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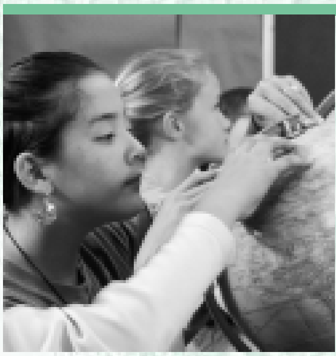

The Science Content Standards for Grades Six Through Eight

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In each grade, kindergarten through grade five, the science content standards cover the areas of physical, life, and earth sciences in approximately equal measures. In each of the middle grades, however, the content standards emphasize an individual area. This organization permits students to probe each area in greater depth.

- In grade six the content standards focus on earth sciences. Students often become environmentally aware at this grade level, and this focus is meant to stimulate intellectual curiosity in that area.
- In grade seven the content standards focus on life sciences. Students at this grade level typically receive a semester of health education, and this focus is designed both to complement that instruction and to prepare students for the biology/life sciences course work that is often taken in the early high school years.
- In grade eight the content standards focus on physical sciences. This focus is designed to prepare students for the physics and chemistry course work that is often taken in the later high school years.

In all three of the middle grades, science instruction is intended to provide students with a solid foundation for the more formal treatment of concepts, principles, and theories called for at the high school level.

Not all students will enter middle school prepared for the rigorous science curriculum called for in the middle grades standards. Teachers should use "catch up" strategies to ensure that students are prepared for high school science. One of the key requirements is for students to have foundational reading and mathematics skills, as outlined in the State Board of Education's *Reading/Language Arts Framework for California Public Schools* and the *Mathematics Framework for California Public Schools.*[1] Those frameworks provide specific strategies for teachers to help students who are below grade level in reading and mathematics.

Students who are prepared to undertake the study of algebra (either as a separate course or as part of an integrated mathematics course) in grade eight, as called for in the *Mathematics Content Standards for California Public Schools*, will be on the pathway for success in high school science.[2] Those who are not as well prepared will struggle and may even fail in their science classes to the great frustration of their teachers and parents/guardians. For example, students who have not mastered arithmetic and algebra skills will find chemistry difficult, if not impossible. Science instruction should provide opportunities for students to use mathematics by solving problems. Teachers may use science to both reinforce mathematical abilities and deepen students' understanding of key mathematical concepts.

Safety is always the foremost consideration in the design of demonstrations, hands-on activities, laboratories, and science projects on site or away from school. Teachers must become familiar with the *Science Safety Handbook for California Public Schools.*[3] It contains specific and useful information relevant to classroom teachers of science. School administrators, teachers, parents/guardians, and students have a legal and moral obligation to promote safety in science education. Safety should be taught. Scientists and engineers in universities and industries are required to follow strict environmental health and safety regulations. Knowing and following safe practices in science are a part of understanding the nature of science and scientific enterprise.

Grade Six — Focus on Earth Sciences

The science curriculum in grade six emphasizes the study of earth sciences. Students at this age are increasing their awareness of the environment and are ready to learn more. The standards in grade six present many of the foundations of geology and geophysics, including plate tectonics and earth structure, topography, and energy. The material is linked to resource management and ecology, building on what students have learned in previous grades. Unless students take a high school earth science class, what they learn in grade six will be their foundation for earth science literacy.

STANDARD SET 1. Plate Tectonics and Earth's Structure

Plate tectonics is a unifying geologic theory that explains the formation of major features of Earth's surface and important geologic events. Although most scientists today consider Alfred Wegener to be the pioneer of the modern continental drift theory, he died with very little recognition for his accomplishment. Wegener asserted that evidence on Earth's surface indicated that the continents were once attached as an entire land mass. He theorized that this land mass broke up into pieces that subsequently drifted apart. Today, geologists know that plate tectonic processes are responsible for most of the major features of Earth's crust (including continental configuration, mountains, island arcs, and ocean floor topography) and are an important contributor to the recycling of material in the rock cycle. Driven by the flow of heat and material within Earth, these processes cause stresses in Earth's crust that are released through earthquakes and volcanic activity. Mountain building counters the constant destructive effects of weathering and erosion that eventually wear down Earth's surface features.

1. Plate tectonics accounts for important features of Earth's surface and major geologic events. As a basis for understanding this concept:

a. *Students know* evidence of plate tectonics is derived from the fit of the continents; the location of earthquakes, volcanoes, and midocean ridges; and the distribution of fossils, rock types, and ancient climatic zones.

Evidence of past plate tectonic movement is recorded in Earth's crustal rocks, in the topography of the continents, and in the topography and age of the ocean floor. Continental edges reflect that they were once part of a single large supercontinent that Wegener named Pangaea. Upon the breakup of this supercontinent, the individual continents were moved to their present locations by the forces that drive plate tectonics. When the continental plates of today are returned to their super-continent positions (through computer modeling), the fossil and sedimentary evidence of ancient life distributions and climate becomes coherent, providing strong support for the existence of Pangaea. As plates move in relation to one another, landforms and topographic features, such as volcanoes, mountains, valleys, ocean trenches, and midocean ridges, are generated along plate boundaries. Those regions are also frequently associated with geothermal and seismic activity. There is strong evidence that the divergence and convergence of the lithospheric plates did not begin and end with Pangaea but have been going on continually for most of the history of Earth.

Students should read and discuss expository texts that explain the process of continental drift and study maps that show the gradual movement of land masses over millions of years. Students may then model the process by cutting out continental shapes from a map of Earth and treating these continents as movable jigsaw puzzle pieces. Students read about the underlying evidence for continental drift and determine that the best-supported model of Pangaea shows a continuation of major geologic features and fossil trends across continental margins. The "broken" pieces of Pangaea can be gradually moved into their modern-day continental and oceanic locations. In doing this students should think carefully about the rate and time scale of the movement. This would be a good point in the curriculum to introduce the differing compositions of the denser ocean floor (basaltic) rock and less-dense continental (granitic) rocks. Students can also learn why most modern-day earthquakes and volcanoes occur at the "leading edges" of the moving continents.

1. b. *Students know* Earth is composed of several layers: a cold, brittle lithosphere; a hot, convecting mantle; and a dense, metallic core.

Earth is not homogeneous solid rock but is composed of three distinct layers: a rocky, thin, fractured outer layer called the *crust;* a denser and thick middle layer called the *mantle;* and a dense, metallic center called the *core.* Geologists also use another classification scheme in which the outer, brittle layer of Earth is called the lithosphere (from the Greek *lithos* for rock). The lithosphere includes the crust and the outermost portion of the mantle and is the part that is broken into the tectonic plates. Students should know the properties of the crust, mantle, core, lithosphere, and plastic mantle region just beneath the lithosphere called the *asthenosphere.*

Temperature increases with increasing depth as a consequence of the heat released by the decay of trace quantities of radioactive atoms that are contained within Earth. Heating lowers the density of parts of the interior. Because an arrangement of high-density material over low-density material cannot be gravitationally stable, a vertical flow called *convection* develops. This convection can be sustained as long as the interior continues to be heated, causing a continuous cycling within Earth's interior. Scientists gather evidence for the details of Earth's layered structure from the analysis of seismic *P* and *S* waves as they pass through the planet. The content of this standard can be learned efficiently by the study of a cross-sectional model or diagram of Earth showing locations (to scale) of the crust, mantle, and core with each subdivision labeled according to temperature, density, composition, and physical state.

1. c. *Students know* lithospheric plates the size of continents and oceans move at rates of centimeters per year in response to movements in the mantle.

Convective flow in the mantle moves at rates measured in centimeters per year, about as fast as fingernails grow. Mantle motion is transferred to the lithosphere at its boundary with the asthenosphere. As a result of this coupling, the lithospheric plates are carried passively along, riding as "passengers" at the same slow rate, in much the same way that ice floats along on slow-moving water. These lithospheric plates may be *oceanic* (i.e., they consist of rocks of basaltic composition) or *continental* (i.e., they consist of a more varied suite of rocks, mostly of granitic composition, covered in many places with a thin veneer of sedimentary rocks). Convective flow is based on the "rising" and "sinking" of materials with different relative densities. Just as a hot-air balloon rises through lower temperature and therefore denser air, hot convecting mantle can rise through lower temperature and therefore denser rock, albeit very slowly. When the material cools and increases in density, it may sink just like the hot-air balloon once the air inside has cooled. Oceanic lithosphere cools after it forms at Earth's surface and can eventually become dense enough that it will sink into Earth's interior, sliding under an adjacent plate that is less dense.

1. d. *Students know* that earthquakes are sudden motions along breaks in the crust called faults and that volcanoes and fissures are locations where magma reaches the surface.

The hot, moving mantle is responsible for many geologic events, including most seismic and volcanic activity. As a result of the relative motion of the lithospheric plates, the boundaries of the plates are subjected to stresses. When the rocks are strained so much that they can no longer stretch or flow, they may rupture. This rupture is manifested as sudden movement along a broken surface and is called a *fault.* The energy released is spread as complex waves (called *earthquakes*) that travel through and around Earth. Volcanic phenomena, including explosive eruptions and lava flows, may also result from interactions at the boundaries between plates. Molten gas-charged magma generated in the crust or mantle rises buoyantly and exerts an upward force on Earth's surface. If these rocks and gases punch through the surface, they result in a variety of volcanic phenomena.

Using California-adopted texts, software, and other instructional materials aligned with the *Science Content Standards,* students can study models of the inner structures of volcanoes, the dynamics of the central crater, and the processes of erupting and flowing lava. Students can study the various types of volcanoes and how they form. They can also learn about different types of lava flows and the three major types of volcanic landforms (cone, shield, and composite).

1. e. *Students know* major geologic events, such as earthquakes, volcanic eruptions, and mountain building, result from plate motions.

Most (but not all) earthquakes and volcanic eruptions occur along plate boundaries where the plates are moving relative to one another. The movement is never smooth; it may produce fractures or faults and may also generate heat. The sudden shift of one plate on another plate along faults causes earthquakes. Volcanic eruptions may occur along faults in which one plate slides under another and sinks deep enough to melt part of the descending material. This process of one plate sliding under another is called *subduction.* Great mountain-building episodes occur when two continental plates collide. The collision (although slow) is enormously powerful because of the mass of the continents. Over long periods of time, this process may crumple and push up the margins of the colliding continents.

Students may use a large map of the world or of the Pacific Ocean (including the entire Pacific Ocean Rim) to plot the locations of major earthquakes and volcanic eruptions during the past ten to 100 years. The locations of those tectonic events may be found on the Internet or in various library resources. Different symbols may be used to represent different depths or magnitudes of events. In studying such a map, students should note that tectonic events form a "ring" that outlines the Pacific Plate and that there is a Hawaiian "hot spot." Landforms associated with the plate boundaries include mountain belts, deep ocean trenches, and volcanic island arcs.

1. f. *Students know* how to explain major features of California geology (including mountains, faults, volcanoes) in terms of plate tectonics.

Most of California resides on the North American lithospheric (continental) plate, one of the several major plates, and many smaller plates that together form the lithosphere of Earth. A small part of California, west of the San Andreas Fault, lies on the adjacent Pacific (oceanic) Plate. Geologic interactions between these two plates over time have created the complex pattern of mountain belts and intervening large valleys that make up the current California landscape. Large parts of the central and southern parts of California were once covered by a shallow sea. Interactions with the Pacific Plate during the past few million years have compressed, fractured, and uplifted the area. This tectonic deformation has buckled the lithosphere upward to create the high-standing coastal and transverse mountain ranges and downward to form the lower-lying Central Valley, Los Angeles Basin, and Ventura Basin.

1. g. *Students know* how to determine the epicenter of an earthquake and know that the effects of an earthquake on any region vary, depending on the size of the earthquake, the distance of the region from the epicenter, the local geology, and the type of construction in the region.

An epicenter is that point on Earth's surface directly above the place of an earthquake's first movement, or *focus.* It is located by seismic data recorded at a minimum of three seismograph stations. The method of locating the epicenter is based on the speed of seismic waves that travel through the ground—seen as their relative times of arrival at seismic stations. These vibrations are called *P*- and *S*-waves. *P*-, or *primary,* waves are compressional with particle motion in the same direction as the wave propagation. *S*-, or *secondary,* waves are shearing with particle motion perpendicular to the direction of wave propagation. *S*-waves travel at about 60 percent of the speed of *P*-waves.

The motion of *P*- and *S*-waves and the difference in their respective velocities are easily modeled with a long and flexible spring (typically sold as a toy). Compressing and releasing a few coils at the end of the spring stretched between two students generates visible *P*-waves that travel the length of the spring and back in the opposite direction. Slapping the side of the spring generates *S*-waves that travel as sideways displacements down the length of the spring. If students measure the distance between the ends of the spring and the time it takes for the *P*- and *S*-waves to travel the full length, they can calculate the different velocities of the two waves along the spring.

Seismographs record the arrival time of the *P*- and *S*-waves. The knowledge that both waves started at the same time allows one to determine the distance of the epicenter. If three or more seismographs record distances to the same event, the epicenter of the earthquake may be determined by triangulation.

Students in grade six can be taught to locate epicenters if they are given the arrival times at various locations on a map, along with a simple velocity model. They may also be asked to locate major geologic features in and near California, such as Mount Lassen, the San Andreas Fault, the Sierra Nevada ranges, Death Valley, the Baja Peninsula, and the San Francisco Peninsula. They can draw and relate these to a map that includes outlines of the major tectonic plates. California's population is primarily concentrated near the San Andreas Fault and the system of faults that surround it. Students can plot on a map the location of their school and nearby active faults and research records of earthquake activity, ground motion, and fracturing.

Seismograph stations also record the amplitude of the ground motion, which can be used to calculate the magnitude of an earthquake (a relative measure of the amount of energy released). Magnitude is often reported according to the Richter scale, with values that generally range from around 0 to a little less than 9. Each increase of one number in magnitude represents a tenfold increase in ground shaking. Geologists may also investigate the effects of an earthquake on structures (and people's reactions) and assign an intensity value to that earthquake. The intensity values are then plotted on a map to give a more complete picture of the earthquake's effects. There are several different intensity scales, but the one most widely used in this country is the Modified Mercalli scale. This scale ranges from I (not felt) to XII (damage nearly total).

The magnitude of an earthquake is determined by the buildup of elastic strain (stored energy) in the crust at the place where ruptures (faults) may eventually occur. Unfortunately, many small earthquakes combined can release only a small fraction of the stored energy. For example, it might take as many as one million earthquakes, each at a magnitude of 4.0 on the Richter scale to release the same amount of energy as a single earthquake at 8.0. Although each increase of one number on the Richter scale reflects a tenfold increase in ground shaking, it represents nearly a thirtyfold increase in energy released. Therefore there is always a possibility that a large, destructive earthquake will release most of the stored energy. Because the materials through which earthquakes move can absorb energy and because the energy is spread over a wider area as its waves propagate outward, an earthquake tends to weaken with increasing distance from its epicenter. As earthquake waves pass through the ground, unconsolidated materials, such as loose sediments or fill, tend to shake more violently or undergo liquefaction more easily than do harder materials. Buildings made of brittle materials (e.g., reinforced concrete, brick, or adobe) tend to suffer greater earthquake damage than do those made of more flexible materials (wood). Taller buildings are often more susceptible to earthquake damage than are single story-buildings.

STANDARD SET 2. Shaping Earth's Surface

Over long periods of time, many changes have occurred in Earth's surface features. Forces related to plate tectonics have elevated mountains. Atmospheric constituents (mostly water, oxygen, and carbon dioxide) have interacted with minerals and rocks at Earth's surface, weakening them and breaking them down through a process called *chemical weathering.* Physical processes involving, for example, the growth of plants, the release of pressure as overlying material is eroded, and the repeated freezing and thawing of water in cracks, have also helped to break down rocks. Fragments are transported downslope by wind, water, and ice. Gravity by itself moves material by way of landslides and slumps (called *mass wasting*). The ultimate destination of most of the products of weathering is the ocean. These products arrive in the form of marine sediment deposits. In time the mountains are laid low, the rivers change their courses and disappear, and lakes and seas expand or dry up. Eventually sediments, which have found their way to the oceans along continental margins, are compacted and changed to rock, then uplifted by continental collision or subducted and melted under the crust. New mountains are formed, and the cycle (called the *geologic cycle*) begins anew. Each cycle takes tens of millions of years.

2. Topography is reshaped by the weathering of rock and soil and by the transportation and deposition of sediment. As a basis for understanding this concept:

a. *Students know* water running downhill is the dominant process in shaping the landscape, including California's landscape.

Water contributes to two processes that help shape the landscape—the breakdown of rock into smaller pieces by mechanical and chemical weathering and the removal of rock and soil by erosion. Water is the primary agent in shaping California's landscape. Surface water flow, glaciers, wind, and ocean waves have all been and continue to be active throughout California and the rest of the world in shaping landscapes.

A "stream table" may be used to demonstrate the effectiveness of running water as an erosion agent. Stream tables can be easily made from plastic bins or dishpans filled with sand or gravel. The water source may be a hose, a siphon that draws from a cup, or even a drip system. Students may use either gradient or water flow rate as the independent variable. Rates of settling of different sizes of sediment through water may be demonstrated through the use of a sediment jar.

2. b. *Students know* rivers and streams are dynamic systems that erode, transport sediment, change course, and flood their banks in natural and recurring patterns.

The energy of flowing water is great enough to pick up and carry sediment, thereby lowering mountains and cutting valleys. Sediment carried by a stream may be directed against solid rock with such force that it will cut or abrade the rock. The steeper the slope and the greater the volume-flow of water, the more energy the stream has to erode the land. The flow of water usually varies seasonally. At times of heavy rainfall in a watershed, a stream may flood and overflow its banks as the volume of water exceeds its containment capacity. Flooding may cause a stream to change its path. A stream bank, which consists of sediment or bedrock, may collapse and change the water's course. One example of this is a stream's tendency to shorten its length by forming oxbow lakes. This redirection of the stream's course usually takes place in natural and recurring patterns year after year.

2. c. *Students know* beaches are dynamic systems in which the sand is supplied by rivers and moved along the coast by the action of waves.

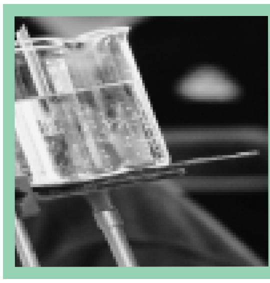
The final destination of sediment is usually the ocean. Coarse sediment (sand size and larger) frequently is temporarily trapped along the shore as beach deposits while the finest sediments are often washed directly out to sea and, in some cases, carried by ocean currents for many miles. Waves that break at oblique angles to the shore move sediment along the coast. Waves wash the sand parallel to the direction in which they break, but the return water-flow brings sand directly down the slope of the beach, resulting in a zigzag movement of the sand. Students can observe differences in sand (e.g., size, color, shape, and composition) by using sand collections that may be obtained from various sources, including family and friends. The differences result from the variety of rock sources from which the sand has come, the weathering processes to which the rock has been subjected, and the completeness of the weathering (i.e., how long the rock has been subjected to weathering).

Students should attempt to identify any minerals or rocks that would indicate the kinds of weathered materials contained in the sand. Students examining sand from California beaches will find constituents such as quartz, feldspar, shell fragments, and magnetite. Magnetite is fun to extract by passing a magnet, wrapped in a plastic bag, through the sand. Magnetite may be saved and later used in place of iron filings to demonstrate magnetic field geometry for another standard.

2. d. *Students know* earthquakes, volcanic eruptions, landslides, and floods change human and wildlife habitats.

Earthquakes can collapse structures, start fires, generate damaging *tsunamis,* and trigger landslides. Landslides can destroy habitats by carrying away plants and animals or by burying a habitat. Volcanic eruptions can bury habitats under lava or volcanic ash, ignite fires, and harm air quality with hot toxic gases. Floods can bury or wash away habitats.

Lives may be lost and property damaged when humans get in the way of those powerful natural processes. Although construction (and human habitation) in areas prone to natural disasters is often impossible to avoid, understanding the likelihood of such disasters and taking steps to mitigate the potential effects would be wise. Moreover, no construction too close to known hazards (e.g., on floodplains) would be advisable. Certainly, the frequency (probability) and severity of flooding, landslides, and earthquakes must be considered when one decides on land use. Making those decisions should be done after consideration of many factors, including the use of scientific evidence to predict catastrophic events and the local impacts. Although catastrophic events are usually adverse in the short term, some of them may be beneficial in the long term. For example, river floods may deliver new, nutrient-enriched soil for agriculture. Other catastrophic changes may introduce new habitats, allow fresh minerals to surface, change climates, or give rise to new species.



STANDARD SET 3. Heat (Thermal Energy) (Physical Science)

Prior to the nineteenth century, the transfer of heat was assumed to be due to the flow of a substance called *caloric,* an invisible, weightless fluid whose total quantity remained constant. The caloric theory subscribed to the belief that an object became hot when it was permeated by a large quantity of caloric and cooled when some of its caloric flowed into other objects that had less caloric. This model was upset by the work of two scientists: Benjamin Thompson (later known as Count Rumford) and James Joule. Rumford supervised the boring of cannons. He noted that the water kept in the bores to prevent overheating boiled continuously. This boiling was supposedly caused by the caloric that flowed from the metal of the cannon as it was cut.

From his observations, however, Rumford deduced that this explanation could not be correct because the boiling continued even when the boring tool became so dull that it no longer had any effect on the metal. Apparently, the caloric was being produced out of nothing. Rumford concluded that it was the work needed to turn the dull tool, instead of caloric transfer, that was being converted into heat. In a series of experiments, Joule showed that a given amount of mechanical work always produced the same amount of heat no matter what kind of mechanical work was done. This demonstration established that heat is indeed a form of energy. Today, it is known that heat is energy contained in the random motion of atoms and molecules and that to heat an object is to increase the energy so stored.

Although students will not be exposed to kinetic molecular theory until high school, teachers who understand the following points will be better able to discuss the subjects of heat and heat transfer. The transfer of heat from a warmer object to a colder object is referred to as *heat flow.* Heat may be transferred by conduction, convection, or radiation. Standard Sets 3 and 4 in grade six deal in depth with the relationships between heat and convection in Earth's mantle, oceans, and atmosphere. Material covered in those standards will build a foundation for the study of heat. Students will learn that atoms are free to move in different ways in solids, liquids, and gases and that heat may be given off or absorbed during chemical reactions. The concept that heat is a form of energy associated with the motion of atoms and molecules is covered in high school. Students in grade six will study the relationship between work and heat flow and will be required to solve problems related to this subject.

3. Heat moves in a predictable flow from warmer objects to cooler objects until all the objects are at the same temperature. As a basis for understanding this concept:

a. *Students know* energy can be carried from one place to another by heat flow or by waves, including water, light and sound waves, or by moving objects.

Energy is transferred from one object to another as the result of a difference in temperature. *Heat flow* is the transfer of energy from a warmer object to a cooler object.

A wave is an oscillating disturbance that carries energy from one place to another without a net movement of matter. For example, sound waves from one vibrating object can cause other objects, such as eardrums, to vibrate. Electromagnetic waves can also carry energy. One example of this phenomenon is the transfer of heat from the Sun to Earth. Students may think of the infrared radiation escaping from a bed of hot coals and warming their hands as another example of heat flow.

Energy can also be transferred by the movement of matter. For example, the energy supplied by the pitcher's arm transports a pitched baseball to the catcher's mitt.

3. b. *Students know* that when fuel is consumed, most of the energy released becomes heat energy.

When fuel is burned, energy stored in the fuel's chemical bonds is released as heat and light. Only a small portion of the energy contained in the original fuel remains locked in the waste products left over after the fuel has been consumed. Although the heat derived from fuels is often used in turn to drive engines that perform useful work, an important understanding is that even the work performed ultimately tends to be transformed into heat. For example, an automobile set into motion and braked to rest transforms most of its kinetic energy into heating the brake pads by friction. As a demonstration the teacher might light a candle in the classroom and let students know that the wax in the candle is the fuel that combines with oxygen in the air to produce both heat and light. Most of the heat is transferred to the room by the hot gases rising from the flame. Glowing particles of soot (the source of the yellow light) also transfer energy from the flame. Students might be asked to develop an explanation of how heat is transferred from the burning fuel to a container of water heated by the candle, using the concepts and principles called for in this standard set.

3. c. *Students know* heat flows in solids by conduction (which involves no flow of matter) and in fluids by conduction and by convection (which involves flow of matter).

This standard focuses on differences between heat transfer by conduction and by convection and begins to build an understanding of the kinetic molecular theory of heat transfer. In both solids and fluids (liquids and gases), heat transfer is measured by changes in temperature.

Conduction occurs when a group of atoms or molecules whose average kinetic energy is greater than that of another group transfers some of that excess energy by means of collisions. Because hot objects have atoms with greater average kinetic energy than do cold ones, there is a transfer of this kinetic energy from hot to cold. In a solid the atoms vibrate in place, but energy may still be transferred from atom to atom as happens when a pan is placed on a stove and its handle becomes hot. The same mechanism describes the conduction of heat in liquids and gases, where the atoms are free to slip past one another provided there is no cumulative flow in the material. To demonstrate conduction a teacher might wrap some paper (to form a handle) around the end of a metal rod about 30 centimeters long and use paraffin to attach a series of thumbtacks, spaced about two centimeters apart, along the rod. The teacher then holds the rod by the handle and places the free end over a candle or in a burner flame. As heat is conducted along the rod, the tacks drop away one by one.

Convection occurs because most fluids become less dense when heated; the hot fluid will rise through cold fluid because of the hot fluid's greater buoyancy. As hot fluid arises away from a heat source, it may cool, become denser, and sink back to the source to be warmed again. The resulting circulation is called a *convection current.* Convection currents account for the water in a kettle reaching a uniform temperature although the kettle is warmed only at the bottom. The effects of convection may be investigated by placing finely shredded paper into a large heat-resistant beaker or roasting pan filled with cold water. After the paper is saturated and sinks to the bottom of the container, the teacher may apply heat from a hot plate and note that the paper particles move upward near the heat source and downward away from it.

3. d. *Students know* heat energy is also transferred between objects by radiation (radiation can travel through space).

Another form of energy transfer between objects is radiation: the emission and absorption of electromagnetic waves. Radiation is fundamentally different from conduction and convection in that the objects do not have to be in contact with each other or be joined by a solid or fluid material. Heating by sunlight is an obvious example of radiant energy transfer. Both the heat and the light that can be seen are forms of electromagnetic radiation. Calling attention to this fact may help dispel the common misconception that all radiation is harmful.

STANDARD SET 4. Energy in the Earth System

Energy that reaches Earth's surface comes primarily as radiation from the Sun. Solar energy includes the full electromagnetic spectrum, but most of it is carried in the visible region. Because the atmosphere is transparent to visible light, most of this incoming energy is transferred to Earth's surface. Conductive transfer and reradiation of this energy heat the lower atmosphere and result in convection currents that distribute the heat into the atmosphere.

Solar radiation heats Earth's surface unevenly, resulting in thermal gradients in the atmosphere. Variations in the angle of sunlight influence the amount of energy reaching each square meter of Earth's surface and largely account for the uneven heating of the surface. The angle of sunlight varies because of Earth's spherical shape and because the Sun's rays travel in a straight line parallel to one another. If a surface area of this planet is directly perpendicular to the Sun (meaning the Sun is directly overhead), then the rays strike at a 90-degree angle, resulting in maximum absorption of solar radiation because the energy is concentrated on a relatively small area. As the surface curves away from this spot, the angle at which sunlight strikes it becomes smaller, and the same amount of solar radiation is spread over a broader area.

The uneven heating of Earth's surface and the tilt of its axis (66.5 degrees to the orbital plane or 23.5 degrees to the perpendicular) account for the seasons and extremely cold north and south poles. Clouds and the varied reflectivity of Earth's surface contribute to uneven heating. In general, however, the total solar energy transferred to Earth is nearly constant, and all the energy gains and losses are in balance. Consequently, Earth enjoys climates that are relatively stable for thousands of years, with predictable temperature ranges and weather patterns that can be broadly forecast.

Various heat exchange mechanisms operate in the Earth system. Ocean surface water is heated by the Sun and mixed by convection currents. The atmosphere exchanges heat with the oceans and land masses by means of conduction. Warm air near Earth's surface rises and cooler air descends, causing atmospheric convection currents. Different parts of the ocean have different temperatures and salinities, resulting in deep convection currents. The convection currents in the atmosphere move evaporated water away from ocean surfaces; from there the water vapor can be picked up by winds and carried to other locations where it may condense as precipitation. In this manner both heat and water are transported.

The observed patterns of surface winds are mostly the result of convection currents caused by uneven surface heating. Winds are deflected by the Coriolis effect (caused by the west-to-east turning of Earth) and by topography. Latitude, winds (speed, direction, and moisture content), and the elevation of the land and its proximity to the ocean largely determine the climate and corresponding weather patterns in any particular region.

Earth's crust contains localized concentrations of internal heat, as evidenced by volcanoes, hot springs, and geysers. However, the total amount of heat transferred to the atmosphere from Earth's crust is minute compared with the amount of heat the surface receives from the Sun.

4. Many phenomena on Earth's surface are affected by the transfer of energy through radiation and convection currents. As a basis for understanding this concept:

a. *Students know* the sun is the major source of energy for phenomena on Earth's surface; it powers winds, ocean currents, and the water cycle.

Radiation from the Sun penetrates the atmosphere by heating the air, the oceans, and the land. Solar radiation is also converted directly to stored energy in plants through photosynthesis. The Sun is a constant, close-to-uniform source of energy that is responsible for the climate and weather, drives the water cycle, and makes life possible on Earth.

4. b. *Students know* solar energy reaches Earth through radiation, mostly in the form of visible light.

A full-wavelength spectrum of electromagnetic energy is present in solar radiation from below the infrared to above the ultraviolet. However, most of the energy radiated by the Sun is in the visible or near visible part of the light spectrum, and that is largely the part that penetrates the transparent atmosphere and reaches Earth's surface. Because blue light is scattered by the atmosphere more than yellow light, the sky looks blue and the Sun looks yellow. Students should understand that both long- and short-wavelength radiation may interact in various ways with atmospheric constituents and may be absorbed by atmospheric constituents in different amounts; however, the wavelengths of visible light are not greatly absorbed by any atmospheric constituent.

4. c. *Students know* heat from Earth's interior reaches the surface primarily through convection.

Heat from the interior of Earth moves toward the cooler crustal surface. Rock is a poor conductor of heat; therefore, most of the transfer of heat occurs through convection. Convection currents in the mantle provide the power for plate tectonic movements. Heat reaching Earth's surface in this manner is transferred to the atmosphere in relatively small amounts.

4. d. *Students know* convection currents distribute heat in the atmosphere and oceans.

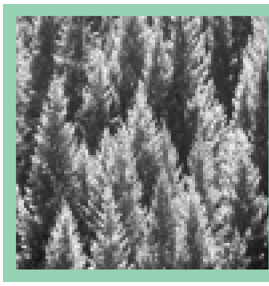
Convection plays a central role in transferring heat energy from place to place in the atmosphere and ocean. Uneven heating of the land and ocean causes convection currents. This movement of air and water creates the wind and ocean currents that are deflected by the geography of the land and the rotation of Earth. Students can investigate atmospheric convection currents on a small scale by using a smoke chimney or fog chamber. In the absence of more sophisticated equipment, much can be observed about atmospheric convection by studying what happens to visible water droplets (condensing steam) as they exit a boiling teakettle.

There are several ways to investigate convection currents in a liquid. One way is to float a large ice cube (tinted with food coloring) on hot water and trace the resulting convection currents. Another way is to heat one end of an elongated cake pan full of water. Convection may be observed by adding drops of food coloring.

4. e. *Students know* differences in pressure, heat, air movement, and humidity result in changes of weather.

Changes in local temperatures, atmospheric pressure, wind, and humidity create the weather that everyone experiences. All those effects are connected directly to the processes associated with the transfer of solar energy to Earth and redistribution of that energy in the form of heat. Precipitation occurs when moist air is cooled below its condensation temperature (dew point).

Great currents circle the globe in the convecting atmosphere and ocean, created by atmospheric pressure and temperature gradients that, in turn, spin off local winds and eddies. Temperature differences also lead to changes in humidity and precipitation. The local set of these descriptive measures is called weather, and the changes result in weather patterns. The long-term seasonal average of these weather patterns defines the climate of an area.



STANDARD SET 5. Ecology (Life Sciences)

All living organisms are a part of dynamic systems that continually exchange energy. These systems are regulated by both biotic and abiotic factors. Nutrients needed to sustain life in an ecosystem are cycled and reused, but the energy that flows through the ecosystem is lost as heat and must constantly be renewed. Green plants are the foundation of the energy flow in most ecosystems because they are capable of producing their own food by photosynthesis. Because energy is either used by consumers or depleted in a logical progression, it can be said to flow through a food web (also known as a food chain). A food web may be represented as an energy pyramid with green plants as a base, midlevel consumers in the middle, and a few top-level predators at the apex. Scavengers and decomposers are the final members of an energy pyramid as they clean up the environment and return matter (nutrients) to Earth. A food web can also show the various roles played by plants and animals as producers, consumers, and decomposers.

5. Organisms in ecosystems exchange energy and nutrients among themselves and with the environment. As a basis for understanding this concept:

a. *Students know* energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis and then from organism to organism through food webs.

A food web depicts how energy is passed from organism to organism. Plants and photosynthetic microorganisms, or producers, are the foundation of a successful food web because they do not need to consume other organisms to gain energy. Instead, they gain their energy by transforming solar energy through photosynthesis into chemical energy that is stored in their cells.

5. b. *Students know* matter is transferred over time from one organism to others in the food web and between organisms and the physical environment.

Energy and matter are transferred from one organism to another organism through consumption. Plants are eaten by primary consumers (herbivores); most herbivores are eaten by secondary consumers (carnivores); and those consumers are eaten by tertiary consumers (often top-level predators). At the microscopic scale photosynthetic bacteria (cyanobacteria) and protists or single-celled eukaryotic organisms (e.g., dinoflagellates) are consumed by heterotrophic protists (e.g., amoebae and ciliates), which are also called *protozoans.* Protozoans are consumed by other larger protozoans and by small animals such as cnidarians, arthropods, and nematodes. Energy is transferred from organisms (microorganisms, plants, fungi, and animals) to the physical environment through heat loss. Carbon is returned to the physical environment as airborne carbon dioxide through the respiration of organisms. Water is also cycled. Students may use science texts and other library materials to research organisms included in the food webs of particular ecosystems. Students can draw model food webs to demonstrate how food energy is transferred from plants to consumers and from consumer to consumer through predation. Students can also depict the hierarchy of consumers and the transfer and loss of energy from herbivores through secondary consumers to the top carnivores in a food web or energy pyramid. Students should know that energy is lost to the physical environment at every hierarchical level.

5. c. *Students know* populations of organisms can be categorized by the functions they serve in an ecosystem.

Organisms in a population may be categorized by whether they are producers of chemical energy from solar energy (e.g., plants and photosynthetic microorganisms) or consumers of chemical energy (e.g., animals, fungi, and heterotrophic protists) and, if they are consumers, whether they are predators, scavengers, or decomposers. Many consumers may be categorized in multiple ways, such as omnivores that eat both plants and animals and opportunistic consumers that act as both predators and scavengers. Teachers may provide the class with a nonordered, noncategorized list of four or five plants, eight to ten consumers (four or five primary consumers, three or four secondary consumers, and one or two tertiary consumers [or top-level predators]), one or two decomposers, and one or two scavengers. Using a science text or appropriate research materials from the school library, students can identify the organisms by food web order and ecological function. Students can then arrange the organisms into an energy pyramid with the decomposers and scavengers identified and noted separately. The final task is to draw arrows between members of the pyramid to depict the predation sequence.

5. d. *Students know* different kinds of organisms may play similar ecological roles in similar biomes.

Ecological roles are defined by the environment and not by any particular organism. For example, Australia has plants that are unique to that continent yet play the same role as other kinds of plants in similar environments elsewhere. In the rain forests of South America, the mammalian consumers and predators are placental (nonmarsupial) sloths, deer, monkeys, rodents, and cats. In the rain forests of Australia, marsupial kangaroos, wallabies, bandicoots, and so forth play the same ecological roles. Students may be assigned or may choose to research specific organisms that occupy similar biomes in widely separated geographic locales. Students should be encouraged to use a variety of library resources, such as expository texts, the Internet, CD-ROM reference materials, videos, laser programs, or periodicals.

5. e. *Students know* the number and types of organisms an ecosystem can support depends on the resources available and on abiotic factors, such as quantities of light and water, a range of temperatures, and soil composition.

There is a greater variety of types of organisms in temperate or tropical environments than in deserts or polar tundra. The number of organisms supported by an ecosystem also varies from season to season. More organisms thrive during temperate summers than can survive icy winters. More organisms can multiply during a desert's cooler, wetter winters than can live through its hotter, drier summers. Students should understand that the richness of plant growth controls the diversity of life types and number of organisms that can be supported in an ecosystem (the base of the pyramid). Richness of plant growth depends on abiotic factors, such as water, sunlight, moderate temperatures, temperature ranges, and composition of the soils. To support vigorous growth, soils must contain sufficient minerals (e.g., nitrogen, phosphorus, potassium) and humus (decomposed organic materials) without excess acidity or alkalinity. The teacher may point out that the number of plant-eating animals in an ecosystem depends directly on the available edible plants, and the number of predators in a system depends on the available prey.

STANDARD SET 6. Resources

Although this standard set deals with the concept of finite resources, the emphasis is on energy. Much of the energy used worldwide is derived from *nonrenewable* fossil fuels, such as coal, oil, and natural gas. Those resources are being consumed at rates far faster than their geologically slow formation rates. Uranium (for fission energy) and deuterium (for fusion energy) are also finite but are in abundant supply (deuterium is almost inexhaustible). Industrial waste and pollution result from nuclear power generation and the burning of fossil fuels. The extraction (mining) and processing (smelting) of both energy and nonenergy resources also have environmental consequences. There are numerous types of renewable energy resources, including solar, wind, hydroelectric, and geothermal, but they are largely undeveloped or underdeveloped. Knowing the forms, conversion processes, end-uses, and impact of wastes involved in using natural resources, whether for energy or materials, is critical in making decisions and trade-offs about how those resources will be used.

6. Sources of energy and materials differ in amounts, distribution, usefulness, and the time required for their formation. As a basis for understanding this concept:

a. *Students know* the utility of energy sources is determined by factors that are involved in converting these sources to useful forms and the consequences of the conversion process.

Useful energy sources are those that can be converted readily to forms of energy needed for heat, light, and transportation. Technologies have been developed to convert various forms of energy (e.g., oil, gas, solar, nuclear, wind, and wave) to meet those needs. For example, manufacturers have learned how to refine oil to make gasoline, which can then be used in the combustion engine to provide transportation or in power generators to produce electricity. The energy sources considered the most useful are those for which the most cost-effective conversion technologies have been developed. For transportation purposes solar energy is not considered as useful mainly because inexpensive and efficient solar energy storage systems have yet to be developed. Until those systems are developed, solar energy will not be able to meet the demand for reliable levels of power or provide a driving range comparable to that provided by gasoline and diesel fuels.

Students should be taught the concept of nonmonetary costs of energy. Mining coal leaves large, open pits and may pollute the atmosphere with the exhaust of heavy mining machinery. Power plants may also pollute the atmosphere with the exhaust from burning fossil fuels. Nuclear power plants must exhaust excess heat, often in the form of hot water introduced into rivers and oceans. Hydroelectric energy, although it is renewable and has no effect on air quality, requires the damming of streams—a measure that carries upstream environmental implications and downstream consequences on sediment load and beaches as well as the possibility of disaster caused by dam failures. Students may use published materials and Internet resources (consistent with Internet-use policies in effect at the school) to research, evaluate, and report on the environmental consequences. In this way they can develop a clearer understanding of the nonmonetary costs of energy in relation to environmental protection (conservation). Students can rate the environmental advantages and disadvantages of heating a home with electricity, natural gas (or propane), solar power, oil, or coal.

6. b. *Students know* different natural energy and material resources, including air, soil, rocks, minerals, petroleum, fresh water, wildlife, and forests, and know how to classify them as renewable or nonrenewable.

Renewable and nonrenewable energy and natural resources depend on both the process and the time needed to create energy sources. Solar energy cannot be exhausted nor can fuels for fusion; therefore, they are sometimes referred to as *renewable.* Hydroelectric power is dependent on the water cycle (driven by solar energy) and is considered a renewable resource. Because biomass will grow back quickly to replace that used for fuel or materials, it is also considered renewable. However, if habitats and species are lost in the process of harvesting the biomass, the resources are nonrenewable in that sense. Trees used for fuel or building materials can be replaced only if the rate of use does not exceed the time needed to grow replacement trees and if the land is not altered to become unusable for that purpose. Fossil fuels (coal, oil, natural gas) were formed on geologic time scales and are considered nonrenewable resources.

6. c. *Students know* the natural origin of the materials used to make common objects.

This standard deals with the ultimate sources of common objects. Students often do not consider or even know the natural origins of commonly used goods. They must be reminded that manufactured items do not appear magically and that the ultimate cost of acquiring the objects goes far beyond the price sticker. Students can count the objects in their classroom to make an inventory and trace them back to the natural materials from which they were manufactured. Students can then classify the materials as renewable or nonrenewable. They may need to do some careful research to discover the origins of some materials. For example, a simple pencil contains wood and lead. But the pencil lead is actually a mixture of graphite and clay. If the pencil has an eraser, the rubber from a plant (or plastic from petroleum) and metal for the holder must be included. Students may realize in looking at clothing, paper, paint, tiles, windows, projectors, computers, chairs, books, chalk, crayons, brooms, and so on that plastics and synthetic materials are derived from oil.

STANDARD SET 7. Investigation and Experimentation

Students are expected to formulate a hypothesis for the first time. A hypothesis is a proposition assumed as a basis for reasoning and often subject to the testing of its validity. The scientific hypothesis provides an explanation of a set of observations and may incorporate observations, concepts, principles, and theories about the natural world. Hypotheses lead to predictions that can be tested. If the predictions are verified, the hypothesis is provisionally corroborated. If the predictions are incorrect, the original hypothesis is proved false and must be abandoned or modified.

Hypotheses may be used to build more complex inferences and explanations. Hypotheses always precede predictions. However, for simple investigations the hypothesis that led to a prediction may not be easily identified because of its simplicity or its complexity. Prediction follows observation in grades three to five. After grade six students should recognize and develop a hypothesis as a part of their experimental design. In grade six the focus on earth science can provide many opportunities in the Investigation and Experimentation standards to develop students' ability to design experiments and to select and use tools for measuring and observing.

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

a. Develop a hypothesis.

b. Select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.

c. Construct appropriate graphs from data and develop qualitative statements about the relationships between variables.

d. Communicate the steps and results from an investigation in written reports and oral presentations.

e. Recognize whether evidence is consistent with a proposed explanation.

f. Read a topographic map and a geologic map for evidence provided on the maps and construct and interpret a simple scale map.

g. Interpret events by sequence and time from natural phenomena (e.g., the relative ages of rocks and intrusions).

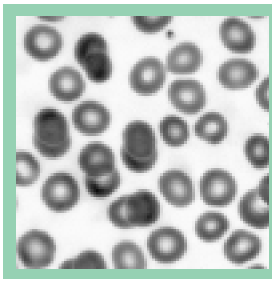
h. Identify changes in natural phenomena over time without manipulating the phenomena (e.g., a tree limb, a grove of trees, a stream, a hillslope).

Grade Seven Focus on Life Sciences

Now is an exciting time for the study of life sciences. Knowledge of biological systems is expanding rapidly, and the development of new technologies has led to major advances in medicine, agriculture, and environmental management. A foundation in modern biological sciences, with an emphasis on molecular biology, is essential for students who will become public school science teachers, college and university science professors and researchers, and specialists in technological fields.

Another definitive reason for a focus on life science in grade seven is the students' own biological and behavioral transition into early adolescence. Young adolescents make decisions that may have an enormous influence on their lives. The study of life science provides a knowledge base on which adolescents can make well-informed and wise decisions about their health and behavior. The relevance of the curriculum to students' lives helps students to maintain an interest in science and to expand their knowledge of the natural sciences.

The *Health Framework for California Public Schools* is a valuable resource for science teachers.[4] It contains grade-level expectations for health education that provide important connections to the life science curriculum. Specific statutes require parental notification regarding the teaching of topics related to human growth and development.



STANDARD SET 1. Cell Biology

In the middle grades students expand their knowledge of living systems to include the study of cells, the fundamental units of life.

In grade five students learned about the organs or tissues for respiration, digestion, waste disposal, and transport of materials in plants and animals. They were also first introduced to cellular functions when they studied cellular respiration in animals and plants and photosynthesis in plants. These studies are complemented in grade seven by new material on the cellular organelles responsible for those functions.

The standards in grade six covered ecology, and students in that grade learned how energy in the form of sunlight is transformed by producers into chemical energy through the process of photosynthesis. The study of energy transfer through food webs provided a foundation for a more detailed exploration at the cellular level of how plant chloroplasts capture sunlight energy for photosynthesis and how mitochondria liberate energy for the work that cells do.

1. All living organisms are composed of cells, from just one to many trillions, whose details usually are visible only through a microscope. As a basis for understanding this concept:

a. *Students know* cells function similarly in all living organisms.

There are fundamental aspects of cell function that are similar regardless of the organism in which the cell resides. For example, cells contain a DNA (deoxyribonucleic acid) genome (i.e., all genetic material in a cell) and express the genome by using a universal genetic code. The biochemical pathways in cells, such as those for cell division and energy production, are strikingly similar even though the cells serve different functions in and between organisms. Many proteins synthesized by cells have similar functions, such as serving as enzymes that promote chemical reactions in the cell. There are significant functional differences between cells in an organism as they become differentiated, or specialized (e.g., a liver or a brain cell). There are also significant differences between cells in different environments, such as the *Escherichia bacterium* living in an intestine or a *Thermophilus bacterium* living in a superheated geyser. Biological science has been greatly advanced by the uncovering of both similarities and differences among cells.

1. b. *Students know* the characteristics that distinguish plant cells from animal cells, including chloroplasts and cell walls.

Plant cells are surrounded by a cell wall (made primarily of cellulose) that is rigid and limits the shape of the cell membrane. Animal cells, however, are not surrounded by a cell wall, and their shape is defined by their underlying cytoskeleton. Many plant cells contain chloroplasts and a central vacuole, neither of which is found in animal cells. Those differences between plant and animal cells may be made apparent by microscopy as sections of plant and animal tissue are appropriately stained to highlight the structures. Images of cells are also available on the Internet and in textbooks. Labeled diagrams will help students learn about structures that are too small to be seen with the use of classroom microscopes.

1. c. *Students know* the nucleus is the repository for genetic information in plant and animal cells.

Chromosomes containing genes reside in the nucleus. When an interphase cell is observed by using a light microscope, the inside of the nucleus may appear to be homogeneous because the chromosomal DNA is not condensed. In an appropriately fixed and stained section of onion root (obtainable from commercial sources), the DNA will be visible as a disk-shaped area, apparently constrained within a nucleus. This is the best stage in which to visualize DNA in learning the content of the standard. If the root tissue had a high rate of growth at the time it was sectioned and fixed, a fraction of the cells may be in one of the stages of mitosis. In that case the chromosomes will be visibly condensed but will not be limited by a nuclear membrane. This phenomenon must be explained carefully so that students do not develop a misconception about the distribution of DNA in a cell on the sole basis of their observation of mitotic chromosomes.

1. d. *Students know* that mitochondria liberate energy for the work that cells do and that chloroplasts capture sunlight energy for photosynthesis.

Students may already understand that the food they eat provides them with energy in an informal sense. At the cellular level the mitochondrion is responsible for efficiently extracting the chemical energy from molecules that have been broken down mostly from ingested food. The energy liberated by mitochondria is still stored in the form of chemical energy but in molecules that are readily accessible for energy release. Chloroplasts use pigments to absorb the energy in sunlight. This captured energy is used to drive a chemical reaction within the chloroplast in which carbon dioxide from the air is used as a source of carbon to form sugar molecules from which mitochondria extract energy used in the cell.

1. e. *Students know* cells divide to increase their numbers through a process of mitosis, which results in two daughter cells with identical sets of chromosomes.

Just as living organisms are said to have a life cycle that relates to their periods of growth and reproduction, cells are said to have a "cell cycle." Cells reproduce themselves by a process called *mitosis.* The process takes place after a period of growth during which the DNA in the nucleus is replicated and cytoplasmic organelles, such as mitochondria and chloroplasts, are doubled in number. During mitosis the replicated DNA chromosomes are segregated so that each daughter cell receives exactly the same number of chromosomes of each type (e.g., two of each type in a diploid organism). Students may observe mitotic chromosomes by light microscopy in a stained section of rapidly growing tissue. Time-lapse videos and movies of cell division will also help to illuminate the process of chromosome segregation.

1. f. *Students know* that as multicellular organisms develop, their cells differentiate.

In most multicellular organisms there is a division of labor among cells. Some cells in humans are brain cells; others are stomach, skin, or muscle cells. Although those cells are clearly different, their ancestry can be traced back to a single fertilized egg. During the development of an embryo, some cells become fixed in their developmental program and are said to be *differentiated.* For example, cells that will eventually divide to give rise to the stomach and intestines are distinguished at a very early stage from cells that will divide to give rise to the central nervous system and eyes. At later stages of development, a more fine-grained differentiation takes place. For example, some cells in the retina of the eye become rod cells (for vision in dim light) and others become cone cells (for color vision). After differentiation, most cells in humans lose the ability to become other types of cells.

In plants the cells often retain the ability to differentiate into other tissues. For example, a leaf of an African violet can set roots in soil and develop into a new plant. Although the leaf is clearly differentiated, it is not fixed in its developmental potential in the way that animal cells typically are (an exception being the animal's germ cells that lead to eggs and sperm).

STANDARD SET 2. Genetics

Genetics is the study of the biological processes involved in transmitting the unique characteristics of an organism to its offspring. Discovering the genetic principles and mechanisms that account for growth, senescence, and heredity has been a great accomplishment of modern science. Gregor Mendel's studies of pea plants revealed the concept of genes and the rules for the inheritance of traits. Today it is understood that those rules are based on the chemical composition and structure of DNA. Students in grade seven will learn some of those rules, which will serve as a foundation for high school biological sciences.

2. A typical cell of any organism contains genetic instructions that specify its traits. Those traits may be modified by environmental influences. As a basis for understanding this concept:

a. *Students know* the differences between the life cycles and reproduction methods of sexual and asexual organisms.

Sexual reproduction entails fertilization, an event in animals that requires the fusion of an egg cell with a sperm cell. The fertilized egg (the zygote) goes through a series of cell divisions (mitosis) and developmental steps to generate a new organism genetically related to its parents. Pollination of flowering plants and growth of a new genetically related plant from seed should also be presented as examples of a sexual life cycle.

Some organisms exclusively reproduce without a fertilization event. This method is called *asexual* reproduction. Protists (single-celled eukaryotic organisms) often have no known sexual cycle and reproduce solely by mitotic division. Fungi and plants often have both sexual and asexual methods of reproduction. For example, plants may be propagated from a seed (sexual method) or a cutting (asexual method). Although a seed is related to two parental plants, a cutting is genetically identical to the plant from which it was taken. Some primitive animals, such as the flatworm Planaria, can divide themselves asexually into two genetically identical organisms. Asexual reproduction should not be confused with reproduction in primitive animals such as nematodes. Asexual reproduction should also not be confused with hermaphroditic sexual reproduction that entails fusion of eggs and sperm generated by a single organism.

2. b. *Students know* sexual reproduction produces offspring that inherit half their genes from each parent.

Sexual reproduction combines the genetic material from two different cells. In most animal species, including humans, the genetic information is contributed from two different parents, nearly half from the biological mother and half from the biological father. Mitochondria DNA is derived solely from the mother, making possible the tracing of heritage from grandmothers to grandchildren with great certainty. During fertilization the egg and sperm cells combine their single sets of chromosomes to form a zygote containing two sets, or the diploid number, of chromosomes for a species (half from each parent).

2. c. *Students know* an inherited trait can be determined by one or more genes.

In the preceding standard the idea of genes was introduced to students as something inherited from each parent in roughly equal quantities. This standard draws a correlation between genes and the inherited traits or features of an organism. For example, attached or unattached earlobes is an inherited trait typically determined by a single gene (inherited from each parent). Having attached or unattached earlobes is very likely just one visible manifestation of that particular gene, which may have many other important roles during development that have not been cataloged. A single gene may affect more than one trait or feature in an organism. Many traits, such as hair and eye color, are determined by multiple genes and do not have simple patterns of inheritance. Although an organism's genes define every inherited trait, there is not always a one-to-one correspondence between trait and gene.

2. d. *Students know* plant and animal cells contain many thousands of different genes and typically have two copies of every gene. The two copies (or alleles) of the gene may or may not be identical, and one may be dominant in determining the phenotype while the other is recessive.

This standard introduces some principles of Mendelian genetics. The most significant concept is that genes exist in multiple versions, called *alleles,* and these units of heredity are not typically changed during mating. Prior to acceptance of Mendel's laws, people believed that the mixing of genetic information was similar to mixing paint; the information (like red or white paint) could be blended to form a combined version (like pink paint) that could be blended still further (making it more white or more red). Using true-breeding strains of peas with variation of a single gene (such as flower color), Mendel showed that this model of blending was incorrect.

In grade seven students will learn that every person has tens of thousands of genes and that there are slight variations, or alleles, of these genes in every individual. Using the correct vocabulary is important: A person with a genetic disorder does not have the *gene* for that trait, but it might be said that the person has the genetic *allele* for that trait. Every person has every gene (and usually in two copies), but some people have an abnormal or different version (or versions) that can lead to a disorder or different trait. The genetic traits of an individual are determined by which alleles of genes are inherited from each parent and how those alleles work together. Some alleles are dominant, meaning that they overcome the influence of the other (recessive) alleles. In grade seven students learn to interpret the genotype-phenotype relationship in offspring (for example, on a premade Punnett Square diagram). In high school biology students will learn many of the details of genetics. Therefore, because this standard provides a foundation for transmission genetics in high school biology, the details of genetics (including the construction of the Punnett Square model) may be deferred.

2. e. *Students know* DNA (deoxyribonucleic acid) is the genetic material of living organisms and is located in the chromosomes of each cell.

Chromosomes in eukaryotes are complexes of DNA and protein. Chromosomes organize the genetic make-up of a cell into discrete units. Humans, for example, have 23 pairs of chromosomes that vary in size. When looking through a microscope at an appropriately stained section of onion root tip, students may see cells that are engaged in mitosis and that have visible, condensed chromosome structures. The proteins in a chromosome help to support its structure and function, but the genetic information of a cell is uniquely stored in the DNA component of the chromosome.

STANDARD SET 3. Evolution

In grade two students developed simple notions of inheritance and variation within a species. Those notions are foundational for the study of evolution, as are the studies in grade three of adaptations to an environment and the processes of extinction. Charles Darwin was a naturalist who traveled widely; students in grade three are retracing his steps when they develop their knowledge of organisms in a wide variety of earth biomes. Students in grade four learn about the survivability (or fitness) of plants and animals in an environment, and students in grade six are provided with a background in earth science. The standards in this set provide a foundation for learning about natural selection in grade seven and understanding the fossil record to be a line of evidence for the evolution of plants and animals.

3. Biological evolution accounts for the diversity of species developed through gradual processes over many generations. As a basis for understanding this concept:

a. *Students know* both genetic variation and environmental factors are causes of evolution and diversity of organisms.

In grade two students learned that some characteristics of an organism are inherited from the parents and that some are caused or influenced by the environment. They also learned that there is variation among individuals in a population. This standard takes these simple ideas to much greater depth by explicitly referring to *environmental factors* and *genetic variation.* Environmental factors are a cause of natural selection, but as the term *selection* implies, there must also be favorable and unfavorable traits uncovered in the population. *Genetic* variability must precede natural selection, or there is some risk that no individuals in the population will survive a crisis. This principle is evident in the worldwide cheetah population and in other endangered species with much genetic homogeneity. Having little genetic variation to spread the risk makes a population more susceptible to extinction, for example, by succumbing to an infectious disease for which there is no natural resistance.

3. b. *Students know* the reasoning used by Charles Darwin in reaching his conclusion that natural selection is the mechanism of evolution.

In his book *On the Origin of Species by Means of Natural Selection,* Charles Darwin explained his line of reasoning for natural selection as the primary mechanism for evolution.[5] Darwin proposed that differences between offspring would occur randomly. Some of those differences would be hereditary and affect an individual offspring's ability to survive and reproduce within a particular environment and ecological setting. With the passage of succeeding generations, those individuals best suited to particular environments would tend to have more progeny and those less well suited would have fewer progeny or even become extinct. Darwin called this process *natural selection* because environmental and ecological conditions essentially "select" certain characteristics of plants and animals for survival and reproduction. Darwin proposed that over very long periods of time, natural selection acting on different individuals within a population of organisms might account for all the great varieties of species seen today and for the great number of extinct and nonextinct species found in the fossil record. Darwin's proposal that natural selection is the mechanism for evolution was drawn in part from the ideas of Thomas Malthus' *Essay on the Principle of Population.*[6] Malthus presented his argument that human populations have a tendency to grow faster than their food supply, causing shortages and a "struggle for existence." Darwin's observations in the Galapagos Islands led him to think that this "struggle for existence" might be generalized to animals and plants.

3. c. *Students know* how independent lines of evidence from geology, fossils, and comparative anatomy provide the bases for the theory of evolution.

Independent lines of evidence from geology, the fossil record, molecular biology, and studies of comparative anatomy support the theory of evolution. Many decades before Darwin proposed his theory, geologists knew that sedimentary rocks formed an important history of life on Earth. Geologically younger rock layers are usually near the top, and older layers are successively closer to the bottom of sedimentary formations. Sometimes the normal sequence of sedimentary layers has been overturned by tectonically caused folding and faulting, resulting in older rock units resting on top of younger units.

Some of the organisms that lived in or were buried by the original sediment were preserved as fossils while the sediment hardened into rock. The process of fossilization preserves evidence of ancient life forms, and geologic interpretation of the enclosing sedimentary rock yields valuable information about the environments in which those ancient organisms lived. Paleontologists find more recently evolved organisms in the geologically younger layers of sedimentary rocks and more ancient life forms in the older layers of rocks. Original material (e.g., shell and/or bone) may be preserved as found, but chemical means may sometimes be used to alter or preserve it.

Radioactive dating provides another highly accurate method of confirming the age of rocks and fossils. Comparative anatomists study similarities and differences among organisms. Anatomists have been able to discover significant similarities in the skeletal architecture and musculature of all vertebrates from fish to humans. The most plausible explanation for this finding is that all vertebrates descended from a common ancestor.

3. d. *Students know* how to construct a simple branching diagram to classify living groups of organisms by shared derived characteristics and how to expand the diagram to include fossil organisms.

Evolutionary relationships among living organisms and their ancestors can be displayed in a diagram that resembles a branching tree. Groups of similar living species belong to a genus, similar genera belong to a family, similar families belong to an order, similar orders belong to a class, and similar classes belong to a phylum. Working back in time from the shared derived characteristics of each living species contained in the diagram will show the evolutionary relationships leading to a common ancestor. The classification of organisms according to their characteristics is called *systematics.* It is based on a system developed in 1758 by the Swedish botanist and explorer Carolus Linnaeus.

3. e. *Students know* that extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient for its survival.

Extinction of a species occurs when the adaptive characteristics of the species are no longer sufficient to allow the species to survive under changing environmental conditions. Evidence from the fossil record indicates that most of the species that once lived on Earth are now extinct. Biological adaptations are produced through the evolutionary process. Random mutations in the DNA of different individuals (plants or animals) produce variations of particular traits in a population of organisms. These mutations result in some individuals acquiring characteristics that give them and their offspring an advantage in surviving and reproducing in their present environments or in a different environment. The offspring of individuals in which these advantageous characteristics are not present may decline in numbers and eventually become extinct, or they may continue to coexist with the offspring of individuals that have the mutational advantage. Natural selection will then lead to the existence of populations better able to survive and reproduce under any one particular environmental condition. However, when particular adaptive characteristics of a species are no longer sufficient for the survival of that species under changing environmental conditions (such as increased competition for resources, newly introduced predators, loss of habitat), that species may become extinct. There are many different environmental causes of the extinction of species.

STANDARD SET 4. Earth and Life History

The process of natural selection is strongly linked to the environment. Students will learn in this standard set that the environment has changed over time. The geologic record provides evidence of both the environments of the past and the plants and animals that inhabited them. The focus in this standard set is on using the geologic evidence to better understand life on Earth, past and present.

This standard set presents two great ideas from the geologic sciences to make clear the relationship between life and geology: (1) the concept of uniformitarianism; and (2) the principle of superposition. *Uniformitarianism* refers to the use of features, phenomena, and processes that are observable today to interpret the ancient geologic record. The idea is that small, slow changes can yield large cumulative results over long periods of time. Standard 4.c states a simplified version of the principle of *superposition* when it indicates that the oldest rock layers are generally found at the bottom of a sequence of rock layers. The principle of superposition is the basis for establishing relative time sequences (i.e., determining what is older and what is younger). Geologic records indicate that both local and global catastrophic events have occurred, including asteroid/comet impacts, that have significantly affected life on Earth. Both the evidence and the impact on life should be addressed in this standard set.

4. Evidence from rocks allows us to understand the evolution of life on Earth. As a basis for understanding this concept:

a. *Students know* Earth processes today are similar to those that occurred in the past and slow geologic processes have large cumulative effects over long periods of time.

This standard approaches two different but related ideas in the geologic sciences. The first (uniformitarianism) uses the present as the key to the past. For example, ripples preserved in ancient sedimentary rock are identical to ripples made by running water in mud and sand today. This idea is only one example of how geologists use the present to interpret features and processes in the geologic past. The second idea (superposition) states that the vastness of geologic time allows even very slow processes, if they continue long enough, to produce enormous effects. Perhaps the most important example of this idea is the dramatic change in the arrangement of the continents (continental drift) caused by the slow movement of lithospheric plates (approximately 5 centimeters per year) during the course of many millions of years. One piece of evidence for plate tectonics, including Pangaea, is the fossil record. The coherence of species in the fossil record is seen when geologic history is properly understood.

4. b. *Students know* the history of life on Earth has been disrupted by major catastrophic events, such as major volcanic eruptions or the impacts of asteroids.

The subject of major catastrophic events is important because such events, although rare in the history of Earth, have had a significant effect on the shaping of Earth's surface and on the evolutionary development of life. Most of the time geologic processes proceed almost imperceptibly, only to be interrupted periodically by the impact of a large meteor or by a major volcanic eruption. The immediate effect of both types of catastrophic events is much the same: injection of large amounts of fine-grained particulate matter into the atmosphere, an event that may have immediate regional or even global consequences for the climate by causing both short- and long-term changes in habitats.

4. c. *Students know* that the rock cycle includes the formation of new sediment and rocks and that rocks are often found in layers, with the oldest generally on the bottom.

Whenever rocks are uplifted and exposed to the atmosphere, they are subject to processes that can break them down. Purely physical processes, such as abrasion and freezing/thawing cycles, break rocks into smaller pieces. At the same time reactions with constituents of the atmosphere, principally acidic rain and oxygen, may cause chemical changes in the minerals that constitute the rocks and result in the formation of new types of minerals. The net result is called *sediment.* It consists of rock and mineral fragments, various dissolved ions, and whatever biological debris happens to be lying around. The sediment is removed by erosion from the sites where it formed and is transported by water, wind, or ice to other sites; there the sediment is deposited and eventually lithified to form new sedimentary rock. The biological portion of accumulated sediment may be fossilized and preserved, providing a partial record of existing life in the source area of the sediment.

Superposition, the fossil record, and related principles, such as crosscutting and inclusions, together form the basis for dating the relative ages of rocks. Students should realize that relative dating establishes only the order of events, not quantitative estimates of when those events actually occurred.

4. d. *Students know* that evidence from geologic layers and radioactive dating indicates Earth is approximately 4.6 billion years old and that life on this planet has existed for more than 3 billion years.

Relative age-dating (see Standard 4.c) provides information about the relative sequence of events in the history of Earth. Absolute dating (putting a numerical estimate on the age of a particular rock sample) requires the use of a reliable "clock" in the form of the radioactive decay of certain naturally occurring elements. Those elements are disaggregated into the various minerals at the time those minerals are formed, generally during the crystallization of igneous rocks. Thus the newly formed minerals in the igneous rock contain only the original radioactive form of the element (parent) and none of the products of radioactive decay (daughter products), which are different from the parent. The rate of transformation by radioactive decay from parent to daughter elements can be measured experimentally. This rate is usually expressed as a *half-life,* which is defined as the amount of time it takes to change one-half of the atoms of the parent element to daughter products.

Earth's surface is always being reworked because of plate tectonics and erosion; therefore, very little of the planet's original material is available for dating. However, moon rocks and meteorites, thought to be the same age as Earth, can also be dated. All the available evidence points to Earth and the solar system being approximately 4.6 billion years old. The earliest rocks containing evidence of life are slightly more than 3 billion years old.

4. e. *Students know* fossils provide evidence of how life and environmental conditions have changed.

Fossils provide evidence of the environments and types of life that existed in the past. As an ancient environment changed, so did the organisms it supported. Thus environmental changes are reflected by the classes of organisms that evolved during the period of environmental change. Uniformitarianism is the foundation on which these interpretations are based. For example, ancient animals exhibiting approximately the same shell shape and thickness as that of the modern clam probably lived in the same environment as clams do today. By examining fossil evidence and noting changes in life types over time, geologists can reconstruct the environmental changes that accompanied (perhaps caused) the changes in life types.

4. f. *Students know* how movements of Earth's continental and oceanic plates through time, with associated changes in climate and geographic connections, have affected the past and present distribution of organisms.

Darwin's work on finches in the Galapagos Island demonstrated clearly the effect of isolation on the distribution of organisms. Geographic separation of individuals in a species prevented the populations from interbreeding. This separation may have led to the accumulation of genetic changes in the two populations, changes that eventually defined them as different species. Plate tectonic movements of lithospheric plates and the uplift of mountain ranges divided (albeit slowly) populations of plant and animal species and isolated the divisions from one another. This principle was illustrated in the fossil record of dinosaur species. Some dinosaurs, as well as other species that were restricted to specific continents after geologic separation, were uniformly distributed prior to continental separation.

4. g. *Students know* how to explain significant developments and extinctions of plant and animal life on the geologic time scale.

Many changes that life has undergone during the history of Earth have been gradual, occurring as organisms adapt to slowly changing environments, evolve into new species, or become extinct. This principle is a fundamental tenet of uniformitarianism. But even uniformitarianism is not consistently true. For example, very early Earth on which the first life appeared was considerably different from the planet of today. Little oxygen was in the atmosphere, and no ozone layer was in the stratosphere to protect against harmful solar radiation. The earliest life was therefore anaerobic and had to be protected from solar radiation. Evidence for this single-celled life can be found in rocks that are slightly more than 3 billion years old.

Photosynthetic cyanobacteria, once referred to as blue-green algae, were an early addition to the prehistoric ecosystem. These early organisms are seen in the fossil record and were very successful, so much so that they still exist worldwide and are essentially unchanged in form after billions of years.

The slow change in Earth's life has been punctuated by sudden events—catastrophic ones—when viewed on the vast geologic time scale. One such remarkable event occurred about 600 million years ago. It is known as the Cambrian Explosion because of the sudden appearance of many different kinds of life, including many new multicellular animals that, for the first time, had preservable hard parts, such as shells and exoskeletons.

At various times life on Earth has also suffered from catastrophic mass extinctions in which the vast majority of species quickly died out. The greatest such event happened about 250 million years ago toward the end of the Paleozoic Era. It is known as the Permian extinction, and as much as 90 percent of marine species may have died out. Another famous mass extinction occurred at the end of the Mesozoic Era and is known as the Cretaceous-Tertiary (K-T) extinction. At the time all species of dinosaurs died out, as did about half of all the plant and animal groups. Evidence is mounting to indicate that this catastrophic event was caused by the impact of an asteroid.

STANDARD SET 5. Structure and Function in Living Systems

Students were first introduced in grade one to the complementary nature of structure and function when they studied the different shapes of animal teeth and inferred the kinds of food those animals eat. Students in grade three studied the external physical characteristics of organisms and considered their functions as a matter of adaptation. Students in grade seven will deepen their understanding of internal structures, a topic that was introduced in grade five.

Anatomists and physiologists consider at different levels the internal structures of living organisms. Mammals have discrete organs, many of which work together as systems. For example, the adrenal and pituitary glands are parts of the endocrine system, and the kidneys and bladder are parts of the excretory system. Flowering plants have tissues, such as xylem and phloem, that are part of a vascular system. Organs themselves may have specific tissues; for example, the white and gray matter of the brain can serve multiple functions. The pancreas produces both digestive enzymes and blood hormones.

Students in grade seven learn about the musculoskeletal system, the basic functions of the reproductive organs of humans, and the structures that help to sustain a developing fetus. Students also study the intricate structures of the eye and ear, which have well-understood functions in sight and hearing. Although many topics are covered in this section, they are all grouped in the fields of anatomy and physiology.

5. The anatomy and physiology of plants and animals illustrate the complementary nature of structure and function. As a basis for understanding this concept:

a. *Students know* plants and animals have levels of organization for structure and function, including cells, tissues, organs, organ systems, and the whole organism.

Protists, such as amoebae, consist of only one cell. All the functions necessary to sustain the life of these organisms must be carried out within that one cell. Multicellular organisms, such as plants and animals, tend to have cellular specialization (differentiation), which means individual cells or tissues may take on specific functions within the organism. For example, the musculoskeletal system of animals comprises individual muscle groups (e.g., biceps) that are bundles of muscle fibers, which are themselves groups of muscle cells, working together to make possible movements of the organism. Within individual muscle cells are organelles, such as the mitochondria, that help provide the energy for muscle contraction.

5. b. *Students know* organ systems function because of the contributions of individual organs, tissues, and cells. The failure of any part can affect the entire system.

Students learned in grade five how blood circulates through the body and how oxygen, O_2, and carbon dioxide, CO_2, are exchanged in the lungs and tissues. The pulmonary–circulatory system functions as a whole because of the functions of its individual components. A person may die from a heart attack (from failure of the heart), suffocation or pneumonia (from insufficient gas exchange in the lungs), shock (from loss of blood volume), or a stroke (sometimes caused by an insufficient gas exchange with brain tissues due to the blockage of blood vessels).

5. c. *Students know* how bones and muscles work together to provide a structural framework for movement.

The skeletal system in animals provides support and protection. Muscles are attached to bones by tendons and work in coordination with the bones and the nervous system to cause movement through coordinated contraction and relaxation of different muscle groups. For example, a muscle in the arm called the *biceps* causes bending of the arm at the elbow so that the angle between the bones (humerus and ulna) decreases. The *triceps* on the back of the arm causes bending so that the same angle increases. This flexion and extension of the arm is a good example of muscle groups that are coordinated. Even in a lifting motion in which one of those two muscle groups is ostensibly the prime mover of the bone (e.g., “curling” a weight with the biceps), the opposing muscle group is involved in producing a smooth, controlled motion of the arm and protecting the joint from strong contraction.

5. d. *Students know* how the reproductive organs of the human female and male generate eggs and sperm and how sexual activity may lead to fertilization and pregnancy.

In males the testes in the external scrotum are the reproductive structures that produce sperm. Immature sperm cells in the walls of the seminiferous tubules of each testis mature into flagellated cells that are transported and stored in the epididymis. During sexual arousal millions of sperm may be transported to the urethra and ejaculated through the penis. Some sperm may exit through the penis before ejaculation (i.e., without the man’s knowledge), and sexual activity that does not result in ejaculation may nonetheless lead to the release of sperm, fertilization, and pregnancy.

In females the ovaries are the reproductive structures that produce and store eggs, also called *oocytes* (pronounced "oh-oh-sights"). An egg develops within an ovarian structure called a *follicle.* A mature follicle can rupture through the wall of the ovary, releasing the egg during the process of ovulation. The egg is then transported by one of the Fallopian tubes to the uterus. If the female, at or around this time, engages in sexual activity that results in sperm being deposited in or near the vagina, a sperm cell can travel through the vagina to the uterus or Fallopian tubes and fertilize the egg. A fertilized egg may implant in the uterus and develop, meaning that the female is pregnant and may deliver a baby approximately nine months later. If the fertilized egg fails to implant and begin development, or if the egg is not fertilized, it will be sloughed off along with several layers of cells lining the uterus and leave the female's vagina during menstruation. One of the first signs of pregnancy is that a woman's regular monthly menstrual cycle stops.

5. e. *Students know* the function of the umbilicus and placenta during pregnancy.

The placenta is an organ that develops from fetal tissue in the uterus during pregnancy. It is responsible for providing oxygen to the developing fetus. The umbilical cord (which enters the body at the *umbilicus,* or navel) is a cord containing arteries and veins that connect the fetus to the placenta. Although the blood of the mother and of her fetus do not mix together, oxygen and nutrients pass from the mother's blood to the fetus. Wastes, such as carbon dioxide from the fetus, are removed. The placenta helps to nourish and protect the fetus; however, most drugs and alcohol can easily pass from the mother's blood into the blood of the fetus, as can many infectious viruses, such as the human immunodeficiency virus (the source of AIDS).

5. f. *Students know* the structures and processes by which flowering plants generate pollen, ovules, seeds, and fruit.

Flowering plants, or *angiosperms,* reproduce sexually by generating gametes in the form of sperms and ova. The reproductive structure of the angiosperms is the flower, which may contain male or female parts or both. Stamens are the male reproductive structures within the flower. Each stamen is composed of an *anther,* the structure that produces pollen granules, and a *filament,* the long thin stalk that connects the anther to the base of the flower (receptacle). The *pistil* is the female reproductive structure located in the center of the flower. The pistil consists of the *stigma,* which receives the pollen grains, and the *style,* a long thin stalk that acts as a guide for the pollen tube. The pollen tube, in turn, provides a migration path for the sperm of the pollen grain down to the ovary at the base of the pistil. The ovary contains one or more ovules, inside of which develop the ova. After fertilization the ovule develops into a seed with the developing embryo inside surrounded by a food source (the endosperm) for the plant embryo. The surrounding ovary may then enlarge and mature into a fruit that can contain one or more seeds.

5. g. *Students know* how to relate the structures of the eye and ear to their functions.

The eye works much like a camera. The eye is equipped with a lens that brings an image into focus on a sheet of light-sensitive cells called the *retina,* which is equivalent in a camera to a sheet of film or a video chip. The amount of light entering the eye is controlled by the iris, which is an adjustable circular aperture. In bright lighting the iris contracts and the pupil (the open area that appears black) becomes smaller in diameter to admit less light. In dim lighting the iris relaxes and the pupil becomes larger to admit more light. The lens of the eye refracts (or bends) the light, much as a magnifying glass does, and focuses an image on the retina. The lens is flexible, and its shape changes when focusing on nearby or distant objects. The retina contains cells that are sensitive to bright colors (cone cells) and others that are sensitive to dim lighting (rod cells). The cells in the retina generate an electrical signal that travels to the brain, which can interpret the visual pattern. Investigative activities with lenses may be practiced both in this standard set and in Standard Set 6, "Physical Principles in Living Systems," which describes the optics of sight.

The external ear (i.e., the part that can be seen) helps to collect sound waves and direct them to the middle ear. Many mammals (e.g., cats and many breeds of dogs) can redirect their external ears to detect faint sounds and determine the direction from which a sound is coming. The middle ear consists of a vibrating eardrum, or *tympanic membrane,* and three small bones (the *malleus,* or hammer; *incus,* or anvil; and *stapes,* or stirrup) that form a series of levers connecting the eardrum to the inner ear. Two small muscles control the tension on the eardrum and middle ear bones to reduce or increase the loudness of sound being transmitted. The inner ear, or labyrinth, contains the sensory cells that turn the waves of sound or pressure into electrical signals that are sent to the brain.

Students may explore the structure of the mammalian eye by performing a dissection. They should be able to identify and explain the function of the different parts of the eye. Students may learn the structure and function of the human ear by building a model from simple materials. Students should be able to identify the different parts of the ear and explain how those parts work together to transmit sensory information through sound waves. The sensory cells lining the cochlea are stimulated by the sound waves, causing nerve impulses to be transmitted through the auditory nerve to the brain.

STANDARD SET 6. Physical Principles in Living Systems

The study of optics and levers, or pressure, is usually reserved for physical science classes. However, these topics are introduced for the first and only time in the seventh grade, so students should learn the principles behind them. Suggestions are made to relate the study of these topics to the eye, muscles, bones, tendons, and heart.

The human eye contains receptors that detect incoming visible light emitted by a luminous object or reflected from an illuminated object. Until the early 1900s physicists believed that the properties of light could be completely understood by viewing light as a wave of electromagnetic energy that was supported by an elusive medium—the so-called *ether*—that was imagined to pervade even a vacuum. The nature of light still seems mysterious to most people because light manifests the properties of both a wave and a particle. In most experiences geometric optics, which treats light as rays traveling in straight lines, adequately accounts for reflection and refraction, mirrors, and lenses. Before starting these topics, students should be able to measure angles, do ratio and proportion problems, and use gram mass weights and metersticks.

Students in grade seven can and should learn how levers confer a mechanical advantage. Given a lever, students should be able to identify the fulcrum and four important quantities: effort distance, effort force, resistance distance, and resistance force. If three of those quantities are known, students should be able to calculate the fourth quantity. Students can make simple levers and hinges (and other simple machines, if time permits) to show how levers can be used to increase forces at the expense of distances or distances at the expense of forces. Metersticks, weight holders, hooked weights, and pivoted supports are commercially available for students to make a straightforward investigation of the operation of levers. A key element of this standard set is to relate the physical principles to the function of muscle and bone in the body. Pressure, a subject that was introduced to students in the context of atmospheric pressure in earth science, is now discussed in the context of blood pressure and heart function.

6. Physical principles underlie biological structures and functions. As a basis for understanding this concept:

a. *Students know* visible light is a small band within a very broad electromagnetic spectrum.

Visible light is a part of a continuum known as the electromagnetic spectrum that extends on both sides of the visible region. This continuum includes the very long wavelengths, such as those of AM and FM radio and TV; the slightly shorter wavelengths, such as radar, microwave, and infrared radiation; and visible light that has wavelengths just less than one-millionth of a meter long. The wavelengths of electromagnetic radiation that the human eye can see vary from about 800 nanometers (0.0000008 m, or red light) to 400 nanometers (0.0000004 m, or blue/violet light). The colors of the visible spectrum are traditionally described as red, orange, yellow, green, blue, indigo, and violet but are actually a continuous spectrum.

6. b. *Students know* that for an object to be seen, light emitted by or scattered from it must be detected by the eye.

This standard deals with the physical principles of the interaction of light with matter. After the initial interaction light rays from an object must pass from the object to the eye. The interactions with those parts of the eye that focus the light, creating an image on the retina, and transfer the light into electrical impulses, which are interpreted by the brain, all depend on the information in the light that enters the eye. This information arises from the initial interaction of the light with the object or the nature of the light emitted by the light source(s) or both. The color and brightness of the light that is emitted or reflected from an object depend on the color, brightness, and angle of incidence from the source illuminating the object. The object then absorbs, reflects, or refracts the illuminating light and imparts a color and brightness. That color is attributed to the object, but color really depends on the source of light and the way the object interacts with it.

This process scatters light in all directions. The eye detects only the light that enters it. This light first encounters the front, rounded, transparent surface of the eye (the cornea), where most of the focusing occurs. Next, it enters the interior of the eyeball through the pupil and passes through the lens, which acts to further focus the light to accommodate both near and far objects. The focused light then falls on the receptors (the rod cells and the cone cells) in the retina, is converted into electrical impulses, and is transferred by the optic nerve to the visual cortex of the brain.

6. c. *Students know* light travels in straight lines if the medium it travels through does not change.

In a vacuum or in a uniformly transparent material, light travels in straight lines. At the interface between two media or between a vacuum and a medium, light rays will bend if they enter at an angle other than perpendicular to the interface. The light-bending properties of objects should be explored. However, transparent materials, such as air, may have differing densities and cause light to bend as it passes through the material. For example, the air heated by a campfire can cause objects to appear to shimmer because the path of the light is not a straight line. The variations in the density of the atmosphere are what cause the stars to twinkle. When light travels from one transparent medium (such as air) into another transparent medium with different optical properties (such as water), the path of the light may bend (or be refracted) depending on the angle of the ray of light in relation to the surface between the two media.

A pencil placed in a glass half full of water will appear bent. By analyzing the path of the light from various points on the pencil to the eye of the observer, students will be able to confirm that the path of the light did change direction as it passed from one medium into another.

6. d. *Students know* how simple lenses are used in a magnifying glass, the eye, a camera, a telescope, and a microscope.

Combinations of lenses are used in telescopes and microscopes to magnify objects. The cornea of the eye plays the major role of a lens in transforming the rays of light diverging from an object into rays of light converging to a focus on the retina. To provide instruction in this standard, teachers may use magnifiers. Simple magnifiers of plastic (or glass) are inexpensive and easily obtained. A magnifier is a converging optic because it can convert rays of light diverging from an object to rays of light converging to form an image. Magnifiers are characterized by their focal lengths, which may be found by lifting a lens up from a table until the sharpest image of a ceiling light is formed. The distance from the magnifier to the image on the tabletop is the focal length. If the magnifier is held at a distance shorter than the focal distance above a printed page, the print is seen magnified because the lens creates an enlarged, virtual image instead of a real image. If the magnifier is held at a distance greater than the focal length above the page, what is seen depends on where the observer's eye is located. The light leaving the lens is now converging so that if the eye intercepts the converging rays, no sharp image will be seen. If the eye is located far enough above the page, the rays from the lens converge to form a real image and pass through it. The eye is now intercepting diverging rays and sees the print upside down.

6. e. *Students know* that white light is a mixture of many wavelengths (colors) and that retinal cells react differently to different wavelengths.

White (visible) light may be dispersed into a spectrum of colors: from red at the longest wavelength to violet at the shortest wavelength. A glass or plastic prism disperses white light into the colors of the spectrum because the angle of refraction is different for each of the different wavelengths (colors). A diffraction grating of closely spaced grooves can also be used to separate white light into various colors because different wavelengths (i.e., different colors) interfere constructively after reflection at different angles. Teachers should present both these effects to show the nature of white light.

The human perception of color is due to specialized color light receptor cells in the retina of the eye. These specialized cells (called cone cells) make color vision possible. Full-color printing is achieved by the use of just four ink colors (usually magenta, yellow, and cyan along with a very dark purple or black). The four colors are printed in combinations of dot patterns too small to perceive (resolve) with the human eye. Color images in magazines are commonly produced in this way.

6. f. *Students know* light can be reflected, refracted, transmitted, and absorbed by matter.

The interaction of light with matter may be classified as reflection, refraction, transmission, or absorption. Light transmitted through air and transparent, uniform materials continues to travel in a straight line. However, when rays of light encounter a surface between two materials or two media, such as air and water or air and glass, the light may be reflected or refracted at the surface. The angle at which the light is reflected or refracted from its original path follows principles that depend on the optical properties of the materials, such as the angle of incidence being equal to the angle of reflection. The principles of refraction are what make it possible for lenses to focus and magnify images.

Light travels (is transmitted) through a transparent medium by a process of absorption and reemission of the light energy by the atoms of the medium. Opaque and translucent objects absorb and scatter light from their original direction much more strongly than do transparent objects. Optically denser materials, such as glass, cause light to travel more slowly than do less optically dense materials, such as water and especially air. Light travels through air just slightly more slowly than through a vacuum. Rays of light may be observed to change direction, or refract (a consequence of light changing speed), in going from one medium to another. However, if light enters a new medium perpendicular to its surface, the light continues in a straight line so that refraction is not observed (even though the light is traveling at a different speed in the second medium). Impurities or imperfections in transparent materials or media cause some of the light to be scattered out of a beam. Smoke, fog, and clouds decrease visibility because they scatter light.

6. g. *Students know* the angle of reflection of a light beam is equal to the angle of incidence.

When a light beam encounters a shiny reflecting surface, the angle of reflection is the same as the angle of incidence. The angle is usually measured in relation to the surface normal.

6. h. *Students know* how to compare joints in the body (wrist, shoulder, thigh) with structures used in machines and simple devices (hinge, ball-and-socket, and sliding joints).

Archimedes is credited with first understanding that a rigid rod (a lever) able to rotate about a fixed pivot point (a fulcrum) can be used to turn a small force into a large force. Joints in the body act as pivot points for bones acting as levers, and muscles provide the force. There are three classes of levers, which are defined by the relative positions of the applied force causing the action, the placement of the fulcrum, and the resistant object being moved. A lever provides one of two principal advantages: It can amplify the force being applied so that a small force applied over a long distance can create a large force over a short distance. This principle is useful to know in lifting heavy objects. The alternative is typical of levers in the human body: A large force applied over a short distance in a short time can be amplified into long, rapid motions, such as in running or in swinging a baseball bat.

6. i. *Students know* how levers confer mechanical advantage and how the application of this principle applies to the musculoskeletal system.

A lever can be used to take advantage of force or speed (or motion). A bone is the lever; a joint is the pivot point (or fulcrum); muscles supply the force; and connective tissues transfer the force to locations that usually give an individual the leverage to increase his or her speed of motion of foot, arm, or hand. Students can make simple levers and hinges (and other simple machines, if time permits) to show how levers may be used to increase force at the expense of distance or distance at the expense of force. Metersticks, weight holders, hooked weights, and pivoted supports are commercially available for students to make straightforward investigations of the operation of levers. These or other hands-on laboratory activities using first-, second-, and third-class levers in simple equipment will make the "law of the lever" more real than will solving a set of mathematical proportion problems or merely identifying the parts of a lever from drawings or pictures.

6. j. *Students know* that contractions of the heart generate blood pressure and that heart valves prevent backflow of blood in the circulatory system.

The heart is a pump in which blood enters a chamber through a blood vessel; a valve closes off the blood vessel to prevent the blood from flowing in the wrong direction; and the heart muscle contracts. This action "squeezes" the blood and increases the pressure to force the blood into another blood vessel. Pressure is defined as force per unit area and is measured in various units, such as millimeters of mercury (mmHg). Students may learn more about the physiology of the heart by reading science texts and studying models.

STANDARD SET 7. Investigation and Experimentation

The essential skills and knowledge of observation, communication, and experimental design are extended in grade seven. Including scale model building in the curriculum helps students to visualize complex structures. Collecting information from a variety of resources is an important part of scientific inquiry and experimental design. Many types of print and electronic resources are available in the school library to support teaching and learning science. The skills needed to search out and recognize accurate and useful resources are complex and generally require significant knowledge of the topic.

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

a. Select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.

b. Use a variety of print and electronic resources (including the World Wide Web) to collect information and evidence as part of a research project.

c. Communicate the logical connection among hypotheses, science concepts, tests conducted, data collected, and conclusions drawn from the scientific evidence.

d. Construct scale models, maps, and appropriately labeled diagrams to communicate scientific knowledge (e.g., motion of Earth's plates and cell structure).

e. Communicate the steps and results from an investigation in written reports and oral presentations.