Louis Pasteur, noted for his discovery of the rabies treatment, also developed several vaccines. Poliovirus, the cause of infantile paralysis (poliomyelitis), was finally conquered in the 1950s through vaccines that Jonas Salk and Albert B. Sabin refined.

10. d. *Students know there are important differences between bacteria and viruses with respect to their requirements for growth and replication, the body's primary defenses against bacterial and viral infections, and effective treatments of these infections.*

A *virus*, which is the simplest form of a genetic entity, is incapable of metabolic life and reproduction outside the cells of other living organisms. A virus contains genetic material but has no ribosomes. Although some viruses are benign, many harm their host organism by destroying or altering its cell structures. Generally, the body perceives viruses as antigens and produces antibodies to counteract the virus. *Bacteria* are organisms with a full cellular structure. They, too, can be benign or harmful. Harmful bacteria and their toxins are perceived as antigens by the body, which in turn produces antibodies. In some cases infectious diseases may be treated effectively with *antiseptics*, which are chemicals that oxidize or in other ways inactivate the infecting organism. Antiseptics are also useful in decontaminating surfaces with which the body may come in contact (e.g., countertops). *Antibiotics* are effective in treating bacterial infections, sometimes working by destroying or interfering with the growth of bacterial cell walls or the functioning of cell wall physiology or by inhibiting bacterial synthesis of DNA, RNA, or proteins. Antibiotics are ineffective in treating viral infections.

Students might research infections caused by protists (malaria, amoebic dysentery), bacteria (blood poisoning, botulism, food poisoning, tuberculosis), and viruses (rabies, colds, influenza, AIDS). They might also investigate the pathogens currently being discussed in the media and study each infectious organism's requirements for growth and reproduction. Teachers should review the dangers of common bacteria becoming resistant to antibiotics through long-standing over-application, as shown by the increasing incidence of drug-resistant tuberculosis and other bacteria. Using a commercially available kit, teachers can demonstrate how antibiotics may act generally or specifically against bacteria. Agar plates may be inoculated with different bacteria, and different antibiotic discs may be placed on these plates to create a clear zone in which growth around the antibiotic discs is inhibited.

10. e. *Students know why an individual with a compromised immune system (for example, a person with AIDS) may be unable to fight off and survive infections by microorganisms that are usually benign.*

When an immune system is compromised (e.g., through infection by the human immunodeficiency virus [HIV]), it becomes either unable to recognize a dangerous antigen or incapable of mounting an appropriate defense. This situation happens when the virus infects and destroys key cells in the immune system.

10. f.* *Students know the roles of phagocytes, B-lymphocytes, and T-lymphocytes in the immune system.*

Phagocytes move, amoebalike, through the circulatory system, consuming waste and foreign material, such as aged or damaged blood cells and some infectious bacteria and viruses. Two broad types of lymphocytes (a class of white blood cells) originate in the bone marrow during embryonic life. One type (the B-lymphocyte) matures in the bone marrow and gives rise to antibody-producing plasma cells that are responsible for humoral immunity. Each mature B-lymphocyte can give rise to only a single type of antibody, which itself may recognize only a single foreign antigen. The other type (the T-lymphocyte) matures in the thymus gland during embryogenesis and gives rise to “cytotoxic” (cell killing) and “helper” T-lymphocytes. The cytotoxic T-cells are particularly useful for surveillance of intra-cellular pathogens. Antibodies cannot reach the intracellular pathogen because of the cell membrane, but the infected cell can be identified and killed. Helper T-cells assist in organizing both the humoral and cellular immune responses.

Investigation and Experimentation

Teachers must convey the skills and knowledge that students need to perform investigations and experiments, the foundation of scientific knowledge. The Investigation and Experimentation standards allow students to make concrete associations between science and the study of nature and to provide many opportunities to take measurements and use basic mathematics. In the sequence for grades nine through twelve, teachers implement these standards in the context of physics, chemistry, biology/life sciences, and earth sciences.

Investigations and experiments engage scientists, catalyzing their highest levels of creativity and producing their most satisfying rewards. The possibility of discovery or of adding new scientific knowledge in the form of facts, concepts, principles, or theories offers a great sense of accomplishment and wonder. Investigation and experimentation can be just as engaging to high school students as they study science. Although students may not discover knowledge new to the scientific community, they may find pleasure in discovering something new to themselves or in seeing the content from their science text illuminated through demonstrations of the concepts. Accordingly, they can experience the pride of creating experimental protocols and realize the joy of discovery and learning.

Teachers need to know and teach the details of the scientific processes addressed by the Investigation and Experimentation standards. To be valid, an experiment needs controls that minimize sources of error and that provide reproducible results. Teachers should select standards-based, well-tested experiments and demonstrations instead of unguided or disorganized “expeditions.” Taught effectively, science courses may be engaging for high school students. Some principles are best pretaught explicitly through direct instruction, then demonstrated with a hands-on activity that reinforces the teaching. Students may easily discover other principles by themselves, and teachers should not rob them of that pleasure. The teacher must be certain that every investigative activity reinforces content and sound thinking.

I. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content of the other four strands, students should develop their own questions and perform investigations. Students will:

- a. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.
- b. Identify and communicate sources of unavoidable experimental error.

- c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- d. Formulate explanations by using logic and evidence.
- e. Solve scientific problems by using quadratic equations and simple trigonometric, exponential, and logarithmic functions.
- f. Distinguish between hypothesis and theory as scientific terms.
- g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.
- h. Read and interpret topographic and geologic maps.
- i. Analyze the locations, sequences, or time intervals that are characteristic of natural phenomena (e.g., relative ages of rocks, locations of planets over time, and succession of species in an ecosystem).
- j. Recognize the issues of statistical variability and the need for controlled tests.
- k. Recognize the cumulative nature of scientific evidence.
- l. Analyze situations and solve problems that require combining and applying concepts from more than one area of science.
- m. Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings. Examples of issues include irradiation of food, cloning of animals by somatic cell nuclear transfer, choice of energy sources, and land and water use decisions in California.
- n. Know that when an observation does not agree with an accepted scientific theory, the observation is sometimes mistaken or fraudulent (e.g., the Piltdown Man fossil or unidentified flying objects) and that the theory is sometimes wrong (e.g., the Ptolemaic model of the movement of the Sun, Moon, and planets).

Chapter 5

The Science
Content
Standards for
Grades Nine
Through
Twelve

**Investigation and
Experimentation**