The Science of Plants

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Learning Objectives

- Discuss how and why most life depend on green organisms
- Discuss how plants and other organisms differ from non-living things
- Summarize the key features of plants
- Distinguish among the three domains and six major groups and give representative organisms from each group
- Discuss how the six groups fit into the new classification of supergroups
- Define the term *botany* and briefly describe at least five botanical disciplines
- Explain the scientific process and outline the steps of the scientific method
- Distinguish between inductive and deductive reasoning

Key Terms

metabolic process
photosynthesis
autotrophs
heterotrophs
cellular respiration
domestication
cells
deoxyribonucleic acid (DNA)
unicellular
multicellular
macromolecules
atoms
tissues
organs
organism
population
community
ecosystem
biomes
biosphere
photoautotrophs
chemoautotrophs
determinate growth
indeterminate growth
differentiation
development
sexual reproduction
asexual reproduction
pneumatophores
systematics
taxonomy
prokaryotes
eukaryotes
embroyophytes
nonvascular plants
vascular seedless plants
vascular seed plants
gymnosperms
angiosperms
discovery-based science
hypothesis testing
independent variable
dependent variable
control group
experimental group
inductive reasoning
deductive reasoning

Congratulations! You are about to embark on a fantastic journey to explore and study the most important organisms on planet Earth, plants. We are totally dependent on plants for survival. Next time when you go to a grocery store or supermarket, take a good look around and you will be amazed at how important plants are to us. All the vegetables and fruits we enjoy are from plants (Figure 1.1). Plants provide food for livestock, poultry, and fish, which in turn provide us with essential sources of protein. Look inside your refrigerator and you will notice without plants we will not have eggs or dairy products such as cheese, butter, yogurt, ice cream, and milk. All the spices and herbs used for cooking are from plant parts and seeds. The beverages you enjoy such as coffee, tea, juice, Coca-Cola, and many others are from plants (Figure 1.2). The chocolate candies and hot cocoa you crave are from plants. Plants also provide us with shelter and clothing. Your home and furniture are mostly made of wood (Figure 1.3). Look inside your closets and you will realize most of your clothing is made of plant fibers. Even your textbooks are made of plant pulp.

Plants are not only the most important group of organisms on planet Earth but also the most diverse and fascinating. Why are plants so important? What are plants? How do they differ from other organisms? What is plant science? In this chapter, we begin our journey by taking a closer look at plants and the science of plants.

metabolic process Series of chemical reactions carried out by living organisms to build or break down organic molecules and to store or release energy to power life.

photosynthesis Complex metabolic process that green organisms use to capture solar energy and convert it into chemical energy of organic molecules such as glucose or food.

autotrophs Organisms that are able to make their own food using photosynthesis.

THE IMPORTANCE OF PLANTS

Plants are the most important green organisms on Earth! They provide food not only for humans but for all other organisms. Green organisms like plants are the only organisms capable of using solar energy to power life. Green organisms carry out a complex **metabolic process** called **photosynthesis** to capture solar energy and store it in organic molecules we call food. Green organisms are referred to as producers or **autotrophs** because they make their own food and do not rely on other organisms to survive. Consumers or **heterotrophs** like us, on the other hand, need to acquire organic molecules and energy from other

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Figure 1.1 Plants provide us with fruits, vegetables, spices, and herbs.

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Figure 1.2 Plants provide beverages such as tea, coffee, juice, and more.

organisms to survive. To release energy stored in food, all organisms carry out **cellular respiration**. Photosynthesis and cellular respiration are the two essential processes that power life and we will take a closer look at them in Chapter 9.

Plants not only produce food but also generate oxygen, which is important to aerobic or oxygen-requiring organisms like us. Plants also prevent carbon dioxide from accumulating in the air by using it to make organic molecules. Excess carbon dioxide in the lower atmosphere traps thermal radiation from the earth's surface. This "greenhouse effect" is responsible for global warming and significant climate changes (see Box 9.1). Excess carbon dioxide also negatively affects the ocean and marine organisms. Carbon dioxide is readily absorbed by the ocean, which acts as a reservoir for carbon. But excess carbon dioxide may

heterotrophs
Organisms that cannot produce their own food but have to depend on other organisms for food.

(a)

(b)

(c)

(d)

(e)

Figure 1.3 Plants provide building materials, cotton, paper, and pulp, and medicines such as taxol.

cellular respiration Complex metabolic process that all organisms use to break down organic molecules and release the stored energy to sustain life.

domestication Selection of particular plant characteristics for cultivation that eventually leads to morphological and physiological changes in a crop plant.

BOX 1.1 Plant Domestication and Its Impacts

Plant domestication altered the course of human history by shifting the once hunter-gatherer societies into agricultural ones. Hunter-gatherer societies relied exclusively on gathering wild plants and hunting wild animals for food. Human societies in different parts of the world began plant domestication and food production between 13,000 and 5,000 years ago (Ross-Ibarra, Morrell, & Gaut, 2007). This transition in human history is often referred to as the "Neolithic Revolution" or "Origins of Agriculture." Plant domestication led to food production economies that stimulated the rise of cities and modern civilization. Surprisingly, humans rely on a very small number of crop plants for food. As much as 70% of the calories consumed by humans are from only 15 crops. Five crops (rice, wheat, maize, sugarcane, and barley), in particular, contribute more than 50% of the calories consumed.

Over time, humans began to select particular plant characteristics for cultivation, which eventually led to morphological and physiological changes in these crop plants. As a result, domesticated species became very different from their wild ancestor and relatives. This process of change or selection is often referred to as **domestication**. For example, domestication of cereals such as wheat, rice, maize, and barley led to more and larger fruits or grains (Figure Box 1.1), thicker stalks, and seeds easily separated from the chaff. Instead of dispersing their seeds, domesticated species retain their mature seeds, allowing them to be harvested for food and replanting. As the domestication process continues, crop plants become more dependent on the humans who cultivate them, just as humans become more dependent on these crop plants.

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Figure Box 1.1 Domestication of maize or corn led to more and larger fruits or kernels.

alter the ocean's natural chemistry and ability to absorb and exchange the gas (Caldeira & Wickett, 2005). Green organisms are extremely important because they remove excess carbon dioxide and replenish oxygen in the atmosphere.

Plants are important components of all ecosystems. They provide food and shelter for many organisms. Plants in coastal wetlands help absorb excess water and control floods. Plant roots help stabilize soils and prevent erosion. Most plant roots form partnerships with nitrogen-fixing bacteria, which convert atmospheric nitrogen into usable forms such as nitrates. This unique partnership between plants and nitrogen-fixing bacteria makes nitrogen available for many other organisms. Plants are not only the dominant primary producers on land but also important contributors to the global carbon and nitrogen cycles.

Plants are an important source of energy for human society. Fossil fuels (natural gas, oil, and coal) that supply over 85% of our energy today were mostly produced from dead plants. As an alternative to fossil fuels, biofuels such as ethanol are produced by fermenting carbohydrates from corn and switchgrass. People living in many developing countries still use plant materials as firewood to cook and heat their homes.

Plants provide important pharmaceutical products for managing human health (Levetin & McMahon, 2006). Many active compounds in medicines today were first discovered in plants. Aspirin, for example, is a popular medicine for reducing pain, fever, and inflammation. The active compound salicylic acid was first isolated from the bark of willow (*Salix*) trees and later replaced by a similar compound called *acetylsalicylic acid*. The letter *a* in the word *aspirin* is from acetylsalicylic acid, and *spirin* from *Spirea*, the plant from which salicylic acid was first isolated. Digoxin and digitoxin from the purple foxglove (*Digitalis purpurea*) are important for treatment and management of congestive heart failure. The burn plant *Aloe vera* contains active compounds such as aloin, which are effective in treating burns, minor cuts, skin conditions, and constipation. *Aloe* sap also has a moisturizing effect and is now a common ingredient in lotions, shampoos, and cosmetics. Taxol is an effective anticancer drug that was first extracted from the bark of the Pacific yew (*Taxus brevifolia*) (see Figure 1.3). Taxol slows tumor growth and is an effective treatment for ovarian cancer and breast cancer. Many additional plant compounds are useful for treatment and management of human diseases. We explore how plants are used in foods, commercial products, and pharmaceuticals in Chapter 22.

PLANT DOMESTICATION AND GLOBAL AGRICULTURE

When did plant domestication begin? Where did cultivated plants originate? In 1882, Alphonse de Candolle, a Swiss botanist, published his work "Origin of Cultivated Plants," which marked the beginning of crop geography. By 1940, Nikolai I. Vavilov, a Russian plant geographer, had identified a total of seven primary centers of origin based on areas of greatest diversity (Vavilov, 1992). Since the 1950s, molecular and archaeological data suggest that some crops do not have centers of origin. Jack R. Harlan revised Vavilov's centers of origin to six major regions of plant domestication: Near Eastern, Africa, North America, Central and South America, South Asia and Pacific Islands, and Chinese regions. Currently, 11 different centers of plant domestication or agriculture have been identified throughout these six regions (Smith, 2006) (Figure 1.4).

The oldest center of plant domestication is the Near East region, which includes present-day Iran, Iraq, Turkey, Syria, Lebanon, Jordan, and Israel. Plant domestication began in this region about 13,000 years ago. Wild barley, emmer wheat, and einkorn wheat were the first domesticated plants and the ancestors of our modern barley and bread wheat. The most recent center of plant domestication is in North America, which is now the United States. Sunflower,

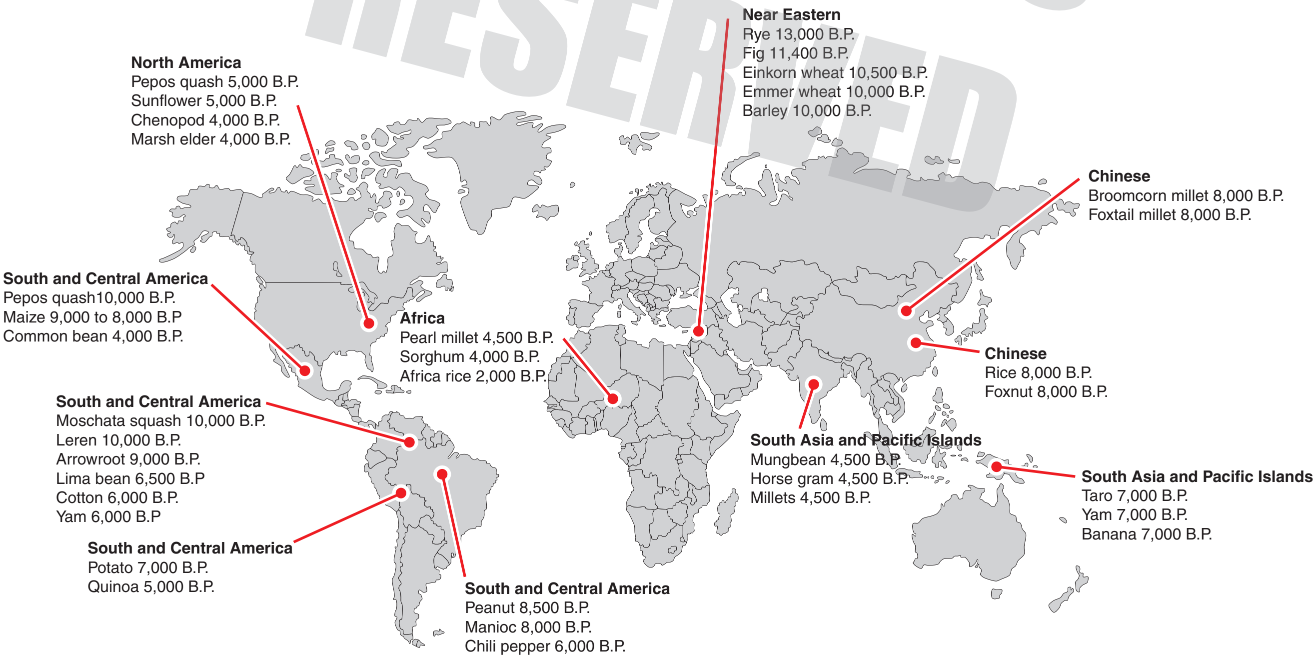

Figure 1.4 Independent centers of plant domestication or agriculture, their first principle crop plants, and estimated times of domestication. B.P., before present, a time scale used in archeology and geology to specify when events occurred in the past. Standard practice uses in 1950 as the origin of the age scale. Adapted from Smith (2006).

pepo squash, marsh elder, and chenopod were domesticated between 5,000 and 4,000 years ago in eastern North America (Smith, 2006). Only sunflower and squash are still being grown here. Although many crops were first cultivated in certain areas of the world, they eventually spread to other areas. For the past 500 years, many crops like wheat, rice, and maize have been cultivated throughout the world in areas where they grow best. For example, rice is now grown in more than 111 countries in the world and also six U.S. states: Arkansas, California, Louisiana, Mississippi, Missouri, and Texas. Arkansas is the top rice producer in the United States and accounts for 40% of rice production in this country (De Datta, 1981). In addition to sunflower and squash, over 100 food crops are now grown in the United States and the market value of these crops sold in 2007 was over $143 billion (U.S. Department of Agriculture, 2007).

The global human population has been increasing at an alarming rate. About 10,000 years ago, the global population was only 5 million; however, it reached 2 billion by 1930. The global population doubled again to 4 billion in 1975. At the start of the 21st century, the global population was about 6 billion (Buhr & Sinclair, 1998). In 2011, it reached 7 billion (Population Reference Bureau, 2011). The need to increase plant production to feed such a rapidly growing population is paramount. Major efforts are being made to improve cultivation practices as well as quality and yield of existing crops. The pressure to increase plant production results in tremendous pressure on the environment. Major environmental concerns associated with increased plant production include loss of biodiversity due to deforestation, loss of crop genetic diversity due to selection, and degradation of land, soil, and fresh water (Buhr & Sinclair, 1998). Efforts are in progress to preserve genetic diversity of crops and their wild relatives by creating seed and clonal banks. With the advances in molecular technology and genetic engineering, crop plants can be genetically modified to enhance their yield and nutritional quality, resistance to insect pests and pathogens, and tolerance to herbicides. We explore plant genetics and its impact on plant breeding in Chapter 13.

CHARACTERISTICS OF LIFE

Plants are very different from animals like us. Plants do not move, run, or swim from one place to another. Most plants do not eat other plants or animals to get their nourishment. Surprisingly, plants and animals are very much alike. They are living organisms and have a number of unique characteristics that distinguish living organisms from nonliving things.

Living Organisms Have Cell(s) and Are Organized

All living organisms are made up of one or more **cells**. Although cells are microscopic and cannot be seen with the naked eye, they are the basic units of life. All life-sustaining processes take place in a cell and it is also where **deoxyribonucleic acid (DNA)**, the genetic blueprint, resides. Some organisms such as bacteria and some algae are single-celled (**unicellular**) whereas organisms such as plants and humans are made up of many cells (**multicellular**). Cells making up a plant body come in a mind-boggling array of sizes, shapes, colors, and functions. We take a closer look at cells and their functions in the next chapter.

Living organisms are highly organized. All cells are made up of smaller components such as cell membrane, ribosomes, DNA, and cytosol, and many have organelles, which are membrane-bound structures. We investigate cellular components that make up plant cells in the following chapter. These cellular components are made up of **macromolecules** or large organic molecules such as

cell Basic unit of life; makes up all living organisms; where all life-sustaining processes take place and where the genetic blueprint, DNA, resides.

deoxyribonucleic acid (DNA) "Blueprint" of life that is responsible for the storage, expression, and transmission of genetic information.

unicellular (*uni-* in Latin means "one") Organisms that are made up of just one cell.

multicellular Organisms that are made up of many cells (*multi* in Latin means "many").

macromolecules Large organic molecules that are made by living organisms; the four major classes are proteins, lipids, carbohydrates, and nucleic acids.

proteins, lipids, carbohydrates, and nucleic acids. These macromolecules, in turn, are made up of smaller units such as amino acids, fatty acids, glycerol, monosaccharides, and nucleotides (see Appendix). These smaller units are made up of **atoms**, which are the smallest functional units of elements. Atoms cannot be broken down further into other substances by ordinary chemical or physical means. In the biological world, atoms form the simplest level of organization (Figure 1.5).

Cells are dynamic environments where molecules are constantly being built or broken down and where energy is being stored or released. These life-sustaining processes help unicellular organisms grow and reproduce. For multicellular organisms like plants, cells come together to form **tissues**, performing tasks individual cells cannot. Epidermis, xylem, and phloem are some examples of plant tissues. We investigate different tissues making up the plant body in the next chapter. When different tissues come together, they form **organs** that carry out complex tasks individual tissues cannot. Roots and leaves are examples of plant organs. We take a closer look at the four major plant organs in Chapters 3–6. When different organs come together, they make up a multicellular **organism** such as a plant (Figure 1.5).

When the same kind of organisms come together and live in the same area, they form a **population** such as a patch of bluebonnets in a field (Figure 1.6a). When populations of different organisms live and interact in the same area, they form a **community** (Figure 1.6b). For example, a forest community consists of not only plants such as trees, shrubs, and vines, but also pollinating insects, the herbivores that feed on them, and the predators that feed on herbivores. When the community is considered together with its physical environment, they form an **ecosystem** such as a forest, grassland, or lake. **Biomes** are defined as major communities classified according to the predominant vegetation and characterized by adaptations of organisms to that particular environment. For example, tundra, desert, grasslands, and rainforest are some of Earth's biomes. When all the ecosystems on planet Earth are considered together, they form the **biosphere**, which is the highest and most complex level of organization in the biological world. We explore biomes and ecosystems further in Chapter 22.

Living Organisms Acquire Energy and Materials

All living organisms require energy and materials to sustain life and they are broadly divided into two main types: autotrophs and heterotrophs. Autotrophs make their own food and do not rely on other organisms to survive. They are further divided into two main types depending on the energy source used for food production. **Photoautotrophs** such as plants and green organisms use solar energy whereas **chemoautotrophs** use chemical energy. Heterotrophs need to feed on other organisms to survive. Some heterotrophs such as animals acquire materials and energy by ingestion while others such as fungi and bacteria do so by absorption. In Chapter 9, we take a closer look at photosynthesis, a process carried out by photoautotrophs to make food, and cellular respiration, a process carried out by all organisms to power life.

Living Organisms Grow and Develop

All living organisms grow, allowing them to increase their size and mass. In unicellular organisms, cell multiplication or division (see the next chapter) increases the number of individuals in a population. In multicellular organisms, cell division and cell enlargement enable the organism to grow in size.

atoms The smallest functional units of elements and the simplest level of biological organization; cannot be broken down further into other substances by ordinary chemical or physical means.

tissues Group(s) of cells coming together to perform specific functions.

organs Group(s) of tissues that come together to perform specific functions.

organism Different organs come together to make up a distinct living entity.

population All individuals of the same species that live and interact in the same area.

community Populations of all organisms that live and interact in the same area.

ecosystem Community and its physical environment in a particular area.

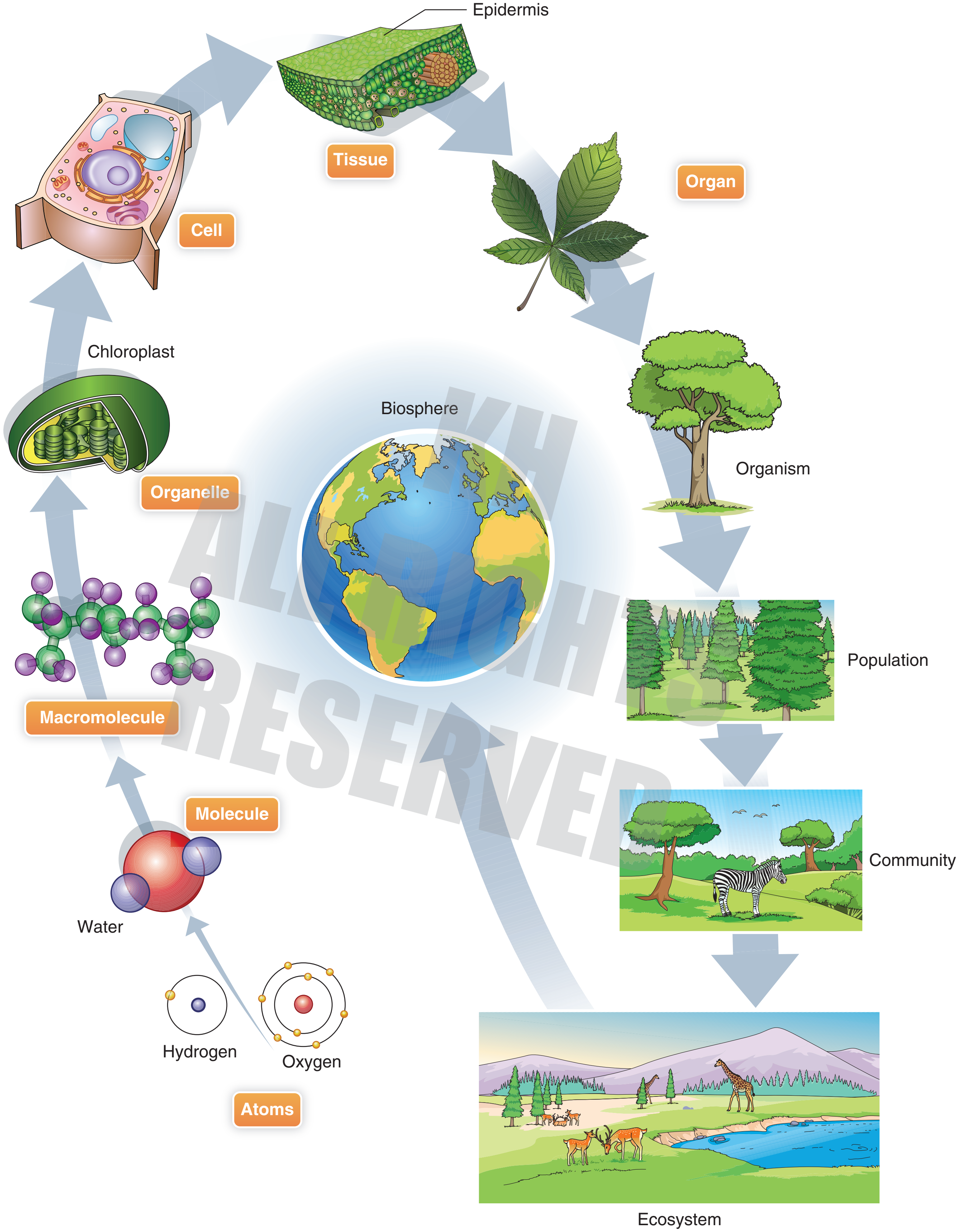

Figure 1.5 Different levels of biological organization—from atoms, the simplest and smallest level, to the biosphere.

(a) (b)

Figure 1.6 A population of bluebonnets and a community of wildflowers and trees.

biome Community of animals, plants, and other organisms living in an environment classified by the type of vegetation and adaptations of organisms to the environment.

biosphere All the ecosystems on Earth; the highest and most complex level of organization in the biological world.

Multicellular organisms such as animals and plants do not have the same type of growth. Animals have **determinate growth** and they stop growing after they reach a certain size. Many plants like trees, on the other hand, have **indeterminate growth**, allowing them to grow throughout their lives. Some plant parts such as fruits, flowers, and leaves, however, have determinate growth.

Multicellular organisms are made up of many cells; cells in different parts of the body are responsible for different tasks. Some cells specialize in storage and others in transportation of water and food. Growth only produces more cells of the same type. **Differentiation** refers to the process when cells take on different shape and form, allowing them to perform different functions. Growth and differentiation are collectively referred to as **development**. In plants, development begins as a fertilized egg, which develops into a multicellular embryo. The embryo (seed) germinates and develops into a seedling with roots, shoots, and leaves (Figure 1.7). The seedling further develops into a mature adult plant.

Living Organisms Reproduce

Reproduction is the most distinctive characteristic of living organisms and enables the genetic blueprint, DNA, to pass from one generation to the next. DNA governs the organization, development, characteristics, and functions of living

(a) (b)

Figure 1.7 Development: unique characteristics of multicellular organisms.

organisms and are examined further in Chapter 13. Some organisms reproduce sexually, which involves gametes or sex cells from two individuals. **Sexual reproduction**, the union of the gametes, produces offspring that are genetically different from their parents. Some organisms reproduce asexually, which does not involve gametes from two individuals. **Asexual reproduction** produces offspring that are genetically identical to their parents. Some organisms such as humans can only reproduce sexually whereas other organisms such as plants can reproduce both sexually and asexually (Figure 1.8). We explore reproduction, a crucial life-continuing process, further in Chapters 6 and 8.

Living Organisms Respond to Stimuli

Living organisms respond to changes in the environment by either moving toward or away from the changes or stimuli. When you touch something hot, your hands quickly move away from the heat. Like animals, plants also respond to stimuli, but their responses may not be as fast or dramatic. For example, when you place a potted plant in front of a window, the leaves will bend toward the light in a few days. Plants often respond to stimuli by changing the direction of growth and growth takes time. However, not all plant responses are slow. Leaves of the sensitive plant, *Mimosa pudica*, fold quickly when touched and unfold themselves when they are left alone. Leaves of the Venus flytrap, *Dionaea muscipula*, resemble tiny foothold or bear traps. When an insect lands on a leaf and brushes against its trigger hairs, the leaf quickly slams shut and traps the insect inside (Figure 1.9). The leaf will then secrete enzymes and digest the insect. Sensitive plants and Venus flytraps manipulate water pressure in their cells to bring about rapid leaf movement.

Living Organisms Adapt to Their Environment

Living organisms change or adapt to their environment in order to survive. They may change in structure, form, and function in response to predation, herbivory (the act of eating a plant or plant-like organism), or availability of oxygen, light, and water. Prickly pear cacti in the genus *Opuntia* are examples of plants adapted to survive in desert environments. Their thick stems are modified for water storage and their leaves are modified into spines to reduce water loss and

photoautotrophs
Autotrophic organisms that use solar energy for food production; compare with chemoautotrophs.

chemoautotrophs
Autotrophic organisms that use chemical energy for food production; compare with photoautotrophs.

determinate growth
After an organism reaches a certain size, growth stops.

indeterminate growth
Growth continues throughout an organism's life.

differentiation
Process when cells take on different shape and form, allowing them to perform different functions.

(a)

(b)

Figure 1.8 Asexual and sexual reproduction: (A) houseleeks, *Sempervivum*, producing smaller plants by asexual reproduction or vegetation growth; (B) dandelions, *Taraxacum*, producing seeds by sexual reproduction.

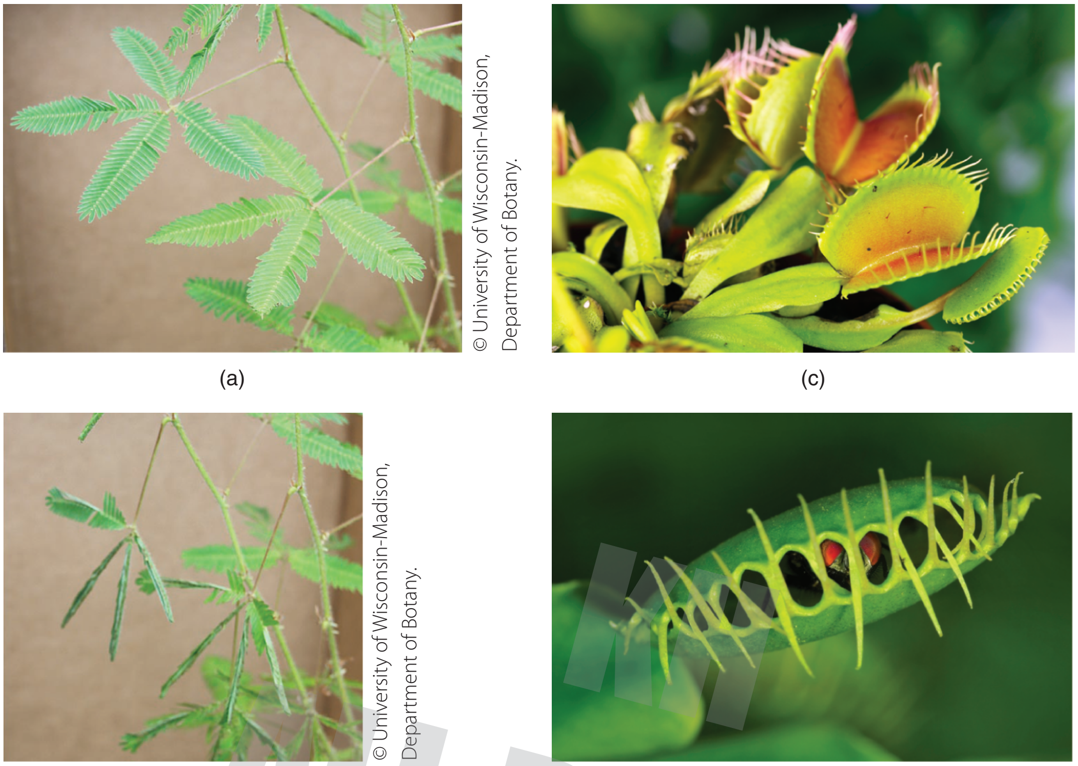

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Figure 1.9 The sensitive plant, *Mimosa pudica*, responding to touch (A and B), and the Venus flytrap, *Dionaea muscipula*, capturing a fly (C and D), are examples of living organisms responding to stimuli.

development
Includes both growth and differentiation.

deter herbivory (Figure 1.10A). Mangrove trees produce specialized roots called **pneumatophores**, which grow out of the soil in order for the plants to breathe (Figure 1.10B). Pneumatophores allow mangrove trees to thrive in swampy environments where their roots are submerged. Pitcher plants in the genus *Sarracenia* produce pitcher-shaped leaves with fluid at the bottom to trap and digest insects (Figure 1.10C). Insect-trapping leaves allow plants such as pitcher plants, Venus flytraps, and sundews to acquire nitrogen from insects, which enables them to grow in nitrogen-deficient bogs and swampy areas. Changes in the characteristics

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Figure 1.10 Various plant adaptations: (A) modified stem and leaves of the prickly pear cactus, (B) pneumatophores of mangroves, and (C) modified leaves of pitcher plants for trapping insects.

of organisms from one generation to the next will allow organisms to be more successful at survival and reproduction. This process of change is often referred to as evolution. We examine the theory of evolution closely in Chapter 12.

DIVERSITY OF LIFE

All living organisms display the six characteristics discussed earlier, but they vary greatly in their shape, size, form, and energy acquisition. Some are unicellular whereas others are multicellular. Some are autotrophs whereas others are heterotrophs. Scientists have been trying to develop a system to organize living organisms and elucidate their evolutionary relationships.

Classification of Living Organisms

For a long time, living organisms were organized or classified into groups based on similarities in their morphological characteristics. With recent advances in molecular technology, we are now capable of comparing and analyzing DNA and even RNA (ribonucleic acid) sequences among organisms. In addition to morphological data, molecular data are being used to classify organisms and examine their evolutionary relationships. **Systematics** refers to the study of biological diversity and evolutionary relationships among organisms. **Taxonomy** is an aspect of systematics that focuses on the description, naming, and grouping of organisms. There are at least 10 schools of taxonomy and each school advocates its own classification concept and scheme (for review, see Christoffersen, 1995). Classification schemes are also influenced by the characteristics (morphological, molecular, or both) used to group organisms.

Ever-Changing Classification

Traditional or Linnaean classification organizes organisms into progressively smaller taxa or ranks. The system begins with the broadest and most inclusive taxon of kingdom and narrows to phylum, class, order, family, genus, and specific epithet or species. Species is the narrowest and most exclusive group, representing only a single group of organism. The taxon of domain was created in the late 1970s to include various kingdoms. Domain is now the broadest and most inclusive taxon. Some systematists (scientists who study systematics) even advocate replacing the Linnaean system with phylogenetic taxonomy, which classifies organisms into clades. We study systematics and taxonomy in greater depth in Chapter 14.

The Three Domains

The three domains of living organisms are Bacteria, Archaea, and Eukarya. Members in the domain Bacteria and Archaea are all unicellular **prokaryotes** (organisms without a nucleus in their cells). Members in the domain Eukarya, on the other hand, are all **eukaryotes** (organisms with a nucleus in their cells) and many of them are multicellular. In the past, the domain Eukarya consisted of four kingdoms: Protista, Plantae, Animalia, and Fungi. Recent phylogenetic analyses reveal that protists do not share a common ancestor (or form a monophyletic group). Kingdom Protista has now been demolished and its members are now classified within several eukaryotic supergroups. The taxon of supergroup lies between domain and kingdom. Kingdom Plantae is now classified within the supergroup called *Archaeplastida* whereas kingdoms Animalia and Fungi are within the supergroup *Opisthokonta* (Figure 1.11).

sexual reproduction Union of the gametes produced by two individuals produces offspring that are genetically different from their parents.

asexual reproduction Does not involve gametes from two individuals and produces offspring that are genetically different from their parent.

pneumatophores Roots growing above the water level to allow for oxygen uptake.

systematics Study of biological diversity and evolutionary relationships among organisms.

taxonomy Study of describing, naming, and grouping of organisms.

prokaryote Organism that is made up of a prokaryotic cell (cell without a nucleus).

eukaryote Organism that is made up of one or more eukaryotic cells (cells with a nucleus).

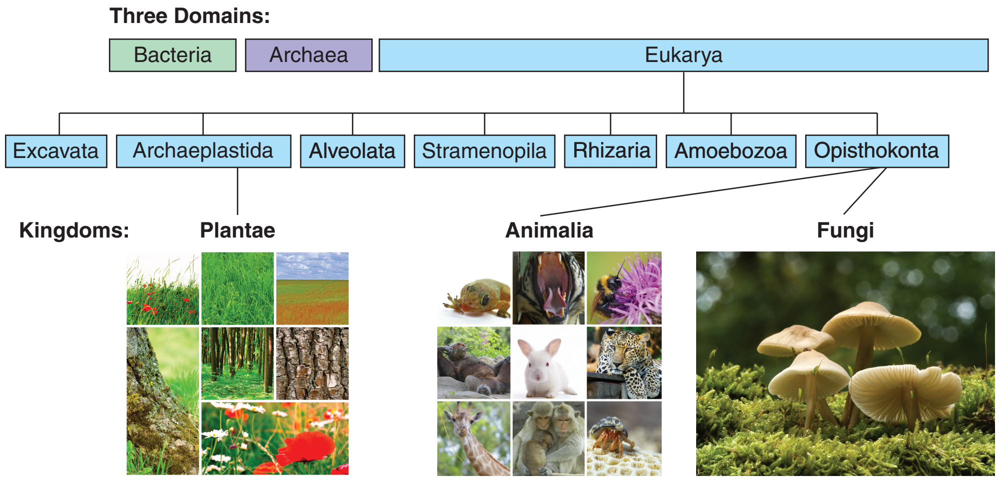

Figure 1.11 The domains, supergroups, and kingdoms of life. Adapted and modified from Brooker, Widmaier, Graham, & Stiling (2011).

Six Major Groups

Living organisms can be broadly divided into six major groups: bacteria, archaea, protists, plants, animals, and fungi. The six groups differ in their cell type, cell number, cell wall component, and energy acquisition (**Table 1.1**). For the rest of the book, we focus our attention on plants, the most important green organisms on planet Earth.

embryophytes or land plants
Autotrophic organisms the embryos of which depend on maternal protection and resources for their development.

Unique Characteristics of Plants

Not all green organisms are classified as plants in kingdom Plantae. Plant taxonomists today only recognize liverworts, hornworts, mosses, club mosses, ferns and their relatives, gymnosperms, and angiosperms as plants. Plants are also referred to as **embroyophytes** because their embryos depend on the

Table 1.1 Key Characteristics of the Six Major Groups of Living Organisms

Group	Domain	Cell Type	Cell Number	Cell Wall Component	Energy Acquisition
Bacteria	Bacteria	Prokaryotic	Unicellular	Peptidoglycan	Mostly heterotrophic, some are autotrophic
Archaea	Archaea			No peptidoglycan	Heterotrophic
Protists	Eukarya	Eukaryotic	Mostly unicellular, some are simple multicellular	Cellulose, silica; some have no cell wall	Autotrophic, heterotrophic
Plants	Eukarya	Eukaryotic	Multicellular	Cellulose	Autotrophic
Animals	Eukarya	Eukaryotic	Multicellular	No cell wall	Heterotrophic
Fungi	Eukarya	Eukaryotic	Mostly multicellular	Chitin	Heterotrophic

female plants for resources and protection. These green organisms share a number of characteristics distinguishing them from other green organisms such as cyanobacteria and green algae. To be classified as plants or embryophytes, the organisms must:

- Be multicellular eukaryotes
- Use chloroplasts to carry out photosynthesis
- Store energy or food as starch
- Have cell walls made up of cellulose
- Have multicellular embryos that develop within female sex organs
- Have a life cycle alternating between haploid and diploid generations

We examine these unique characteristics of plants throughout this book. We also take a look at the two other inhabitants of the green world, cyanobacteria and green algae, in Chapter 15.

Major Plant Groups

Kingdom Plantae consists of more than 300,000 species of living plants, which can be divided into informal groupings: **nonvascular plants** (bryophytes), **vascular seedless plants** (club mosses, ferns, and their relatives), and **vascular seed plants**. Vascular seed plants are subdivided into two major groups: **gymnosperms** (cone-bearing plants) and **angiosperms** (flowering plants). We explore the unique characteristics of these plant groups in Chapters 16–20.

THE SCIENCE OF PLANTS

Simply put, plant science or plant biology is the scientific study of plants. The scope of plant science includes the origin, diversity, structure (cellular, molecular, and organismal levels), physiology, and genetics of plants as well as their interactions with other organisms and their physical environment. Our interest in plants, at first, was mostly practical and focused mainly on enhancing production of food and forage. Eventually, we became curious about what plants were made of and how they developed and reproduced.

Disciplines of Plant Science

Plant Science is divided into various disciplines or specialties:

- **Plant molecular biology**—the study of macromolecules (their structures and functions) and macromolecular mechanisms (gene replication, mutation, and expression) found in plants.
- **Plant biochemistry**—the study of chemical interactions within plants.
- **Plant cell biology**—the study of plant cell structure and function.
- **Plant anatomy**—the study of the internal structure of plants.
- **Plant morphology**—the study of the form and structure of the plant body.
- **Palynology**—the study of plant pollen and spores.
- **Plant physiology**—the study of plant function.
- **Plant genetics**—the study of plant heredity and variation that includes plant breeding and genetic engineering.
- **Plant systematics**—the study of evolutionary relationships among plant groups.

nonvascular plants Group of plants that has no vascular tissues, true roots, true stems, or true leaves; has gametophytes that are dominant and sporophytes that are small and dependent on gametophytes for survival; includes liverworts, hornworts, and mosses.

vascular seedless plants Group of plants that have vascular tissues, true roots and stems; use spores for dispersal; have sporophytes that are dominant and gametophytes that are small but independent from sporophytes; includes club mosses, ferns, and their relatives.

vascular seed plants Group of plants that have vascular tissues, true roots, true stems, and true leaves; use seeds for dispersal; have sporophytes that are dominant and gametophytes that are small and dependent on sporophytes for survival; includes gymnosperms and angiosperms.

- **Plant taxonomy**—the study of describing, naming, and grouping of plants, viewed as one aspect of plant systematics.
- **Plant ecology**—the study of interactions among plants and between plants and their environment.
- **Paleobotany**—the study of fossil plants.
- **Ethnobotany**—the study of the traditional knowledge and customs of a people concerning plants and their medical, religious, and other uses.
- **Economic botany**—the study of relationships between plants and people.
- **Forensic botany**—the use of plant materials to help solve crimes or other legal problems.

In addition to these specialties, many botanists study or specialize in particular types of plants and their production systems.

- **Agronomy**—the science of soil management and crop production.
- **Horticulture**—the science of growing fruits, vegetables, flowers, or ornamental plants.
- **Forestry**—the science of cultivating, managing, and developing forests.
- **Bryology**—the study of bryophytes (mosses, liverworts, and hornworts).
- **Pteridology**—the study of ferns.

Scientific Processes

Scientific study is more than just a collection of facts about plants or the natural world. It is a dynamic process that involves observation, identification, investigation, analysis and interpretation of data, and reevaluation. The goal of scientific study, simply put, is to discover general principles that govern the operation of the natural world. These general principles will then help solve problems or provide new insights. Scientific study can be either discovery based or hypothesis testing. **Discovery-based science** is done without any preconceived hypothesis or expectation. It focuses on collecting and analyzing information that eventually lead to hypothesis testing. **Hypothesis testing** is often done in a series of steps leading to the rejection or acceptance of a hypothesis. The steps of hypothesis testing are often referred to as the scientific method.

The Scientific Method

In general, there are six steps in the scientific method and the goal is to develop and test a hypothesis.

1. **Ask a question**. Scientific study often begins with an observation that either stimulates our desire to know more about what we observed or to find a solution to the observed problem. We come up with a number of questions but eventually identify a single principal question.
2. **Formulate a hypothesis**. We review relevant scientific literature to find possible explanations to the observed phenomenon or solutions to the observed problem. Based on information we gathered from the literature, we formulate a number of hypotheses. Each **hypothesis** is basically an educated guess or a plausible solution to explain the problem. A specific prediction made by the hypothesis is then tested and possibly invalidated.

gymnosperms Group of vascular seed plants that produce seeds and their seeds are not enclosed within a fruit (*gymnos* in Greek means "naked" and *sperma* means "seed"); includes cycads, ginkgo, gnetophytes, and conifers.

angiosperms Group of vascular seed plants that produce seeds and their seeds are enclosed within a fruit, which is a mature or ripened ovary. *Angeion* in Greek means "vessel" and *sperma* means "seed."

discovery-based science Collection and analysis of data without any preconceived hypothesis or expectation; generally leads to hypothesis testing.

hypothesis testing See *scientific methods*.

3. **Test with an experiment**. An experiment is designed and carried out to test the validity of the hypothesis. The goal of a carefully designed experiment is to gather information or data and evaluate if the results support or refute the predicted outcome. A good experiment must have the following components:
   a. **Independent variable** and **dependent variable.** An **independent variable** is the one variable, condition, or factor being manipulated and tested. All other variables, conditions, or factors are kept the same. The response to the independent variable being measured is called a **dependent variable**.
   b. **Control group** and **experimental group**. The two groups are identical, with one exception. The **experimental group** is exposed to the independent variable or the variable tested while the **control group** is not. When the experimental group responds differently from tahe control, it is most likely due to the independent variable.
4. **Analyze and interpret the results**. When the experiment is complete, the results are evaluated and a conclusion is made. The results either support or refute the predicted outcome from the hypothesis.
5. **Accept or reject the hypothesis**. If the results refute the hypothesis, it has to be modified and retested or rejected completely. If the results support the hypothesis, it simply means we have not found any contradicting evidence to reject the hypothesis. We can never prove whether a hypothesis is true or not because we do not know everything and have not tested all the variables. If new evidence appears later, the hypothesis has to be modified or abandoned.
6. **Communicate the finding(s)**. Scientists publish their findings in scientific journals and books. They also present their findings in conferences and meetings. Sharing new knowledge with the scientific community enriches the scientific literature and also permits other scientists to repeat the experiment or design new experiments to confirm the validity of the hypothesis.

independent variable One variable, condition, or factor being manipulated and tested in an experiment.

dependent variable Response to the independent variable that is being measured.

The scientific method is often described or presented as discrete linear steps. They actually form a cycle (Figure 1.12). At the end of the experiment, you often end up with more questions than before the start of the experiment, which lead to more hypotheses and experiments. Sometimes, the results can be confusing

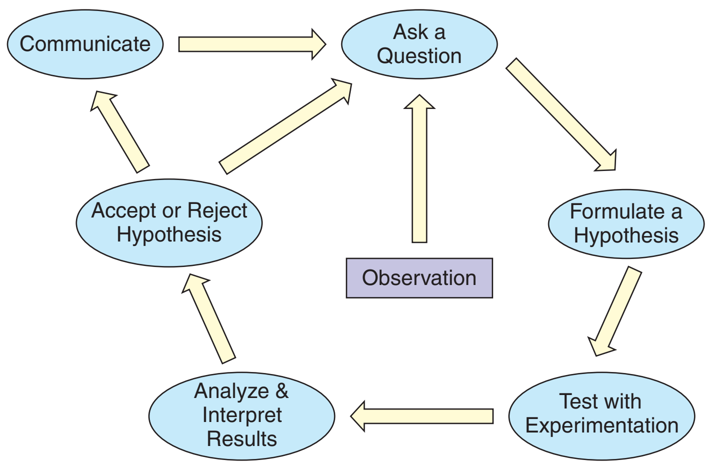

Figure 1.12 The scientific method cycle.

and seemingly contradictory. Scientific study is rarely a neat or straightforward process. However, a general principle or "big picture" emerges when results from different experiments are consistent.

Two Types of Reasoning

inductive reasoning Generates a unifying explanation or general principle after carefully evaluating specific studies; begins with specific studies and ends with a general principle.

Scientists use two types of reasoning or argument to interpret the data: inductive reasoning and deductive reasoning. **Inductive reasoning** is about generating a unifying explanation or general principle after carefully evaluating specific studies. Around 400 B.C., Hippocrates of Cos, a famous Greek physician and the father of modern medicine, used inductive reasoning to develop general theories about diseases (Killeffer, 1973).

An example of inductive reasoning:

Observation #1: My roses are pink.

Observation #2: My neighbor's roses are pink.

Observation #3: My cousin's roses are pink.

Conclusion: All roses are pink.

If you find a white rose, the argument "all roses are pink" needs to be revised. Inductive reasoning generates new knowledge but is prone to error. When contradictory results come to light, the general principle needs to be revised. However, many important theories are generated by inductive reasoning. For example, the cell theory, which we learn in the next chapter, was generated after cells were repeatedly observed in plants, animals, and microbes.

deductive reasoning Makes a specific prediction from a general principle and then tests it; begins with a general principle and ends with specific studies.

Deductive reasoning, on the contrary, makes a specific prediction from a general principle and then tests it.

An example of deductive reasoning:

General principle: All plants have waxy cuticles on their surfaces.

Observation: Cotton is a plant.

Conclusion: Cotton has a waxy cuticle on its surfaces.

Deductive reasoning begins with a general principle and ends with specific studies whereas inductive reasoning begins with specific studies and ends with a general principle. Deductive reasoning does not generate new knowledge but provides additional data to validate a general principle.

SUMMARY

- Plants are important to all organisms because they provide food, oxygen, and shelter. Plants also remove excess carbon dioxide from the air. In addition, plants are an important source of energy and medicine for humans.
- Organisms are divided into two main groups: autotrophs and heterotrophs.
- Photosynthesis and cellular respiration are two essential processes that power life.
- All living organisms display six characteristics distinguishing them from nonliving things. All living organisms:
  - Have cell(s) and distinct levels of organization
  - Acquire energy and materials
  - Grow and develop

  - Reproduce
  - Respond to stimuli
  - Adapt to their environments
- Systematics is the study of biological diversity and evolutionary relationships among organisms while taxonomy is the study of describing, naming, and grouping of organisms.
- Organisms are often organized into progressively smaller taxa or ranks. The system begins with the broadest and most inclusive taxon of domain and narrows to kingdom, phylum, class, order, family, genus, and species.
- Organisms are grouped into three domains: Bacteria, Archaea, and Eukarya.
- Based on differences in their cell type, cell number, cell wall component, and energy acquisition, organisms can be classified into six groups: bacteria, archaea, protists, plants, animals, and fungi.
- Plants or embryophytes are distinct from other organisms. To be classified as plants, the organisms must:
  - Be multicellular eukaryotes
  - Use chloroplasts to carry out photosynthesis
  - Store energy or food as starch
  - Have cell walls made up of cellulose
  - Have multicellular embryos developing within female sex organs
  - Have a life cycle alternating between haploid and diploid generations
- Plants are divided into informal groupings: nonvascular plants, vascular seedless plants, and vascular seed plants. Vascular seed plants are subdivided into two major groups: gymnosperms and angiosperms.
- Plant science or plant biology is the scientific study of plants. The scope of plant science includes the origin, diversity, structure (cellular, molecular, and organismal levels), physiology, and genetics of plants as well as their interactions with other organisms and their physical environment. These aspects are covered in different disciplines or specialties.
- Scientific study can be either discovery based or hypothesis testing and involves observation, identification, investigation, analysis and interpretation of data, and reevaluation. The goal of scientific study is to discover general principles that govern the operation of the natural world.
- The cycle of scientific method begins with:
  - Ask a question
  - Formulate a hypothesis
  - Test with an experiment
  - Analyze and interpret the results
  - Accept or reject the hypothesis
  - Communicate the finding(s)
- Inductive reasoning and deductive reasoning are used by scientists to interpret data.

REFLECT

1. ***Imagine one day when the sun no longer shines and Earth becomes dark.*** What do you think will happen to all living organisms on earth?
2. ***After watching the movie* i, Robot*, you and your friend debate whether robots will someday evolve into living entities.*** Discuss the characteristics advanced robots must have to be classified as living organisms.

3. ***You encounter a weird-looking organism on your way to class. You ask, "What type of organism is this?"*** Recall the characteristics you use to determine whether an organism is a bacterium, protist, plant, animal, or fungus.
4. ***What are plants?*** Describe the characteristics all plants have.
5. ***Convince me with numbers!*** You are the production manager of a major greenhouse corporation and believe you can produce good-quality bell peppers using less fertilizer. You decide to run some experiments and show corporate headquarters your numbers. Using the scientific method, design an experiment that will show the effect of fertilizer on bell pepper production.

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