Earth, a planet teeming with life, is seen here in a satellite photograph.

Bryan Allen/Corbis

Study Plan

1 Introduction to Biological Concepts and Research

Why It Matters

Life abounds in almost every nook and cranny on Earth. A lion creeps through the brush of an African plain, ready to spring at a zebra. The leaves of a sunflower in Kansas turn slowly through the day, keeping their surfaces fully exposed to the sun's light. Fungi and bacteria in the soil of a Canadian forest obtain nutrients from decomposing organisms. A child plays in a park in Madrid, laughing happily as his dog chases a tennis ball. In one room of a nearby hospital, a mother hears the first cry of her newborn baby; in another room, an elderly man sighs away his last breath. All over the world, countless organisms are born, live, and die every second of every day. How did life originate, how does it persist, and how is it changing? Biology, the science of life, provides scientific answers to these questions.

What *is* life? Offhandedly, you might say that although you cannot define it, you know it when you see it. The question has no simple answer, because the story of life has been unfolding for billions of years, ever since ancient events assembled nonliving materials into the first organized, living cells. Clearly, any list of criteria for the living state only hints at the meaning of "life." Deeper insight requires a wide-ranging examination of the characteristics of life, which is what this book is all about.

Over the next semester or two, you will encounter examples of how organisms are constructed, how they function, where they live, and what they do. The examples provide evidence in support of concepts that will greatly enhance your appreciation and understanding of the living world, including its fundamental unity and striking diversity. This chapter provides a brief overview of these basic concepts. It also describes some of the ways in which biologists conduct research: the process in which they observe nature, formulate explanations of their observations, and test their ideas. It is through research that we further our knowledge of living systems.

1.1 What Is Life? Characteristics of Living Systems

Picture a lizard on a rock, slowly shifting its head to follow the movements of another lizard nearby **(Figure 1.1).** You know that the lizard is alive and that the rock is not. If you examine both at the atomic and molecular levels, however, you will find that the differences between them blur. Lizards, rocks, and all other things are composed of atoms and molecules, which behave according to the same physical laws. Nevertheless, living systems share a set of characteristics that collectively set them apart from nonliving matter.

Figure 1.1
Living organisms and inanimate objects. All living organisms, such as this lizard *(Iguana iguana)*, have characteristics that are fundamentally different from those of inanimate objects, such as the rock on which it is sitting.

Kevin Schafer

The differences between a lizard and a rock depend not only on the kinds of atoms and molecules present but also on their organization and their interactions. Individual organisms are at the middle of a hierarchy that ranges from the atoms and molecules within their bodies to the assemblages of organisms that occupy Earth's environments. Within every individual, certain biological molecules contain instructions for building other molecules, which, in turn, are assembled into complex structures. Living organisms must gather energy and materials from their surroundings to build new biological molecules, grow in size, maintain and repair their parts, and produce offspring. They must also respond to environmental changes by altering their chemistry and activity in ways that allow them to survive. Finally, the structure and function of living systems often change from one generation to the next.

Living Systems Are Organized in a Hierarchy, with Each Level of Organization Having Its Own Emergent Properties

The organization of life extends through several levels of a hierarchy **(Figure 1.2).** Complex biological molecules exist at the lowest level of organization, but by themselves, these molecules are not alive. The properties of life do not appear until they are organized into cells. A **cell** consists of an organized chemical system, including many specialized molecules, surrounded by a membrane. A cell is the lowest level of biological organization that can survive and reproduce—as long as it has access to a usable energy source, the necessary raw materials, and appropriate environmental conditions. However, a cell is alive only as long as it is organized as a cell; if broken into its component parts, a cell is no longer alive even if the parts themselves are unchanged. Characteristics that depend on the level of organization of matter, but do not exist at lower levels of organization, are called **emergent properties.** Life is thus an emergent property of the organization of matter into cells.

Many single cells, such as bacteria and protozoans, exist as **unicellular organisms.** By contrast, plants and animals are **multicellular organisms.** Their cells live in tightly coordinated groups and are so interdependent that they cannot survive on their own. For example, human cells cannot live by themselves in nature because they must be bathed in body fluids and supported by the activities of other cells. Like individual cells, multicellular organisms have emergent properties that their individual components lack; for example, humans can learn biology.

The next, more inclusive level of organization is the **population,** a group of unicellular or multicellular organisms of the same kind that live together in the same place. The humans who occupy the island of Tahiti, a colony of penguins in Antarctica, or a group of bacteria in a laboratory flask are examples of populations. Like multicellular organisms, populations have emergent properties that do not exist at lower levels of organization. For example, a population has characteristics such as its birth or death rate—that is, the number of individuals who are born or die over a period of time—that do not exist for single cells or individual organisms.

Working our way up the biological hierarchy, all the populations of different organisms that live in the same place form a **community.** The bacteria, penguins, fishes, seals, whales, and other organisms that

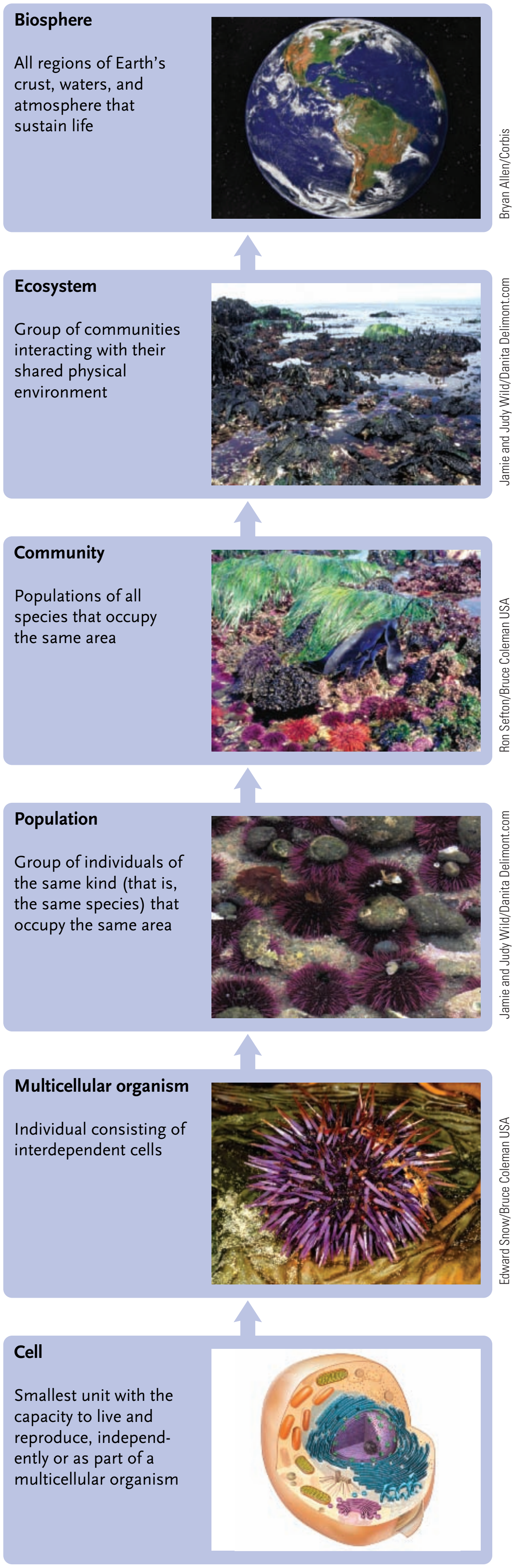


Figure 1.2
The hierarchy of life. Each level in the hierarchy of life exhibits emergent properties that do not exist at lower levels. The middle four photos depict a rocky intertidal zone on the coast of Washington State.

live along the coast of Antarctica, taken together, make up a community. The next highest level, the **ecosystem**, includes the community *and* the nonliving environmental factors with which it interacts. For example, a forest ecosystem comprises a community of living organisms, as well as soil, air, water, minerals, and the input of the energy in sunlight. The highest level, the **biosphere**, encompasses all the ecosystems of Earth's waters, crust, and atmosphere. Communities, ecosystems, and the biosphere also have emergent properties. For example, communities can be described in terms of their *diversity*—the number and types of different populations they contain—and their *stability*—the degree to which the populations within the community remain the same through time.

Living Systems Contain Chemical Instructions That Govern Their Structure and Function

The most fundamental and important molecule that distinguishes living systems from nonliving matter is **deoxyribonucleic acid (DNA; Figure 1.3).** DNA is a large, double-stranded, helical molecule that contains instructions for assembling a living organism from simpler molecules. The organisms that we recognize as bacteria, trees, fishes, or humans include some striking differences in their DNA. Thus, molecular building blocks are arranged differently in each of these organisms, producing differences in their appearance and function. (Some nonliving systems, notably certain viruses [see Chapter 25 for a discussion of viruses], also contain DNA, but biologists do not consider viruses to be alive because they cannot reproduce independently of the organisms they infect.)

DNA functions similarly in all living organisms. The information in DNA is copied into molecules of a related substance, **ribonucleic acid (RNA),** which then directs the production of different protein molecules **(Figure 1.4). Proteins** carry out most of the activities of life, including the synthesis of all other biologi-

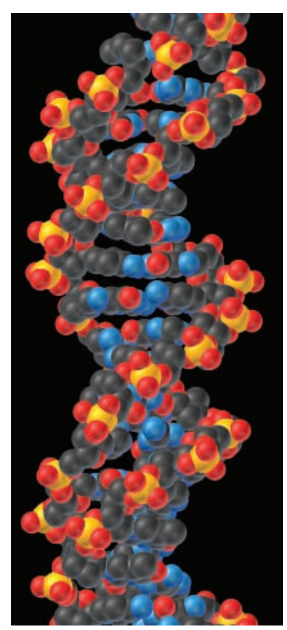


Figure 1.3
Deoxyribonucleic acid (DNA). A computer-generated model of DNA illustrates that it is made up of two strands twisted into a double helix.

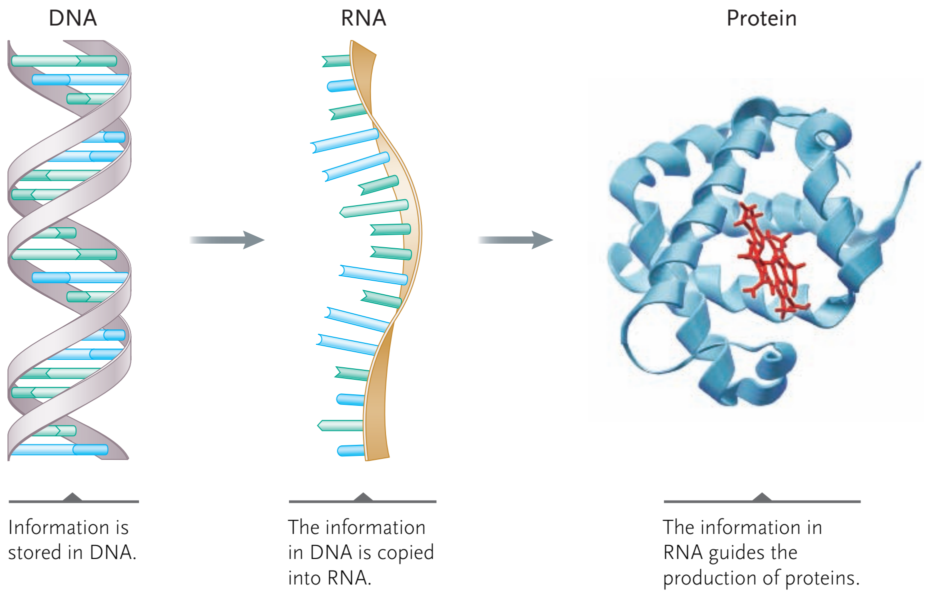


Figure 1.4
The pathway of information flow in living organisms. Information stored in DNA is copied into RNA, which then directs the construction of protein molecules. The protein shown here is one of four subunits of hemoglobin, an oxygen-carrying protein found inside red blood cells.
(PDB ID: 1BBB; Silva, M. M., Rogers, P. H., Amone, A. A third quaternary structure of hemoglobin A at 1.7-Å resolution, *J Biol Chem*, 267, p. 17248, 1992.)

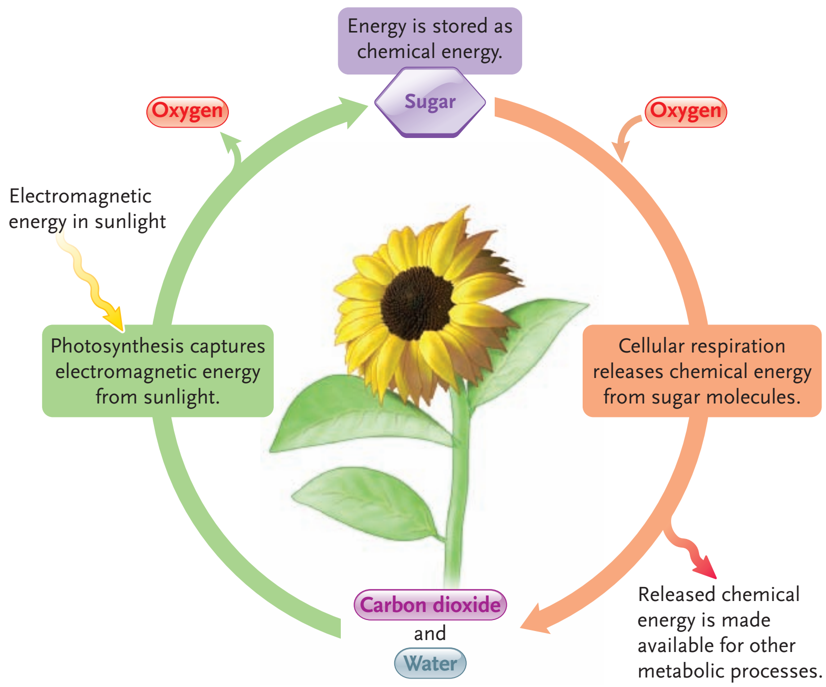


Figure 1.5
Metabolic activities. Photosynthesis uses the energy in sunlight to build sugar molecules from carbon dioxide and water, releasing oxygen as a by-product of the reaction. The process converts the electromagnetic energy in sunlight into chemical energy, which is stored in sugars and starches. Cellular respiration uses oxygen to break down sugar molecules, releasing their chemical energy and making it available for other metabolic processes.

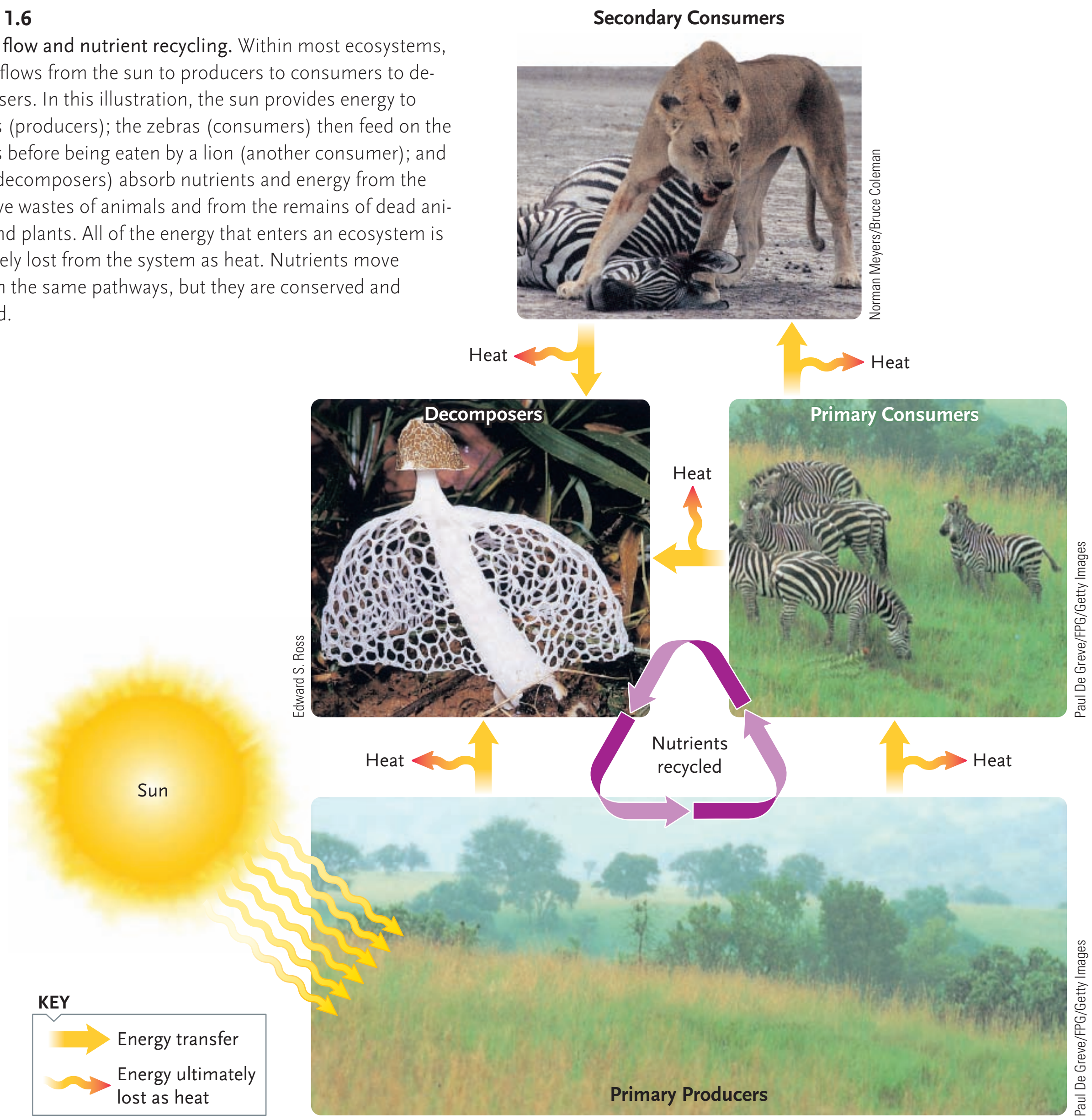
cal molecules. This information pathway is preserved from generation to generation by the ability of DNA to direct its own replication so that offspring receive the same basic molecular instructions as their parents.

Living Organisms Engage in Metabolic Activities

Metabolism is a key property of living cells and organisms. **Metabolism** describes the ability of a cell or organism to extract energy from its surroundings and use that energy to maintain itself, grow, and reproduce. As a part of metabolism, cells carry out chemical reactions that assemble, alter, and disassemble molecules **(Figure 1.5).** For example, a growing sunflower plant carries out **photosynthesis,** in which the electromagnetic energy in sunlight is absorbed and converted into chemical energy. The cells of the plant store some chemical energy in sugars and starches, and they use the rest to manufacture other biological molecules from simple raw materials obtained from the environment.

Sunflowers concentrate some of their energy reserves in seeds from which more sunflower plants may grow. The chemical energy stored in the seeds also supports other organisms, such as insects, birds, and humans, that eat them. Most organisms, including sunflower plants, tap stored chemical energy through another metabolic process, **cellular respiration,** in which complex biological molecules are broken down with oxygen, releasing some of their energy content for cellular activities.

Figure 1.6
Energy flow and nutrient recycling. Within most ecosystems, energy flows from the sun to producers to consumers to decomposers. In this illustration, the sun provides energy to grasses (producers); the zebras (consumers) then feed on the grasses before being eaten by a lion (another consumer); and fungi (decomposers) absorb nutrients and energy from the digestive wastes of animals and from the remains of dead animals and plants. All of the energy that enters an ecosystem is ultimately lost from the system as heat. Nutrients move through the same pathways, but they are conserved and recycled.



Energy Flows and Matter Cycles through Living Systems

With few exceptions, energy from sunlight supports life on Earth. Plants and other photosynthetic organisms absorb energy from sunlight and convert it into chemical energy, which they use to assemble complex molecules, such as sugars, from simple raw materials, such as water and carbon dioxide. As such, photosynthetic organisms are the **primary producers** of the food on which all other organisms rely. By contrast, animals are **consumers:** directly or indirectly, they feed on the complex molecules manufactured by plants **(Figure 1.6).** For example, zebras tap directly into the molecules of plants when they eat grass, and lions tap into it indirectly when they eat zebras. Certain bacteria and fungi are **decomposers:** they feed on the remains of dead organisms, breaking down complex biological molecules into simpler raw materials, which may then be recycled by the producers.

Some of the energy that photosynthetic organisms trap from sunlight *flows* within and between populations, communities, and ecosystems. But because the biological processes that transfer energy from one organism to another are not 100% efficient, some of the energy is lost as heat. Although heat energy can be used by some animals to maintain body temperature, it cannot sustain other life processes. By contrast, matter—nutrients such as carbon and nitrogen—*cycles* between living organisms and the nonliving components of the biosphere, to be used again and again (see Figure 1.6).

Living Organisms Compensate for Changes in the External Environment

All objects, whether living or nonliving, respond to changes in the environment; for example, a rock warms up on a sunny day and cools at night. But only living systems have the capacity to detect environmental changes and *compensate* for them through controlled responses. They do so by means of diverse and varied *receptors*—molecules or larger structures, located on individual cells and body surfaces, that are able to detect changes in external and internal conditions. When stimulated, the receptors trigger reactions that produce a compensating response.

For example, your internal body temperature remains reasonably constant, even though the environment in which you live is usually either cooler or warmer than you are. Your body compensates for these environmental variations and maintains its internal temperature at about 37° Celsius (C). When environmental temperatures decrease significantly, receptors in your skin detect the temperature change and transmit that information to your brain. Your brain may send a signal to your muscles, causing you to shiver; the muscular activity of shivering releases heat that keeps your body temperature from dropping below its optimal level. When environmental temperatures increase significantly, glands in your skin secrete sweat, which evaporates, cooling the skin and its underlying blood supply. The cooled blood circulates internally and keeps your body temperature from rising above 37°C. People also compensate behaviorally by dressing warmly on a cold winter day or jumping into a swimming pool in the heat of summer. Maintaining your body's internal temperature within a narrow tolerable range is one example of **homeostasis**—a steady internal condition maintained by responses that compensate for changes in the external environment. All organisms have mechanisms that help maintain homeostasis in relation to temperature, blood chemistry, or other important factors.

Living Organisms Reproduce and Undergo Development

Humans and all other organisms are part of an unbroken chain of life that began billions of years ago. This chain continues today through **reproduction**, the process in which parents produce offspring. Offspring generally resemble their parents because the parents pass copies of their DNA—with all the accompanying instructions for virtually every life process—to their offspring. The transmission of DNA (that is, genetic information) from one generation to the next is called **inheritance.** For example, the eggs produced by storks hatch into little storks, not into pelicans, because they inherited stork DNA, which is different from pelican DNA.

Multicellular organisms also undergo a process of **development**, a series of programmed changes encoded in DNA, through which a fertilized egg divides into many cells that ultimately are transformed into an adult, which is itself capable of reproduction. As an example, consider the development of a moth **(Figure 1.7).** This insect begins its life as a tiny egg that contains all the instructions necessary for its development into an adult moth. Following these instructions, the egg first hatches into a caterpillar, a larval form adapted for feeding and rapid growth. The caterpillar increases in size until internal chemical signals indicate that it is time to spin a cocoon and become a pupa. Inside its cocoon, the pupa undergoes profound developmental changes that remodel its body completely. Some cells die, and others multiply and become organized in different patterns. When these transformations are complete, the adult moth emerges from the cocoon. It is equipped with structures and behaviors, quite different from those of the caterpillar, that enable it to reproduce.

The sequential stages through which individuals develop, grow, maintain themselves, and reproduce are known collectively as the **life cycle** of an organism. The moth's life cycle includes egg, larva, pupa, and adult stages. Adult moths, through reproduction, continue the cycle by producing the sperm and eggs that unite to form the fertilized egg, which starts the next generation.

Figure 1.7
Life cycle of a giant silkworm moth (family Saturniidae).

a. Egg **b.** Larva **c.** Pupa **d.** Recently emerged adult **e.** Adult

Photographs by Jack de Coningh

Populations of Living Organisms Change from One Generation to the Next

Although offspring generally resemble their parents, individuals with unusual characteristics sometimes suddenly appear in a population. Moreover, the features that distinguish these oddballs often are inherited by their offspring. Our awareness of the inheritance of unusual characteristics has had an enormous impact on human history because it allows plant and animal breeders to produce crops and domesticated animals with especially desirable characteristics.

Biologists have observed that similar changes also take place under natural conditions. In other words, populations of all organisms change from one generation to the next, because some individuals experience changes in their DNA and they pass those modified instructions along to their offspring. We consider this fundamental process, **biological evolution,** in the next section.

Study Break

1. List the major levels in the hierarchy of life and identify one emergent property of each level.
2. What do living organisms do with the energy they collect from the external environment?
3. What is a life cycle?

1.2 Biological Evolution

All research in biology—ranging from analyses of the precise structure of biological molecules to energy flow through the biosphere—is undertaken with the knowledge that biological evolution has shaped life on Earth. Our understanding of the evolutionary process reveals several truths about the living world: (1) all populations change through time, (2) all organisms are related through a shared ancestry, and (3) evolution has produced the spectacular diversity of life that we see around us. Evolution is the unifying theme that links all the subfields of the biological sciences.

Darwin and Wallace Explained How Populations of Organisms Change through Time

How do evolutionary changes take place? One important mechanism was first explained in the mid-nineteenth century by two British naturalists, Charles Darwin and Alfred Russel Wallace. On a 5-year voyage around the world, Darwin observed many strange and wondrous organisms. He also found fossils of species that are now extinct (that is, all members of the species are dead). The extinct forms often resembled living species in some traits but differed in others. Originally a believer in special creation—the idea that living organisms were placed on Earth in their present numbers and kinds and have not changed since their creation—Darwin became convinced that organisms do not remain constant with the passage of time, but change from one form into another. Wallace came to the same conclusion through his observations of the great variety of plants and animals in the Amazon basin and the region now called Malaysia.

Darwin also studied the process of evolution through observations and experiments on domesticated animals. Pigeons were among his favorite experimental subjects. Domesticated pigeons exist in a variety of sizes, colors, and shapes **(Figure 1.8).** Darwin noted that pigeon breeders who wished to promote a certain characteristic, such as elaborately curled tail feathers, selected individuals with the most curl in their feathers as parents for the next generation. By permitting only these birds to mate, the breeders fostered the desired characteristic and gradually eliminated or reduced other traits. The same practice is still used today to increase the frequency of desired traits in tomatoes, dogs, and other domesticated plants and animals. Darwin called this practice **artificial selection.** He termed the equivalent process that occurs in nature **natural selection.**

In 1858, Darwin and Wallace formally summarized their observations and conclusions explaining biological evolution. (1) Most organisms can produce

Figure 1.8
Artificial selection. Using artificial selection, pigeon breeders have produced more than 300 varieties of domesticated pigeons from ancestral wild rock doves *(Columba livia)*.

Wild rock dove

Photographs courtesy Derrell Fowler, Tecumseh, Oklahoma numerous offspring, but environmental factors limit the number that actually survive and reproduce. (2) Heritable variations allow some individuals to compete more successfully for space, food, and mates. (3) These successful individuals somehow pass the favorable characteristics to their offspring. (4) As a result, the favorable traits become more common in the next generation, and less successful traits become less common. This process of natural selection results in evolutionary change. Today, evolutionary biologists recognize that natural selection is just one of several potent evolutionary processes.

Over many generations, the evolutionary changes in a population may become extensive enough to produce a new kind of organism. These new types are distinct from their ancestors and cannot interbreed with them. Nevertheless, parental and descendant species often share many characteristics, allowing researchers to understand their relationships and reconstruct their shared evolutionary history. Starting with the first organized cells, this aspect of evolutionary change has contributed to the diversity of life that exists today.

Darwin and Wallace described evolutionary change largely in terms of how natural selection changes the commonness or rarity of particular variations over time. Their intellectual achievement was remarkable for its time. Although Darwin and Wallace understood the central importance of variability among organisms to the process of evolution, they could not explain how new variations arose or how they were passed to the next generation.

Photographs courtesy of Hopi Hoekstra, University of California, San Francisco

Figure 1.9
Camouflage in rock pocket mice *(Chaetodipus intermedius)*. Sandy-colored mice are well camouflaged on pale rocks, and black mice are well camouflaged on dark rocks (top); but mice with fur that does not match their backgrounds (bottom) are easy to see.

Mutations in DNA Are the Raw Materials That Allow Evolutionary Change

Today, we know that both the origin and the inheritance of new variations arise from the structure and variability of DNA, which is organized into functional units called **genes.** Each gene contains the code for (that is, the instructions for building) a protein molecule or one of its parts. Proteins determine all the structural and functional characteristics of an organism.

Variability among individuals—the raw material molded by evolutionary processes—arises ultimately through **mutations,** random changes in the structure, number, or arrangement of DNA molecules. When mutations occur in the DNA of reproductive cells, they may change the instructions for the development of offspring that the reproductive cells produce. Many mutations are of neutral value to individuals bearing them, and some turn out to be harmful. On rare occasions, however, a mutation is beneficial under the prevailing environmental conditions. Beneficial mutations increase the likelihood that individuals carrying the mutation will survive and reproduce. Thus, through the persistence and spread of beneficial mutations among individuals and their descendants, the genetic makeup of a population will change from one generation to the next.

Adaptations Enable Organisms to Survive and Reproduce in the Environments Where They Live

Favorable mutations may produce **adaptations,** characteristics that help an organism survive longer or reproduce more under a particular set of environmental conditions. To convey the sense of how organisms benefit from adaptations, consider an example from the recent literature on *cryptic coloration* (camouflage) in animals. Many animals have skin, scales, feathers, or fur that matches the color and appearance of the background in their environment, enabling them to blend into their surroundings. Camouflage makes it harder for predators to identify and then catch them—an obvious advantage to survival. Animals that are not camouflaged are often just sitting ducks.

The rock pocket mouse *(Chaetodipus intermedius)*, which lives in the deserts of the southwestern United States, is mostly nocturnal (that is, active at night). At most desert localities, the rocks are pale brown, and rock pocket mice have sandy-colored fur on their backs. However, at several sites, the rocks—remnants of lava flows from now-extinct volcanoes—are black. At these localities, rock pocket mice have black fur on their backs. Thus, like the sandy-colored mice in other areas, they, too, are camouflaged in their habitats **(Figure 1.9).** Camouflage appears to be important to these mice because owls, which locate prey using their exceptionally keen eyesight, frequently eat nocturnal desert mice.

Examples of cryptic coloration are well documented in the scientific literature, and biologists generally interpret them as adaptations that reduce the likelihood of being captured by a predator. Nevertheless, few researchers have been able to identify precisely the genetic mutations that produced these adaptations. Michael W. Nachman, Hopi E. Hoekstra, and their colleagues at the University of Arizona tackled this problem in a study of the genetic and evolutionary basis for the color difference between rock pocket mice that live on light and dark backgrounds. In an article published in 2003, they reported the results of an analysis of mice sampled at six sites in southern Arizona and New Mexico. In two regions (Pinacate, AZ, and Armendaris, NM), both light and dark rocks were present, allowing the researchers to compare mice that lived on differently colored backgrounds. Two other sites had only light rocks and sandy-colored mice.

Nachman and his colleagues found that nearly all of the mice they captured on dark rocks had dark fur and that nearly all of the mice they captured on light rocks had light fur **(Figure 1.10).** The researchers then studied the structure of *Mc1r,* a gene known to influence fur color in laboratory mice. The 17 black mice from Pinacate all shared certain mutations in their *Mc1r* gene, which established four specific changes in the structure of the Mc1r protein. However, none of the 12 sandy-colored mice from Pinacate carried these mutations. The exact match between the presence of the mutations and the color of the mouse strongly suggests that these mutations in the *Mc1r* gene are responsible for the dark fur in the mice from Pinacate. Thus, data on the distributions of light and dark mice coupled with analyses of their DNA suggest that the color difference is the product of specific mutations that were favored by natural selection.

Nachman's team then analyzed the *Mc1r* gene in the dark and light mice from Armendaris and in the light mice at two intermediate sites. Because the mice in these regions also closely matched the color of their environments, the researchers expected to find the *Mc1r* mutations in the dark mice but not in the light mice. However, none of the mice from Armendaris shared any of the mutations that contributed to the dark color of mice from Pinacate. Apparently, mutations in some other gene or genes, which the researchers have not yet identified, are responsible for the camouflaging black coloration of mice that live on black rocks in Armendaris.

The example of an adaptation provided by the rock pocket mice illustrates the observation that genetic differences often develop between populations. Sometimes these differences become so great that the organisms develop different appearances and adopt different ways of life, and biologists regard them as distinct types. Over immense spans of time, evolutionary processes have produced many types of organisms, which

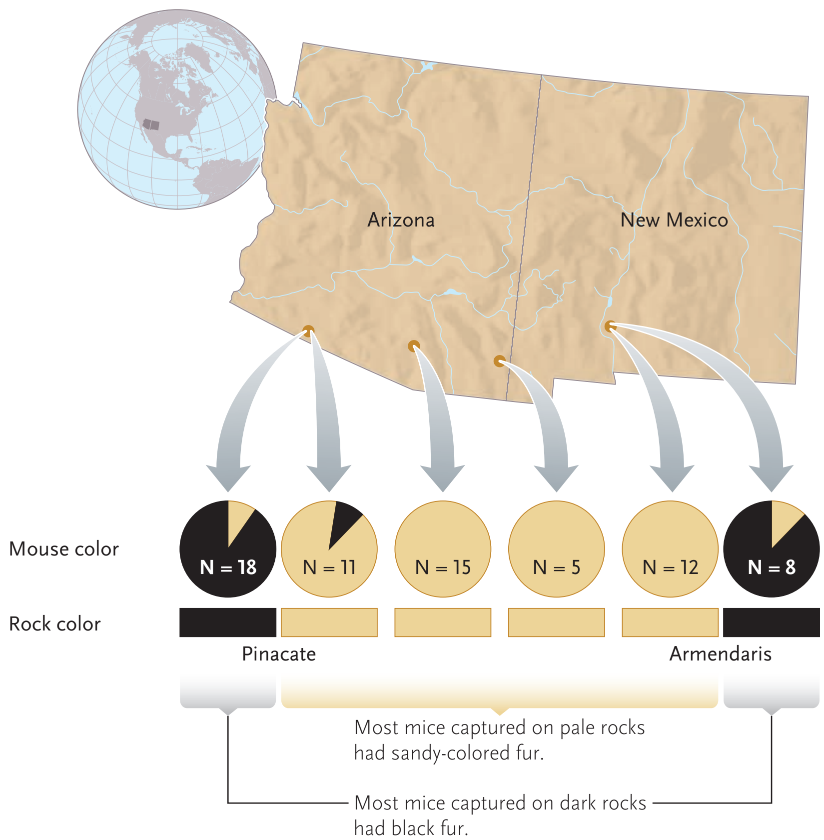


Figure 1.10
Distributions of rock pocket mice with light and dark fur. At six sites in Arizona and New Mexico, mouse fur color closely matched the colors of the backgrounds where they lived. The pie charts below the map show the proportion of mice with sandy-colored or black fur. N indicates the number of mice sampled at each site. The bars beneath the pie charts indicate the rock color.

constitute the diversity of life on Earth. In the next section, we survey this diversity and consider how it is classified for study by biologists.

Study Break

1. What is the difference between artificial selection and natural selection?
2. How do random changes in the structure of DNA affect the characteristics of organisms?
3. What is the usefulness of being camouflaged in natural environments?

1.3 Biodiversity

The great diversity of life, the product of evolution, represents the many different ways in which the common elements of life's organization have combined to provide new and successful ways to survive and reproduce.

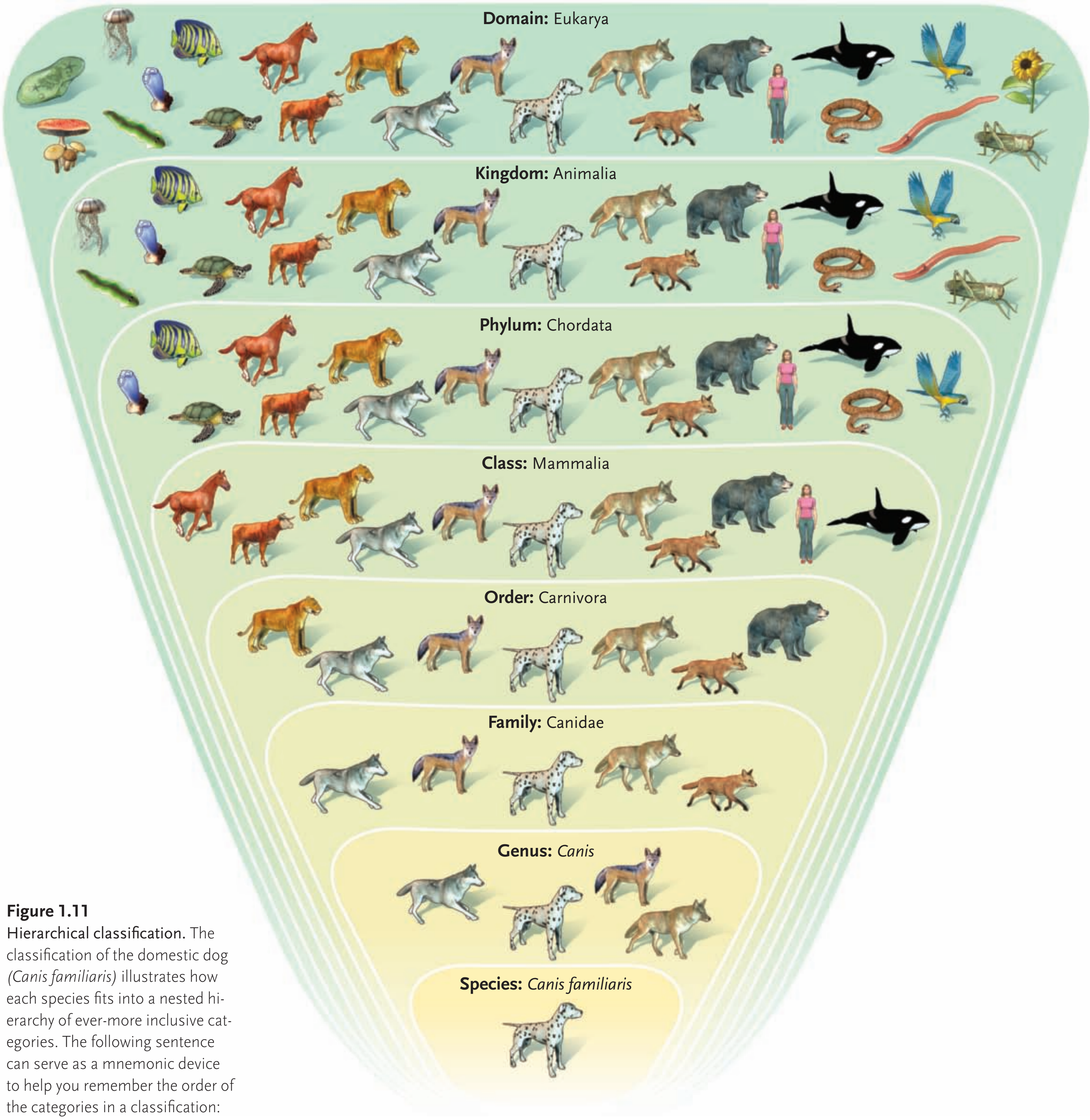


Figure 1.11
Hierarchical classification. The classification of the domestic dog *(Canis familiaris)* illustrates how each species fits into a nested hierarchy of ever-more inclusive categories. The following sentence can serve as a mnemonic device to help you remember the order of the categories in a classification: Diligent Kindly Professors Cannot Often Fail Good Students.

Millions of different kinds of organisms live on Earth. Many millions more existed in the past and became extinct. To make sense of the past and present diversity of life on Earth, scientists have developed classification systems that attempt to arrange organisms, living and dead, into groups that reflect their relationships and evolutionary origins. Although scientists traditionally relied on similarities and differences in external appearance to understand these evolutionary relationships, they now use analyses of proteins and DNA in this effort. The task is so daunting that there is no consensus on the numbers and kinds of divisions and categories to use; the classification system also changes as investigators learn more about extinct and living organisms. The attempt is worth the effort, however, because the classification of life leads to greater understanding of the relationships between living organisms and sheds light on the pathways of evolutionary change.

Biologists Consider the Species to Be a Fundamental Unit in a Hierarchy of Categories

Most biologists consider the species to be the most fundamental grouping in the diversity of life. A **species** is a group of populations in which the individuals are so closely related in structure, biochemistry, and behavior that they can successfully interbreed. At the level directly above the species, biologists recognize the **genus** (plural, *genera*), a group of similar species that share recent common ancestry. Species in the same genus usually also share many characteristics. For example, a group of closely related four-legged mammals that have elongated faces, large piercing teeth at the front of the mouth, slicing teeth behind them, and crushing teeth at the back of the mouth are classified together in the genus *Canis,* commonly known as dogs.

Each species is assigned a two-part **scientific name:** the first part identifies the genus to which it belongs, and the second part designates a particular species within that genus. In the genus *Canis,* for example, *Canis familiaris* is the scientific name of the domesticated dog; *Canis lupus,* the gray wolf, and *Canis latrans,* the coyote, are two other species in the same genus. Scientific names are always written in italics, and only the genus name is capitalized. After its first mention in a discussion, the genus name is frequently abbreviated to its first letter, as in *C. familiaris* and *C. lupus*.

At successively more inclusive levels **(Figure 1.11),** related genera are placed in the same **family,** related families in the same **order,** and related orders in the same **class.** Related classes are grouped into a **phylum** (plural, *phyla*), and related phyla are assigned to a **kingdom.** In recent years, biologists have added the **domain** as the most inclusive group.

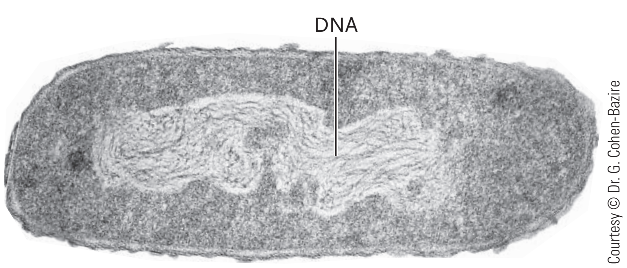
Biologists Classify Organisms into Three Domains and Several Kingdoms

Biologists distinguish three domains—Bacteria, Archaea, and Eukarya. Each domain represents a group of cellular organisms with characteristics that set it apart as a major branch of the evolutionary tree. Two of the three domains, Bacteria and Archaea, are described as **prokaryotes** (*pro* = before; *karyon* = nucleus) because they exhibit a relatively simple organization of their DNA and cell structures **(Figure 1.12a).** In these organisms, the DNA is suspended in the cell interior without separation from other cellular components. By contrast, the Eukarya are described as **eukaryotes** (*eu* = typical) because their DNA is enclosed in a nucleus, a separate structure within cells **(Figure 1.12b).** The nucleus and other specialized internal compartments of eukaryotic cells are called **organelles** ("little organs").

The Domain Bacteria. The Domain Bacteria **(Figure 1.13a)** comprises unicellular organisms that are generally visible only under the microscope. These prokaryotes live as producers or decomposers almost everywhere on Earth, utilizing metabolic processes that are the most varied of any organisms. They share a relatively simple cellular organization of DNA and internal structures with the archaeans, but bacteria have some structural molecules and mechanisms of photosynthesis that are unique and found only in this domain.

The Domain Archaea. Like bacteria, species in the Domain Archaea **(Figure 1.13b)** are unicellular, microscopic organisms that live as producers or decomposers. However, many archaeans inhabit extreme environments—hot springs, extremely salty ponds, or habitats with little or no oxygen—that other organisms cannot tolerate. They are distinguished by some structural molecules and by a primitive form of photosynthesis that are unique to their domain. Although archaeans are pro-

a. *Escherichia coli*, a prokaryote



b. *Paramecium aurelia*, a eukaryote

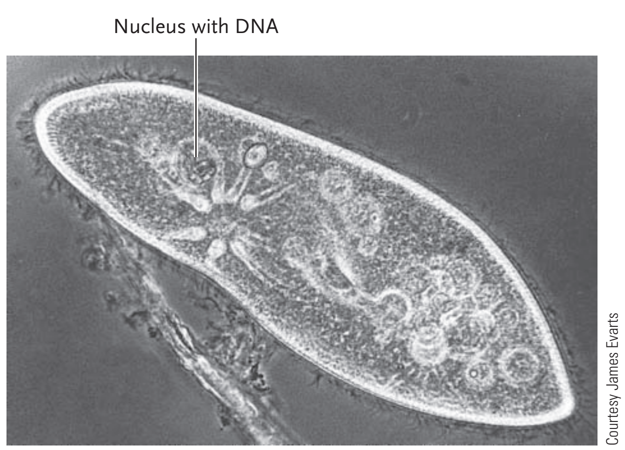


Figure 1.12
Prokaryotic and eukaryotic cells. **(a)** *Escherichia coli,* a prokaryote, lacks the complex internal structures apparent in **(b)** *Paramecium aurelia*, a eukaryote. Most eukaryotic cells are 25 to 50 times larger than prokaryotic cells.

karyotic, they have some molecular and biochemical characteristics that are typical of eukaryotes, including features of DNA and RNA organization and processes of protein synthesis.

The Domain Eukarya. All the remaining organisms on Earth, including the familiar plants and animals, are members of the Domain Eukarya **(Figure 1.13c).** The organisms of this domain, all eukaryotic in cell structure, are divided into four kingdoms: Protoctista, Plantae, Fungi, and Animalia.

1. **The Kingdom Protoctista.** The Kingdom Protoctista forms a large and diverse group of single-celled and multicellular eukaryotic species. Most researchers divide the Protoctista into several kingdoms, but they do not yet agree on a classification. Protozoans, which are primarily unicellular, and algae, which range from single-celled, microscopic species to large, multicellular seaweeds, are the most familiar protoctistans. Protozoans live as consumers and decomposers, but almost all algae are producers because they carry out photosynthesis.
2. **The Kingdom Plantae.** Members of the Kingdom Plantae are multicellular organisms that, with few exceptions, carry out photosynthesis; they therefore function as producers in ecosystems. Except for the reproductive cells (pollen and seeds) of some species, plants do not move from place to place. The kingdom includes the familiar flowering plants, conifers, and mosses.
3. **The Kingdom Fungi.** The Kingdom Fungi includes a highly varied group of unicellular and multicellular species, among them the yeasts and molds.

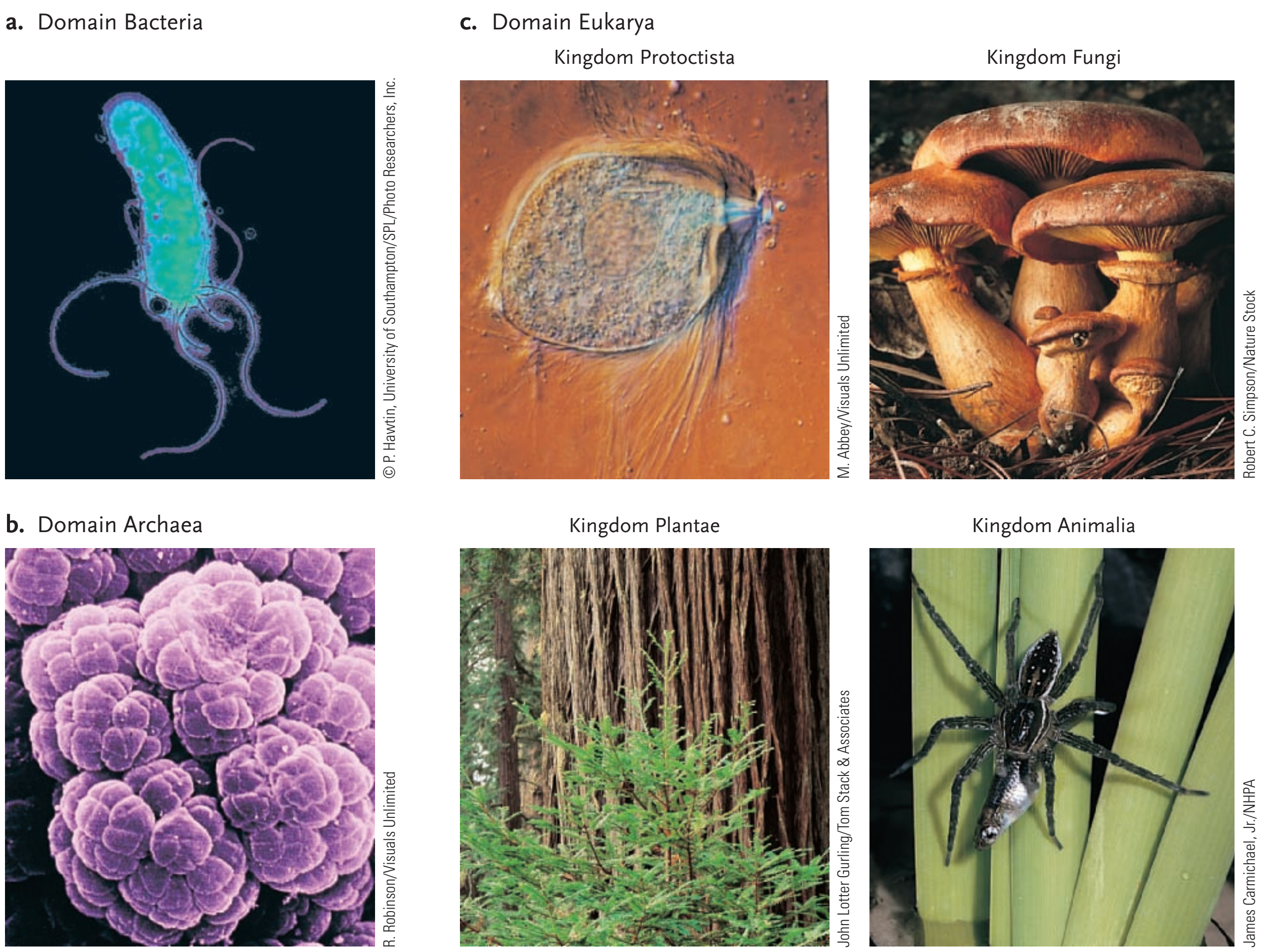


Figure 1.13
Three domains of life. **(a)** This member of the Domain Bacteria *(Helicobacter pylori)* causes ulcers in the digestive systems of humans. **(b)** This example from the Domain Archaea (*Methanosarcina* species) lives in the oxygen-free muck of swamps and bogs. **(c)** The Domain Eukarya is divided into four kingdoms in this book. The Kingdom Protoctista is represented by a trichomonad (*Trichonympha* species) that lives in the gut of a termite. Coast redwoods *(Sequoia sempervirens)* are among the largest members of the Kingdom Plantae; the picture shows a young tree with the trunk of an older tree behind it. The Kingdom Fungi includes the big laughing mushroom (*Gymnophilus* species), which lives on the forest floor. Members of the Kingdom Animalia are consumers, as illustrated by the fishing spider (*Dolomedes* species), which is feasting on a minnow it has captured.

Most fungi live as decomposers by breaking down and then absorbing biological molecules from dead organisms. No fungi carry out photosynthesis.

4. **The Kingdom Animalia.** Members of the Kingdom Animalia are multicellular organisms that live as consumers by ingesting organisms in all three domains. One of the distinguishing features of animals is their motility, the ability to move actively from one place to another during some stage of their life cycles. The kingdom encompasses a great range of organisms, including groups as varied as sponges, worms, insects, fishes, amphibians, reptiles, birds, and mammals.

Now that we have introduced the characteristics of living systems, basic concepts of evolution, and biological diversity, we turn our attention to the ways in which biologists examine the living world to make new discoveries and gain new insights about life on Earth.

Study Break

1. What is a major difference between prokaryotic and eukaryotic organisms?
2. In which domain and in which kingdom are humans classified?

1.4 Biological Research

The entire content of this book—every observation, experimental result, and generality—is the product of **biological research,** the collective effort of countless individuals who have worked to understand how living systems function. This section describes how researchers working today define and answer questions about biology.

People have been adding to our knowledge of living systems ever since our distant ancestors first thought about gathering food or hunting game. However, beginning about 500 years ago in Europe, inquisitive people began to understand that direct observation is the most reliable and productive way to study natural phenomena. By the nineteenth century, researchers were using the **scientific method,** an investigative approach to acquiring knowledge in which scientists make observations about the natural world, develop working explanations about what they observe, and then test those explanations by collecting more information.

Grade school teachers often describe the scientific method as a strict, stepwise procedure for observing and explaining the world around us, but it is really more of an attitude—an attitude of inquiry and skepticism. Successful scientists question the current state of our knowledge and challenge old concepts with new ideas and new observations. Scientists like to be shown why an idea is correct, rather than simply being told that it is. They refuse to accept explanations of natural phenomena unless they are backed up by objective evidence rooted in observation and measurement. Most important, scientists develop ideas that can be confirmed or refuted by different researchers testing them in different settings.

Biologists Confront the Unknown by Conducting Basic and Applied Research

Although nonscientists may be intimidated by natural processes they do not understand, scientists embrace the "unknown." To a scientist, unexplained phenomena provide opportunities to apply creative thinking to important problems. As you read this book, at first you may be uncomfortable discovering how many fundamental questions have not been answered. How and where did life begin? How exactly do genes govern the growth and development of an organism? What triggers the signs of aging? To help you develop an appreciation of how exciting it is to enter unknown territory, most chapters close with a discussion of Unanswered Questions. Although the concepts and facts that you will learn about biological systems are profoundly interesting, you will discover that the unanswered questions are even more exciting. In many cases, we do not even know exactly how you and other scientists of your generation will answer these questions.

Research science is often broken down into two complementary activities—basic research and applied research—that constantly inform one another. Biologists who conduct **basic research** search for explanations about natural phenomena to satisfy their own curiosity and to advance our collective knowledge of living systems. Sometimes, they may not have a specific practical goal in mind. For example, some biologists study how lizards control their body temperatures in different environments. At other times, basic research is inspired by specific practical concerns. For example, understanding how certain bacteria attack the cells of larger organisms might someday prove useful for the development of a new antibiotic (that is, a bacteria-killing agent). Many chapters in this book include a *Focus on Research,* which describes particularly elegant or insightful basic research that advanced our knowledge.

Other scientists conduct **applied research,** with the goal of solving specific practical problems. For example, biomedical scientists conduct applied research to develop new drugs and to learn how illnesses spread from animals to humans or through human populations. Similarly, agricultural scientists try to develop varieties of important crop plants that are more productive and more pest-resistant than the varieties currently in use. Examples of applied research are presented throughout this book, some of them described in detail as a *Focus on Research.*

Biologists Conduct Research by Collecting Observational and Experimental Data

Biologists generally use one of two complementary approaches—or a combination of the two—to advance our knowledge. In many cases, they collect **observational data**, basic information on biological structures or the details of biological processes. This approach, which is sometimes called *descriptive science,* provides information about systems that have not yet been well studied. For example, biologists are now collecting observational data about the precise chemical structure of the DNA in different species of organisms. When conducting descriptive research, a scientist must make detailed observations and describe the methods of observation as carefully and accurately as possible so that other researchers can repeat and verify those observations at a later time.

In other cases, researchers collect **experimental data**, information that describes the result of a careful manipulation of the system under study. Experimental science often answers questions about why or how systems work as they do. For example, a biologist who wonders whether a particular snail species influences the distribution of algae on a rocky shoreline might remove the snail from some enclosed patches of shoreline and examine whether the distribution of algae changes as a result. Similarly, a geneticist who wants to understand the role of a particular gene in the functioning of an organism might make mutations in the gene and examine the consequences.

Researchers Often Test Hypotheses with Controlled Experiments

Research on a previously unexplored system usually starts with basic observations. Once a solid base of carefully observed and described facts is established, scientists may develop a **hypothesis**, a "working explanation" of the observed facts. And whenever scientists create a hypothesis, they simultaneously define—either explicitly or implicitly—a **null hypothesis**, a statement of what they would see if the hypothesis being tested is not correct.

The development of a scientific hypothesis is a creative activity that is constrained by one crucial requirement: it must be *falsifiable* by experimentation or further observation. In other words, scientists must describe an idea in such a way that, if it is wrong, they will be able to demonstrate that it is wrong. The principle of falsifiability helps scientists define testable, focused hypotheses. Hypotheses that are testable and falsifiable fall within the realm of science, whereas those that cannot be falsified—although possibly valid and true—do not fall within the realm of science.

Hypotheses generally explain the relationship between **variables**, environmental factors that may differ among places or organismal characteristics that may differ among individuals. Thus, hypotheses yield testable **predictions**, statements about what the researcher expects to happen to one variable if another variable changes. And if data from just one experiment refute a scientific hypothesis (that is, demonstrate that its predictions are incorrect), the scientist must modify the hypothesis and test it again or abandon it altogether. However, no amount of data can *prove* beyond a doubt that a hypothesis is correct; there may always be a contradictory example somewhere on Earth, and it is impossible to test every imaginable example. That is why scientists say that positive results *are consistent with, support,* or *confirm* a hypothesis.

To make these ideas more concrete, consider a simple example of hypothesis creation and testing. Say that a friend gives you a plant that she grew on her windowsill. Under her loving care, the plant flowered profusely. You place the plant on your windowsill and water it regularly, but the plant never blooms. You know that your friend always gave fertilizer to the plant—your observation—and you wonder whether fertilizing the plant would make it flower. In other words, you create a hypothesis with a specific prediction: "This type of plant will produce flowers if it receives fertilizer." This is a good scientific hypothesis because it is falsifiable. To test the hypothesis, you would simply give the plant fertilizer. If it blooms, the data—the fact that it flowers—confirm your hypothesis. If it does not bloom, the data force you to reject or revise your hypothesis.

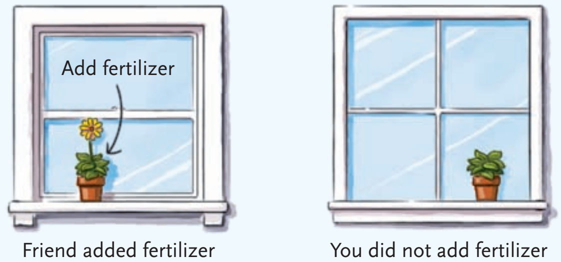
One problem with this experiment is that the hypothesis does not address other possible reasons that the plant did not flower. Maybe it received too little water. Maybe it did not get enough sunlight. Maybe your windowsill was too cold. All of these explanations could be the basis of **alternative hypotheses**, which a conscientious scientist always considers when designing experiments. You could easily test any of these hypotheses by providing more water, more hours of sunlight, or warmer temperatures to the plant.

But even if you provide each of these necessities in turn, your efforts will not definitively confirm or refute your hypothesis unless you introduce a control treatment. The **control**, as it is often called, tells what we would see in the absence of the experimental manipulation. For example, your experiment would need to compare plants that received fertilizer (the experimental treatment) with plants grown without fertilizer (the control treatment). The presence or absence of fertilizer is the **experimental variable**, and in a controlled experiment, everything except the experimental variable—the flower pots, the soil, the amount of water, and exposure to sunlight—is exactly the same, or as close to exactly the same as possible. Thus, if your experiment is well controlled **(Figure 1.14)**, any difference in flowering pattern observed between plants that receive the experimental treatment (fertilizer) and those that receive the control treatment (no fertilizer) can be attributed to the experimental variable. If the plants that receive fertilizer did not flower more than the control plants, you would reject your initial hypothesis.

Figure 1.14 Experimental Research

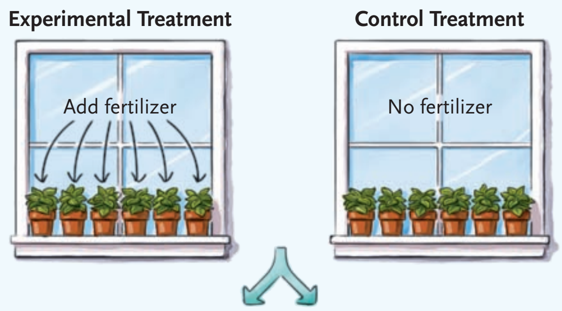
Hypothetical Experiment Illustrating the Use of Control Treatment and Replicates

OBSERVATION: Your friend fertilizes a plant that she grows on her windowsill, and it flowers profusely. After she gives you the plant, you put it on your windowsill, but you do not give it any fertilizer and it does not flower.



HYPOTHESIS: The plant requires fertilizer to produce flowers.

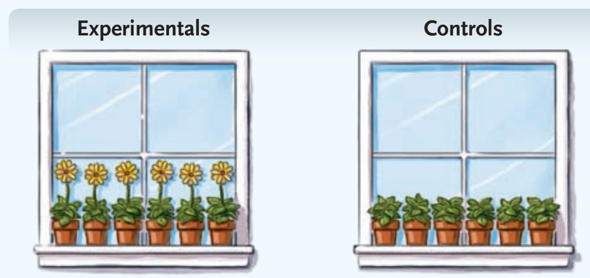
METHOD: Establish six replicates of an experimental treatment (identical plants grown with fertilizer) and six replicates of a control treatment (identical plants grown without fertilizer).



POSSIBLE RESULT 1: Neither experimental nor control plants flower.

CONCLUSION: Fertilizer alone does not cause the plant to flower. Consider alternative hypotheses and conduct additional experiments, each testing a different experimental treatment, such as the amount of water or sunlight the plant receives or the temperature to which it is exposed.

POSSIBLE RESULT 2: Plants in the experimental group flower, but plants in the control group do not.



CONCLUSION: The application of fertilizer induces flowering in this type of plant, confirming your original hypothesis. Pat yourself on the back and apply to graduate school in plant biology.

The elements of a typical experimental approach, as well as our hypothetical experiment, are summarized in Figure 1.14. Figures that present observational and experimental research using this basic format are provided throughout this book.

Notice that in the preceding discussion we discussed plants (plural) that received fertilizer and plants that did not. Nearly all experiments in biology include **replicates**, multiple subjects that receive either the same experimental treatment or the same control treatment. Scientists use replicates in experiments because individuals typically vary in genetic makeup, size, health, or other characteristics—and because accidents sometimes disrupt a couple of replicates. By exposing multiple subjects to both treatments, we can compare the average result of the experimental treatment with the average result of the control treatment, giving us more confidence in the overall result. Thus, in the fertilizer experiment we described, we might expose six or more individual plants to each treatment and compare the results obtained for the experimental group with those obtained for the control group. We would also try to ensure that the individuals included in the experiment were as similar as possible. For example, we might specify that they all must be the same species and the same age or size.

When Controlled Experiments Are Unfeasible, Researchers Use Null Hypotheses to Evaluate Observational Data

In some fields of biology, especially ecology and evolution, the systems under study may be too large or complex for experimental manipulation. In such cases, biologists can use a null hypothesis to evaluate observational data. For example, Paul E. Hertz of Barnard College studies temperature regulation in lizards. As in many other animals, a lizard's body temperature can vary substantially as environmental temperatures change. Research on many lizard species has demonstrated that they often compensate for fluctuations in environmental temperature—that is, maintain thermal homeostasis—by perching in the sun to warm up or in the shade when they feel hot. Previous observations of two closely related lizard species in Puerto Rico, *Anolis cristatellus* and *Anolis gundlachi,* suggested that the two species respond differently to variations in environmental temperature. Based on this prior work, Hertz's working hypothesis was that *A. gundlachi* almost never tries to regulate its body temperature, whereas *A. cristatellus* often does, particularly when environmental temperatures are low.

To discover whether these two lizard species differed in their thermoregulatory behaviors, Hertz needed to determine what he would see if lizards were *not* trying to control their body temperatures. In other words, he needed to know the predictions of a null hypothesis that states: "Lizards do not regulate their body temperature, and they select perching sites at random with respect to factors that influence body temperature" **(Figure 1.15).** Of course, it would be impossible to force a natural population of lizards to perch in places that define the null hypothesis. Instead, he and his students created a population of artificial lizards, copper models that served as lizard-sized, lizard-shaped, and lizard-colored thermometers. Each hollow copper model was equipped with a built-in temperature-sensing wire that can be connected to an electronic thermometer. After constructing the copper models, Hertz and his students verified that the models reached the same internal temperatures as live lizards under various laboratory conditions. They then traveled to Puerto Rico and hung 60 models at randomly selected positions in the habitats where the two lizard species lived.

How did the copper models allow Hertz and his students to interpret their data? Because the researchers placed these inanimate objects at random positions in the lizards' habitats, the percentages of models observed in sun and in shade provided a measure of how sunny or shady a particular habitat was. In other words, the copper models established the null hypothesis about the percentage of lizards that would perch in sunlit spots just by chance. Similarly, the temperatures of the models provided a null hypothesis about what the temperatures of lizards would be if they perched at random in their habitats. Hertz and his students gathered data on the use of sunny perching places and temperatures from both the copper models and live lizards. By comparing the behavior and temperatures of live lizards with the random "behavior" and random temperatures of the copper models, they demonstrated that *A. cristatellus* did, in fact, regulate its body temperature but that *A. gundlachi* did not (see Figure 1.15).

Biologists Often Use Model Organisms to Study Fundamental Biological Processes

Certain species or groups of organisms have become favorite subjects for laboratory and field studies because their characteristics make them relatively easy subjects of research. In most cases, biologists began working with these **model organisms** because they have rapid development, short life cycles, and small adult size. Thus, researchers can rear and house large numbers of them in the laboratory. Also, as fuller portraits of their genetics and other aspects of their biology emerge, their appeal as research subjects grows because biologists have a better understanding of the biological context within which specific processes occur.

Because many forms of life share similar molecules, structures, and processes, research on these small and often simple organisms provides insights into biological processes that operate in larger and more complex organisms. For example, early analyses of inheritance in a fruit fly *(Drosophila melanogaster)* established our basic understanding of genetics in all eukaryotic organisms. Research in the mid-twentieth century with the bacterium *Escherichia coli* demonstrated the mechanisms that control whether the information in any particular gene is used to manufacture a protein molecule, fueling additional work on this important subject in both prokaryotes and eukaryotes. In fact, the body of research with *E. coli* formed the foundation that now allows scientists to make and clone (that is, produce multiples copies of) DNA molecules. Similarly, research on a tiny mustard plant *(Arabidopsis thaliana)* is providing information about the genetic and molecular control of development in all plants. Other model organisms facilitate research in ecology and evolution. For example, the *Anolis* lizards described earlier are just 2 of more than 400 *Anolis* species. The geographic distribution of these species allows researchers to study general processes and interactions that affect the ecology and evolution of all forms of life. You will read about eight of the organisms most

Figure 1.15 Observational Research

A Field Study Using a Null Hypothesis

HYPOTHESIS: *Anolis cristatellus* and *Anolis gundlachi* differ in the extent to which they use patches of sun and shade to regulate their body temperatures.

NULL HYPOTHESIS: Because these species do not regulate their body temperatures, they select perching sites at random with respect to environmental factors that might influence body temperature.

METHOD: The researchers created a set of hollow, copper lizard models, each equipped with a temperature-sensing wire. At study sites where the lizard species live in Puerto Rico, the researchers hung 60 models at random positions in trees. They observed how often live lizards and the randomly positioned copper models were perched in patches of sun or shade, and they measured the temperatures of live lizards and the copper models. Data from the randomly positioned copper models define the predictions of the null hypothesis.

RESULTS: The researchers compared the frequency with which live lizards and the copper models perched in sun or shade as well as the temperatures of live lizards and the copper models. The data revealed that the behavior and temperatures of *A. cristatellus* were different from those of the randomly positioned models but that the behavior and temperatures of *A. gundlachi* were not. These data therefore confirmed the original hypothesis.

Anolis gundlachi

Kevin de Queiroz, National Museum of Natural History, Smithsonian Institution

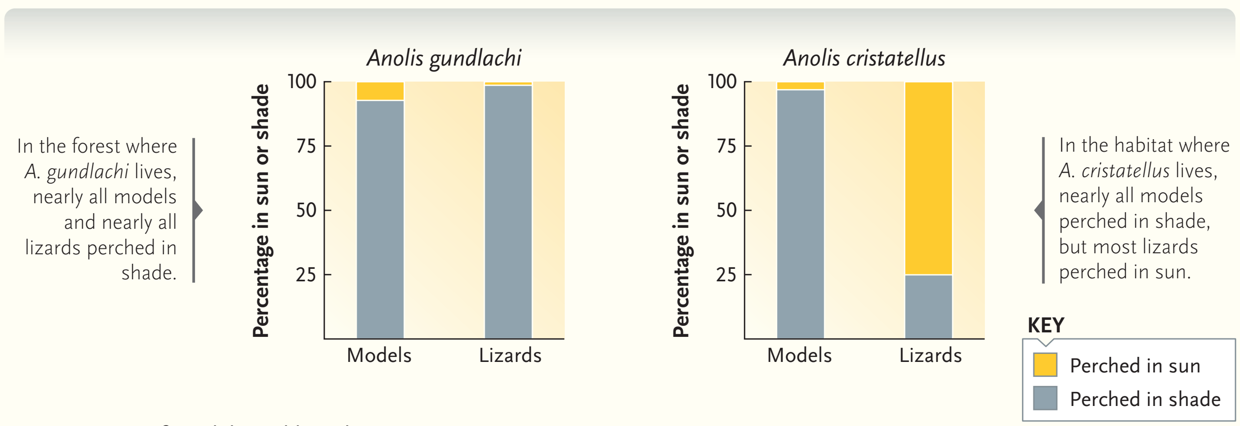
Anolis cristatellus

Alejandro Sanchez

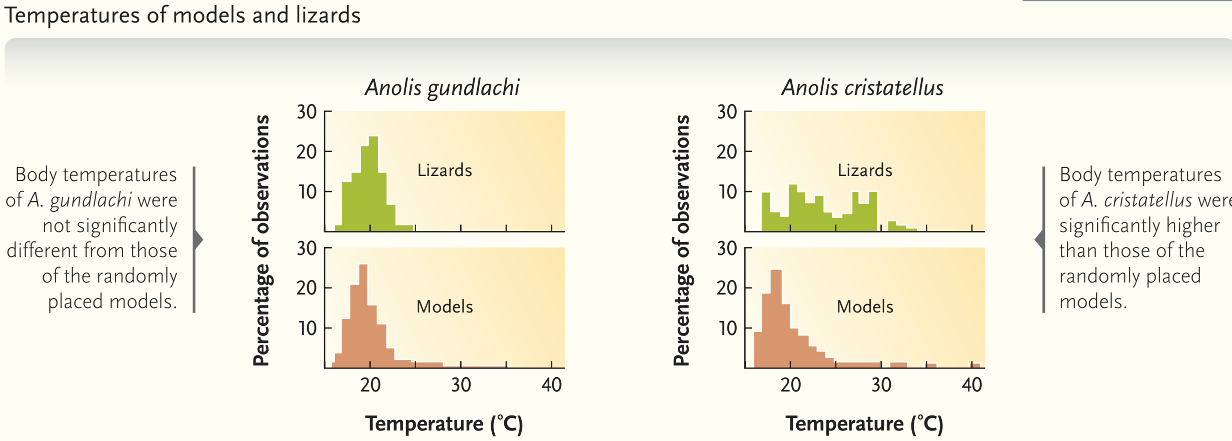
Copper *Anolis* model

Kevin de Queiroz, National Museum of Natural History, Smithsonian Institution

Percentage of models and lizards perched in sun or shade



Temperatures of models and lizards



CONCLUSION: *A. cristatellus* uses patches of sun and shade to regulate its body temperature, but *A. gundlachi* does not.

frequently used in research in some of the *Focus on Research* boxes distributed throughout this book.

Molecular Techniques Have Revolutionized Biological Research

In 1941, George Beadle and Edward Tatum used a simple bread mold *(Neurospora crassa)* as a model organism to demonstrate that genes provide the instructions for constructing certain proteins. Their work represents the beginning of the molecular revolution. In 1953, James Watson and Francis Crick determined the structure of DNA, giving us a molecular vision of what a gene is. In the years since those pivotal discoveries, our understanding of the molecular aspects of life has increased exponentially, because many new techniques allow us to study life processes at the molecular level. For example, we can isolate individual genes and study them in detail—even manipulate them—in the test tube. We can modify organisms by replacing or adding genes. We can explore the interactions that each individual protein in the cell has with other proteins. We can identify and characterize each of the genes in an organism and learn its exact structure. The list of experimental possibilities is nearly endless.

This molecular revolution has made it possible to answer questions about biological systems that we could not even ask just a few years ago. For example: What specific DNA changes are responsible for genetic diseases? How is development controlled at the molecular level? What genes do humans and chimpanzees share? In particular, the continued unraveling of the structure of DNA in many organisms is fueling a new intensity of scientific enquiry focused on the role of whole genomes (all of the DNA of an organism) in directing biological processes. To give you a sense of the exciting impact of molecular research on all areas of biology, most chapters in this book include a box dedicated to *Insights from the Molecular Revolution*.

Advances in molecular biology have also revolutionized applied research. DNA "fingerprinting" allows forensic scientists to identify individuals who left molecular traces at crime scenes. **Biotechnology**, the manipulation of living organisms to produce useful products, has also revolutionized the pharmaceutical industry. For example, insulin—a protein used to treat the metabolic disorder diabetes—is now routinely produced by bacteria into which the gene coding for this protein has been inserted. Current research on gene therapy and the cloning of stem cells also promises great medical advances in the future.

Scientific Theories Are Grand Ideas That Have Withstood the Test of Time

When a hypothesis stands up to repeated experimental tests, it is gradually accepted as an accurate explanation of natural events. This acceptance may take many years, and it usually involves repeated experimental confirmations. When every conceivable test has confirmed a hypothesis that addresses many broad questions, it may become regarded as a **scientific theory.** In chemistry and physics, long-established theories of fundamental importance are called *laws* of science. However, living systems are so variable that we do not really recognize many overarching biological laws.

Most scientific theories are supported by exhaustive experimentation; thus, scientists usually regard them as established truths that are not likely to be contradicted by future research. Note that this use of the word *theory* is quite different from its informal meaning in everyday life. In common usage, the word *theory* most often labels ideas that are either speculative or downright suspect, as in the expression "It's only a theory." But when scientists talk about theories, they do so with reverence for ideas that have withstood the test of many experiments.

Because of the difference between the scientific and common usage of the word *theory,* many people fail to appreciate the extensive evidence that supports most scientific theories. For example, nearly every scientist accepts the theory of evolution as fully supported scientific truth: all species change with time, new species are formed, and older species eventually die off. Although evolutionary biologists debate the details of how evolutionary processes bring about these changes, very few scientists doubt that the theory of evolution is essentially correct. Moreover, *no scientist who has tried to cast doubt on the theory of evolution has ever devised or conducted a study that disproves any part of it*. Unfortunately, the confusion between the scientific and common usage of the word *theory* has led to endless public debate about supposed faults and inadequacies in the theory of evolution.

Curiosity and the Joy of Discovery Motivate Scientific Research

What drives scientists in their quest for knowledge? The motivations of scientists are as complex as those driving people toward any goal. Intense curiosity about ourselves, our fellow creatures, and the chemical and physical objects of the world and their interactions is a basic ingredient of scientific research. The discovery of information that no one knew before is as exciting to a scientist as finding buried treasure. There is also an element of play in science, a joy in the manipulation of scientific ideas and apparatus, and the chase toward a scientific goal. Biological research also has practical motivations—for example, to cure disease or improve agricultural productivity. In all this research, one strict requirement of science is honesty—without honesty in the gathering and reporting of results, the work of science is meaningless. Dishonesty is actually rare in science, not least because repetition of experiments by others soon exposes any funny business.

Whatever the level of investigation or the motivation, the work of every scientist adds to the fund of knowledge about us and our world. For better or worse, the scientific method—that inquiring and skeptical attitude—has provided knowledge and technology that have revolutionized the world and improved the quality of human life immeasurably. This book presents the fruits of the biologists' labors in the most important and fundamental areas of biological science—cell and molecular biology, genetics, evolution, systematics, physiology, developmental biology, ecology, and behavior.

Study Break

1. In your own words, explain the most important requirement of a scientific hypothesis.
2. What information did the copper lizard models provide in the study of temperature regulation described earlier?
3. Why do biologists often use model organisms in their research?
4. How would you respond to a nonscientist who told you that Darwin's ideas about evolution were "just a theory"?

Review

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1.1 What Is Life? Characteristics of Living Systems

- Living systems are organized in a hierarchy, each level having its own emergent properties (Figure 1.2). Cells, which represent the lowest level of organization that is alive, are organized into unicellular or multicellular organisms. At the next level of organization, populations are groups of organisms of the same kind that live together in the same area. An ecological community comprises all the populations living in an area, and ecosystems include communities that interact through their shared physical environment. At the highest level, the biosphere includes all of Earth's ecosystems.
- Living organisms have complex structures established by instructions coded in their DNA (Figure 1.3). The information in DNA is copied into RNA, which guides the production of protein molecules (Figure 1.4). Proteins carry out most of the activities of life.
- Living cells and organisms engage in metabolism, the activity of obtaining energy and using it to maintain themselves, grow, and reproduce. The two primary metabolic processes are photosynthesis and cellular respiration (Figure 1.5).
- Energy that flows through the hierarchy of life is eventually released as heat, which cannot be used by living systems. By contrast, matter is recycled within the biosphere (Figure 1.6).
- Cells and organisms use receptors to detect changes in their environment. Detection of an environmental change triggers a compensating reaction that allows the organism to survive.
- Organisms reproduce, and their offspring develop into mature, reproductive adults (Figure 1.7).
- Populations of living organisms undergo evolutionary change as generations replace one another over time.

Animation: Life's levels of organization

Animation: One-way energy flow and materials cycling

Animation: Insect development

1.2 Biological Evolution

- The structure, function, and types of organisms change with time. According to the theory of evolution by natural selection, certain characteristics allow some organisms to survive better and reproduce more than others in their population. If the instructions that produce those characteristics are coded in DNA, successful characteristics will become more common in later generations. As a result, the average characteristics of the offspring generation differ from those of the parent generation (Figure 1.8).
- The instructions for many characteristics are coded by segments of DNA called genes, which are passed through reproduction from parents to offspring.
- Mutations—changes in the structure, number, or arrangement of DNA molecules—create variability among individuals. Variability is the raw material of natural selection and other processes that cause biological evolution.
- Over many generations, the accumulation of favorable characteristics may produce adaptations, which enable individuals to survive longer or reproduce more (Figures 1.9 and 1.10).
- Over long spans of time, the accumulation of different adaptations and other genetic differences between populations has produced the diversity of life on Earth.

1.3 Biodiversity

- Scientists classify organisms in a hierarchy of categories. The species is the most basic category, followed by genus, family, order, class, phylum, and kingdom as increasingly inclusive categories (Figure 1.11).
- Most biologists organize the kingdoms into three domains—Bacteria, Archaea, and Eukarya—based on fundamental characteristics of cell structure. The Bacteria and Archaea each include one kingdom; the Eukarya is divided into four kingdoms: Protoctista, Plantae, Fungi, and Animalia (Figures 1.12 and 1.13).

Animation: Life's diversity

1.4 Biological Research

- Biologists conduct basic research to advance our knowledge of living systems and applied research to solve practical problems.
- Scientists may collect observational data, which describe biological organisms or the details of biological processes, or experimental data, which describe the results of an experimental manipulation.
- Scientists develop hypotheses—working explanations about the relationships between variables. Scientific hypotheses must be falsifiable.
- A well-designed experiment considers alternative hypotheses and includes control treatments and replicates (Figure 1.14). When experiments are unfeasible, biologists often use null hypotheses, explanations of what they would see if their hypothesis was wrong, to evaluate observational or experimental data (Figure 1.15).

- Model organisms, which are easy to maintain in the laboratory, have been the subject of much research.
- Molecular techniques allow detailed analysis of the DNA of many species and the manipulation of specific genes in the laboratory.
- A scientific theory is a set of broadly applicable hypotheses that have been completely supported by repeated tests under many conditions and in many different situations. The theory of evolution by natural selection is of central importance to biology because it explains how life evolved through natural processes.

Animation: Sample size and accuracy

Animation: How do scientists use random samples to test hypotheses?

Questions

Self-Test Questions

1. What is the lowest level of biological organization that biologists consider to be alive?
   a. a protein
   b. DNA
   c. a cell
   d. a multicellular organism
   e. a population of organisms
2. Which category falls immediately below "class" in the systematic hierarchy?
   a. species
   b. order
   c. family
   d. genus
   e. phylum
3. Which of the following represents the application of the "scientific method"?
   a. comparing one experimental subject to one control subject
   b. believing an explanation that is too complex to be tested
   c. using controlled experiments to test falsifiable hypotheses
   d. developing one testable hypothesis to explain a natural phenomenon
   e. observing a once-in-a-lifetime event under natural conditions
4. Houseflies develop through a series of programmed stages from egg, to pupa, to larva, to flying adult. This series of stages is called:
   a. artificial selection.
   b. respiration.
   c. homeostasis.
   d. a life cycle.
   e. metabolism.
5. Which structure allows living organisms to detect changes in the environment?
   a. a protein
   b. a receptor
   c. a gene
   d. RNA
   e. a nucleus
6. Which of the following is *not* a component of Darwin's theory as he understood it?
   a. Some individuals in a population survive longer than others.
   b. Some individuals in a population reproduce more than others.
   c. Heritable variations allow some individuals to compete more successfully for resources.
   d. Mutations in genes produce new variations in a population.
   e. Some new variations are passed to the next generation.
7. What role did the copper lizard models play in the field of study on temperature regulation?
   a. They attracted live lizards to the study site.
   b. They measured the temperatures of live lizards.
   c. They established null hypotheses about basking behavior and temperatures.
   d. They scared predators away from the study site.
   e. They allowed researchers to practice taking lizard temperatures.
8. Which of the following questions best exemplifies basic research?
   a. How did life begin?
   b. How does alcohol intake affect aging?
   c. How fast does avian flu spread among humans?
   d. How can we reduce hereditary problems in pure bred dogs?
   e. How does the consumption of soft drinks promote obesity?
9. When researchers say that a scientific hypothesis must be falsifiable, they mean that:
   a. the hypothesis must be proved correct before it is accepted as truth.
   b. the hypothesis has already withstood many experimental tests.
   c. they have an idea about what will happen to one variable if another variable changes.
   d. appropriate data can prove without question that the hypothesis is correct.
   e. if the hypothesis is wrong, scientists must be able to demonstrate that it is wrong.
10. Which of the following characteristics would *not* qualify an animal as a model research organism?
    a. It has rapid development.
    b. It has small adult size.
    c. It has a rapid life cycle.
    d. It has unique genes and unusual cells.
    e. It is easy to raise in the laboratory.

Questions for Discussion

1. Viruses are infectious agents that contain either DNA or RNA surrounded by a protein coat. They cannot reproduce on their own, but they can take over the cells of the organisms they infect and force those cells to produce more virus particles. Based on the characteristics of living organisms described in this chapter, should viruses be considered living organisms?
2. While walking through the woods, you discover a large rock covered with a gelatinous, sticky substance. What tests could you perform to determine whether the substance is inanimate, alive, or the product of a living organism?
3. Explain why control treatments are a necessary component of well-designed experiments.

Experimental Analysis

Design an experiment to test the hypothesis that the color of farmed salmon is produced by pigments in their food.

Evolution Link

When a biologist first tested a new pesticide on a population of insects, she found that only 1% of the insects survived their exposure to the poison. She allowed the survivors to reproduce and discovered that 10% of the offspring survived exposure to the same concentration of pesticide. One generation later, 50% of the insects survived this experimental treatment. What is a likely explanation for the increasing survival rate of these insects over time?