SCIENCE BACKGROUND—*Tools of Science*

We learn about our world through our senses: **seeing, hearing, touching, tasting,** and **smelling.** Our senses keep us safe—we pull away from something sharp, or react to the smell of smoke or the sound of a car horn. Our senses give us pleasure in life as we enjoy the beautiful sounds, smells, and sights of our world. Our eyes, ears, noses, tongues, and skin are our sense organs. Each sense organ has tiny **nerve cells** that can send messages directly to the brain. The brain receives and interprets these signals. Then we know what we are seeing, hearing, touching, smelling, or tasting.

Sight is the sense that relates an object's visual properties—shape, size, color, location, and movement—to the brain. The **eyes** are the sense organs responsible for sight. We see when light is reflected or emitted by objects into our eyes. Four-fifths of the information that reaches our brain comes from our eyes.

Hearing is the sense that relates information to the brain about sound. The **ears** are the sense organs responsible for hearing. Sound is produced when something vibrates, producing a chain reaction of vibrating air molecules called a sound wave, which enter the ear. In the inner ear, these vibrations are converted to impulses that are carried to the brain to be interpreted as sounds.

Touch is the sense that relates information to the brain about physical contact with objects in our environment. The **skin** is the sense organ responsible for feeling touch. Our skin contains several different types of sensory receptors that take in information about touch, pressure, pain, heat, or cold. That information is carried via the spinal cord to the brain, and then it is interpreted as a sensation, or a feeling.

Smell is the sense that relates information to the brain about scent. The **nose** is the sense organ responsible for smell. Molecules of the substance being smelled are breathed in through the nostrils and captured by sensory receptors. The receptors detect odors and convert them to impulses that are sent to the brain. The brain interprets the impulses and tells us what we are smelling.

Taste is the sense that relates information about flavor to the brain. The **tongue** is the sense organ responsible for taste. The tongue is a flexible muscle covered with thousands of taste buds containing receptors that detect four basic tastes: sweet, salty, sour, and bitter. Taste nerves at the base of the taste buds send electrical impulses to the brain, where they are interpreted as tastes.

We use our five senses to observe and **compare** the properties of objects—that is, to find out and describe how objects are alike and different. **Properties** are attributes, traits, or characteristics of an object that can be detected by the senses. Properties include the object's shape, color, texture, weight, size, and composition. A property may also be an effect that a material or substance has on another object, such as magnetism or buoyancy.

Properties can be sorting criteria. For example, objects can be **sorted** by size (big and little), by texture (rough and smooth), by color (blue and not blue), by shape (round and square), and so on. Young learners typically sort into two groups, although some may further divide the groupings.

Tools are devices that help us do work. We use tools to make, move, build, and fix things. Some tools are simple machines, such as levers, pulleys, screws, and wedges, powered by the force of humans or animals. Other tools are complex machines operated by mechanical, electrical, or some other form of energy, and ranging from miniature to massive in size.

The oldest known tools date from more than 2.5 million years ago! These early tools were basic essentials—fishhooks, axes, and chisels, for example—made from natural materials such as bone and stone. By Roman times, households and workers had many hand tools that would be familiar to us today. Every profession and craft has specialized tools for unique purposes.

Tools—in particular, measuring tools—also help us compare objects by allowing us to learn and label information about size. Different types of tools are used to take different types of **measurements,** using different sets of **standard units.** For example, rulers and meter sticks are used to measure length, width, height, and distance. Measuring cups and pitchers are used to measure volume. Scales and balances measure weight and mass. Thermometers measure temperature. Clocks measure time.

At one time, every country had its own system of units of measure, and often several different systems. During the 1790s, the metric system was devised in Europe to bring uniformity to measurement. The metric system largely replaced the traditional, variable units. A basic metric unit was established for each quantity: the meter for length, the gram for weight and mass, and the liter for volume. Multiples and fractions of the basic units are created by multiplying or dividing by 10. (For example, 10 millimeters equal 1 centimeter; 100 centimeters equal 1 meter; 1,000 meters equal one kilometer.) Most countries, and all scientists, use the metric system of measurement. In the United States today, two systems are used: the **metric system** and the **U.S. customary system.** The following list shows how they compare:

Length/Distance
1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 yard = 0.9144 meter
1 mile = 1.6093 kilometers

1 millimeter = 0.03937 inch
1 centimeter = .3937 inch
1 meter = 39.37 inches
1 kilometer = 0.621 mile

Weight/Mass
1 ounce = 28 grams
1 pound = 0.45 kilograms

1 gram = 0.035 ounces
1 kilogram = 2.2 pounds

Volume/Capacity
1 teaspoon = 5 milliliters
1 tablespoon = 15 milliliters
1 cup = 0.24 liters
1 pint = 0.47 liters
1 quart = 0.95 liters
1 gallon = 3.8 liters

1 milliliter = 0.03 fluid ounces
1 liter = 1.06 quarts

SCIENCE BACKGROUND—*Water*

Water is the most common substance on Earth and is the basis of all life as we know it. Because of its many unique properties, water plays a major role in a vast number of chemical reactions.

In nature, atoms join together principally to fill their outer energy levels with electrons, becoming more stable in the process. There are several kinds of bonds that can form between atoms. One is a covalent bond, in which atoms share electrons. By sharing electrons, each atom gets a filled outer energy level because the covalent, or shared, electrons are in the outer levels of both atoms at the same time.

Water forms when two atoms of **hydrogen** join together covalently with an atom of **oxygen.** However, the negatively charged electrons are not located evenly within each molecule. Instead, the "shared" electrons are clustered toward the oxygen end of the molecule. As a result, this end of the molecule holds a partial negative charge and the hydrogen ends of the molecule hold a partial positive charge. This difference in charge within a molecule is called polarity. Hence, water is a polar molecule.

The polarity of the water molecule accounts for many of water's unique **properties.** For example, water has a high degree of **cohesion,** or attraction of one water molecule for another. The partial positive charge on the hydrogen atom is attracted to the partial negative charge on a neighboring oxygen atom. Indeed, the force of attraction between neighboring water molecules is strong enough to be called a **bond.** The bond is called a hydrogen bond and, while not as strong as a covalent bond, acts as a bridging bond between neighboring water molecules.

Because of hydrogen bonding, water molecules at the surface of a body of water have a high degree of attraction, or cohesion, for one another and for other water molecules beneath them. This special force on the surface of water, which pulls water molecules inward, is called **surface tension.** It is surface tension that gives water drops their smooth, round shape and makes water look as if it has a stretchy "skin" on its surface.

The clustering of water molecules due to hydrogen bonding also explains why water is a liquid at room temperature when similar compounds are gaseous. Indeed, water is one of the only substances that exists naturally as a **solid, liquid,** and **gas.** Water's **boiling point** is 100°C (212°F), which is far higher than that of any similar compound. (Because its molecules have such a strong attraction for one another, only a few molecules can escape into the gaseous state at lower temperatures.)

The polarity of the water molecule also accounts for the fact that so many substances **dissolve** in water. The polar ends of the water molecule serve to attract other compounds, encouraging them to separate and dissolve into the water.

The molecules that make up water, like all molecules, vibrate. Those at the surface of the water are able to vibrate more vigorously than the ones below, and so they escape into the air as molecules of gas called **water vapor.** This process, by which liquid water changes into a gas, is called **evaporation.** The rate of evaporation increases with increasing temperature (which causes water molecules to vibrate more rapidly).

The amount of water vapor in the atmosphere is known as **humidity.** At any one temperature, air can only hold a certain amount of water vapor. Water constantly evaporates from seas, lakes, and the surfaces of plants adding to the vapor in the air. When the air can take up no more water vapor, it is said to be **saturated.** Once it is saturated, evaporation stops and droplets of water condense from the air, forming clouds or dew, and eventually falling to the ground as rain or snow. **Condensation,** the process by which a gas changes to a liquid, is therefore the opposite of evaporation.

A liquid with a strong attraction to a solid material, or a high degree of **adhesion,** seeks to come in contact with as much surface area of that material as possible. When the solid material is porous, a liquid that shows a high degree of adhesion to that solid material will move to fill the small spaces between its particles. Water moves upward from the roots of plants to their leaves because of **capillary action,** or the tendency of water to travel upward in thin tubes and porous materials.

Density is a measure of mass per unit volume. Whether an object floats or sinks in water, in general, depends on the relative densities of the object and water. Objects that are less dense than water **float.** Objects that are more dense than water **sink.**

However, dense objects can be made to float by reshaping them to increase the volume of water they displace which, in turn, increases the weight of the water displaced and the upward force of the water.

Soap reduces water's degree of cohesion and, therefore, its surface tension. As a result, soap helps water stretch and spread out. For this reason, soapy water is good for blowing bubbles. Bubbles are round because soapy water tries to pull itself into as small a shape as possible, just like drops of water.

Although almost three-fourths of Earth's surface is covered with water, less than 3 percent of that water is **fresh water.** The huge amount of water people consume every day comes from rivers, lakes, and wells. We take our water from this limited supply, and we use it over and over again. With the exception of private wells, which use **groundwater** that has been naturally filtered, all of this water has to be cleaned before it is again safe for use.

SCIENCE BACKGROUND—*Weather*

Weather is one of the most relevant issues in our lives. It affects what we wear, what we do, where we go, and how we get there. People buy newspapers and turn on the news to find out what the weather is going to be. Knowing the **forecast,** they can then plan their day.

Weather is the condition of the **atmosphere,** the blanket of air that surrounds Earth. Weather occurs in the lowest and densest layer of the atmosphere, called the **troposphere.** It is here that air, moisture from Earth's surface, and the Sun's energy interact, causing the **wind** to blow, **clouds** to form, and rain to fall.

Weather is different from climate. **Climate** is the average weather over a long period of time. Climate, which is described in terms of the average **temperature** of a region or the average amount of rain or snow a region receives, generally stays the same from year to year.

In contrast, weather is the condition of the air in a certain place over a brief period of time. It can change from day to day—even hour to hour. Weather also changes markedly from **season** to season. Of course, at any given time the weather varies from place to place, too. For example, it might be warm and sunny in Miami while it is cloudy and cool in San Francisco; it may be raining in one part of town and dry just a few blocks away.

If temperature is the "spoon that mixes the atmosphere," then the Sun is the hand that holds the spoon. The Sun heats Earth, causing water to **evaporate** and warm air to rise. When warm, moist air rises, cooler air rushes in to take its place. The uneven heating and cooling of the earth causes the air in the atmosphere to circulate. This continuous circulation of warm and cool air brings changes in the weather.

The United States experiences the greatest variety of weather of any nation on Earth. Regions of the United States are some of the wettest and driest, hottest and coldest, in the world.

Keeping track of all this weather is the job of the National Weather Service, a federal agency made up of professional weather watchers. With approximately 10,000 staffed and unstaffed weather stations worldwide, the National Weather Service issues over two million **forecasts** per year, including flood and storm warnings. By its own account, it is accurate about three-fourths of the time.

Weather forecasting is still an inexact science, but it has come a long way since 4,000 years ago, when people looked to the stars to predict the weather on Earth. Forecasting became more reliable with the advancement of scientific instruments, most of which has taken place within the last four centuries.

In 1593 Italian scientist Galileo invented a type of **thermometer.** In 1634 Evangelista Torricelli, a mathematician, physicist, and pupil of Galileo's, invented the first **barometer,** an instrument to measure **air pressure.** The first **anemometer**—a device that measures wind speed—was developed in 1667.

Today **meteorologists** have a variety of sophisticated instruments available to measure and record the weather. Meteorologists have begun to use unstaffed weather balloons, called radiosondes; specially equipped aircraft—literally flying weather stations; radar; and **satellites.** With the detailed and timely information these instruments provide, weather watching is more accurate than ever before.

Of course, you do not have to be a scientist to watch the weather. Students are some of the savviest weather watchers because they are naturally observant and spend so much time outdoors.

Students know a great deal about the weather, even if they do not know the scientific name for something or the physics behind it. They know, for example, that wet snow makes better snowballs than dry snow, although dry snow is better for sledding than wet snow. They understand about **wind chill**—that on a windy summer day, it is sometimes warmer to stay in the pool than to get out.

SCIENCE BACKGROUND—*Plants*

Plants are everywhere. They grow in fields and forests, oceans and deserts. They grow indoors and out, in cities and in villages. There are over a half million different kinds of plants ranging in size from the 367-foot-tall sequoia to the microscopic duckweed.

Plants fall into two basic categories, **nonflowering** and **flowering** plants. Nonflowering plants include mosses, ferns, and conifers as well as other lesser-known groups. All the plants studied in these activities are flowering plants.

When the female parts of plants are fertilized with the pollen produced by the male parts of plants, they form **seeds.** Seeds are formed in the cones or **flowers** of plants. Flowering plants produce seeds in **fruit.**

Although most seeds are very small, they are capable of growing into new plants.

Seeds may remain inactive for weeks, months, or even years, lying in wait for growing conditions to be just right for sprouting. When the temperature is favorable and the water supply is adequate, they become active and quickly begin to sprout and grow.

A seed contains both the embryo capable of growing into a plant and the stored food needed to nourish the new plant. The part of the embryo that provides food is called the cotyledon. The embryo and food are surrounded by a seed coat that tightly encloses and protects them.

A seed sprouts, or begins to grow, when moisture penetrates the seed coat and the temperature is warm enough. Although we usually plant seeds in soil, they do not actually need to be in contact with soil in order to sprout. However, soil gives a sprouting seed several advantages: it holds the water that keeps the seed properly moist; it acts as insulation to moderate any temperature fluctuations; and it provides a stable foundation in which a seed can establish its first **roots.**

Different types of seeds sprout in different lengths of time. The rate at which a plant grows is affected by a number of things: the species of the plant, the amount of sunlight and water it receives, the temperature, and the nutrients available in the soil.

Water is important to plants for several reasons. Plants pull a large volume of water through their roots and **stems** and release it through their **leaves** as water vapor in a process known as transpiration. This process helps move nutrients through the plant, helps give the plant its shape, and helps keep the plant cool.

A lack of water causes a plant's cells to contract and the plant to wilt. It is water that dissolves nutrients in the soil and carries them through the plant to where they are needed.

Plants use sunlight to make food through the process of photosynthesis. Using the energy in the light that falls on them, they are able to convert carbon dioxide and water into sugar and oxygen. This sugar provides the food needed by plants. The food made in the leaves is transported throughout the plant to feed all its cells. The sugar reserves are sometimes stored in the roots. When we eat plants, we are eating the nutritious food created and stored in plants.

The study of plants is known as **botany.** Since prehistoric times, humans have been profoundly interested in plants. In hunter-gatherer cultures, the primary food source was often the seeds, roots, leaves, fruits, and stems of plants. These people had an intimate knowledge of plants—which ones were edible or medicinal, where they grew, and when they were ripe for harvest. Once human societies began to cultivate crops, the study of seeds, planting techniques, and the care of growing plants became vitally important.

Today, we still eat foods produced by all parts of the plant. The rice, wheat, and corn that form the staple diets of most of the people of the world are actually the seeds of three members of the grass family. We eat roots when we eat sweet potatoes, beets, and carrots; stems when we eat asparagus and celery; and leaves when we eat leafy lettuce and spinach. Some foods contain many parts of the plant. Even the flowers of such plants as violets and nasturtiums are eaten in salads.

SCIENCE BACKGROUND—*Butterflies*

Together, the **butterflies** and moths make up the scientific order **Lepidoptera,** from the Greek words for "scale" and "wing." The multitude of colors that make their wings so distinctive come from the soft and fuzzy scales that cover their wings. Only the Lepidoptera have these scales, and the scales cover every part of the Lepidopterans' bodies, from their wings to their feet.

There are more varieties of butterflies and moths than any other sort of **insect** except beetles: more than 175,000 known species. The division of the Lepidopterans into butterflies and moths is actually an artificial one, based on a number of observable differences, all of which have at least some exceptions to the rule.

There are many more kinds of moths than butterflies, about 155,000 moths compared to about 20,000 kinds of butterflies. Some people argue that butterflies are just a kind of specialized day-flying moth!

The Lepidopterans are insects with all the characteristics of that group. They have six **legs,** two **antennae,** and three **body parts:** a **head,** a **thorax,** and an **abdomen.** Adults have **compound eyes** and **wings.** When in the larval, or immature stage of their life, many Lepidopterans have only tiny antennae, small simple eyes rather than huge compound eyes, and extra "false legs" to help them move about.

As insects grow and develop, they pass through distinct life stages, a process known as **metamorphosis.** Some insects begin life as eggs, hatch into **nymphs** that usually resemble the adults, and eventually become adults, complete with sex organs and (usually) wings. This type of development is called **incomplete metamorphosis.**

Other insects also begin life as eggs but hatch into a form called **larvae,** young insects that do not resemble the adults at all and usually eat completely different foods. After growing to many times their original size, larvae enter a pupal stage, or changing stage. This is sometimes called the "resting stage," because there is no outward sign of activity, but is actually a time of huge transformation.

While in the **pupa** stage, many complex chemical changes take place, and the insect's entire body structure is rearranged. When the insect emerges from the pupa, it is an **adult,** with sex organs and wings. This type of development is called **complete metamorphosis.** Lepidopterans all go through complete metamorphosis as they develop from eggs into adults.

The Lepidopterans, like all insects, have a stiff **exoskeleton,** or cuticle, on the outside of their bodies to provide them with support. As one can imagine, having a skeleton on the outside presents some problems when growing. During the larval stage, the Lepidopterans grow to many times their original size; they solve the problem of outgrowing their exoskeleton by **molting,** or shedding it and hardening a new, larger one that can support their larger body size. The change into the pupal stage is actually a specialized kind of molt. Once they are adults, Lepidopterans do not molt at all.

Butterflies range in size from the tiny Pygmy Blue of California, which is only about 1 cm (0.4 in.) across, to the Queen Alexandra's Birdwing of New Guinea, which measures about 25 cm (10 in.) from wing tip to wing tip. The largest moths are just as big, but the smallest moths are only a quarter the size of the tiny Pygmy Blue. Lepidopterans are found throughout the world from the arctic to the tropics, on islands, on mountaintops, in deserts, and in cities.