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CHAPTER

1

Biology: *Exploring Life*

BIG IDEAS

Themes in the Study of Biology
(1.1–1.4)

Common themes help to organize the study of life.

Evolution, the Core Theme of Biology
(1.5–1.7)

Evolution accounts for the unity and diversity of life and the evolutionary adaptations of organisms to their environment.

The Process of Science
(1.8–1.9)

In studying nature, scientists make observations, form hypotheses, and test predictions with experiments.

Biology and Everyday Life
(1.10–1.11)

Learning about biology helps us understand many issues involving science, technology, and society.

This young lemur spends much of its time on its mother's back. But it is also groomed and cared for by other females of the troop, a group of about 15 members led by a dominant female. About the size of large cats, these ring-tailed lemurs (scientific name, *Lemur catta*) are noted for their distinctive tails, dark eye patches and muzzle, and, as you can see on the cover of this book, entrancing eyes. They are also highly vocal primates, with 28 distinct calls, such as "predator alert," "stay out of my territory," and purrs of contentment.

About 33 species of lemurs live on the island of Madagascar, and before humans arrived 2,000 years ago, there were even more. The size of Texas, Madagascar is located about 400 km (240 miles) off the southeast coast of Africa. It is home to many plants and animals found nowhere else in the world. Its geographic history helps explain its remarkable biodiversity.

Madagascar was once part of a supercontinent that began breaking apart about 150 million years ago—before the primates (lemurs, monkeys, apes, and humans) had evolved. Apparently, 60 million years ago, ancestral lemurs floated on logs or vegetation from Africa to the island. Their new home was relatively free of predators and competitors and offered many different habitats, from tropical forests to deserts to highlands with spiny shrubs. Over millions of years, lemurs diversified on this isolated island.

The wonderful assortment of lemurs on Madagascar is the result of evolution, the process that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. In this chapter, we begin our exploration of biology—the scientific study of life, its evolution, and its amazing diversity.

Themes in the Study of Biology

1.1 All forms of life share common properties

Defining **biology** as the scientific study of life raises the obvious question: What is *life*? How would you describe what distinguishes living things from nonliving things? Even a small child realizes that a bug or a flower is alive, while a rock or water is not. They, like all of us, recognize life mainly by what living things do. **Figure 1.1** highlights seven of the properties and processes that we associate with life.

(1) *Order.* This close-up of a sunflower illustrates the highly ordered structure that typifies life. Living cells are the basis of this complex organization.

(2) *Reproduction.* Organisms reproduce their own kind. Here an emperor penguin protects its baby.

(3) *Growth and development.* Inherited information in the form of DNA controls the pattern of growth and development of all organisms, including this hatching crocodile.

(4) *Energy processing.* When this bear eats its catch, it will use the chemical energy stored in the fish to power its own activities and chemical reactions.

(5) *Response to the environment.* All organisms respond to environmental stimuli. This Venus flytrap closed its trap rapidly in response to the stimulus of a damselfly landing on it.

(6) *Regulation.* Many types of mechanisms regulate an organism's internal environment, keeping it within limits that sustain life. Pictured here is a typical lemur behavior with a regulatory function—"sunbathing"—which helps raise the animal's body temperature on cold mornings.

(7) *Evolutionary adaptation.* The leaflike appearance of this katydid camouflages it in its environment. Such adaptations evolve over many generations as individuals with traits best suited to their environment have greater reproductive success and pass their traits to offspring.

Figure 1.1 reminds us that the living world is wondrously varied. How do biologists make sense of this diversity and complexity, and how can you? Indeed, biology is a subject of enormous scope that gets bigger every year. One of the ways to help you organize all this information is to connect what you learn to a set of themes that you will encounter throughout your study of life. The next few modules introduce several of these themes: novel properties emerging at each level of biological organization, the cell as the fundamental unit of life, the correlation of structure and function, and the exchange of matter and energy as organisms interact with the environment. We then focus on the core theme of biology—evolution, the theme that makes sense of both the unity and diversity of life. And in the final two sections of the chapter, we look at the process of science and the relationship of biology to our everyday lives.

Let's begin our journey with a tour through the levels of the biological hierarchy.

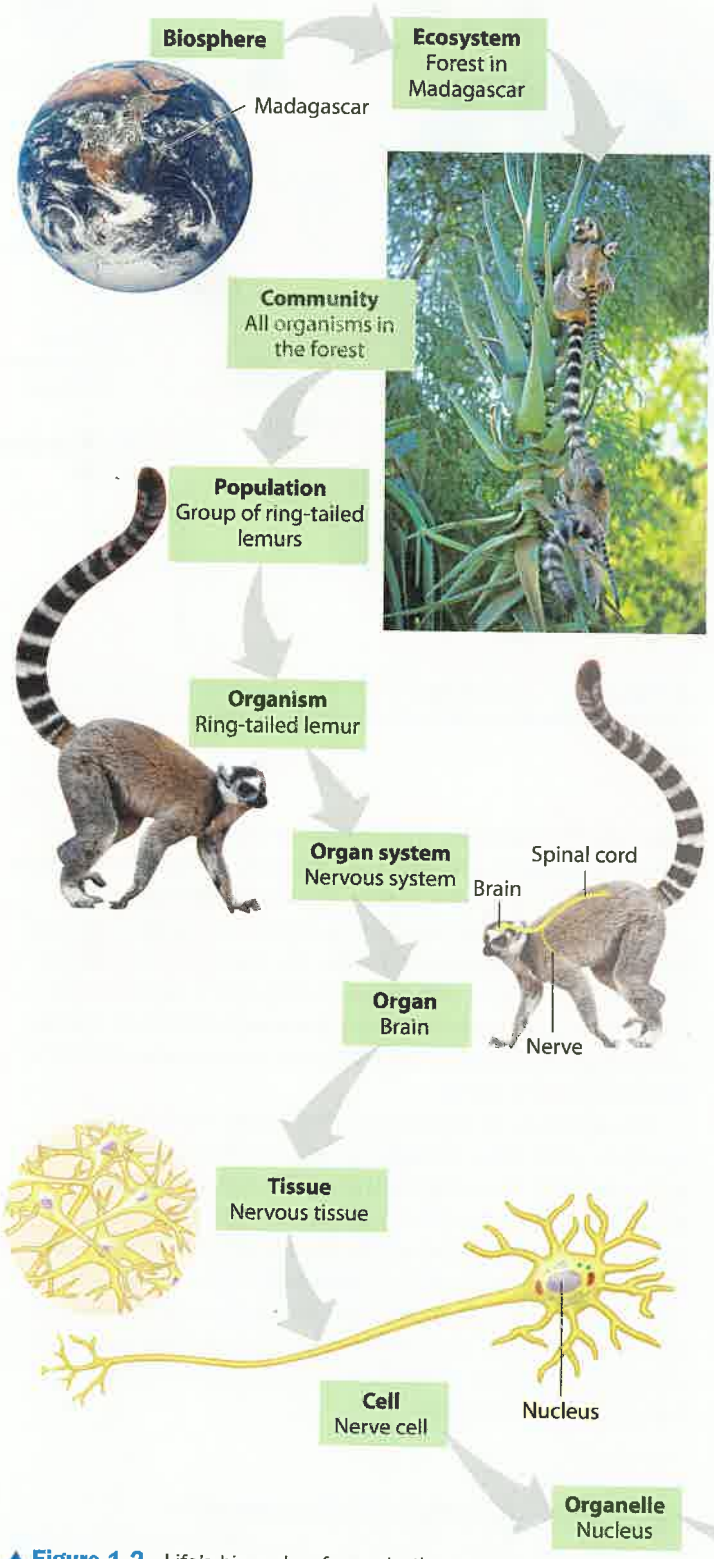
? **How would you define life?**

Life can be defined by a set of common properties such as those described in this module.

▲ **Figure 1.1** Some important properties of life

1.2 In life's hierarchy of organization, new properties emerge at each level

As **Figure 1.2** illustrates, the study of life extends from the global scale of the biosphere to the microscopic scale of molecules. At the upper left we take a distant view of the **biosphere**, all of the environments on Earth that support life. These include most regions of land, bodies of water, and the lower atmosphere.



▲ **Figure 1.2** Life's hierarchy of organization

A closer look at one of these environments brings us to the level of an **ecosystem**, which consists of all the organisms living in a particular area, as well as the physical components with which the organisms interact, such as air, soil, water, and sunlight.

The entire array of organisms in an ecosystem is called a **community**. The community in this forest ecosystem in Madagascar includes the lemurs and the agave plant they are eating, as well as birds, snakes, and catlike carnivores called civets; a huge diversity of insects; many kinds of trees and other plants; fungi; and enormous numbers of microscopic protists and bacteria. Each unique form of life is called a species.

A **population** includes all the individuals of a particular species living in an area, such as all the ring-tailed lemurs in the forest community. Next in the hierarchy is the **organism**, an individual living thing.

Within a complex organism such as a lemur, life's hierarchy continues to unfold. An **organ system**, such as the circulatory system or nervous system, consists of several organs that cooperate in a specific function. For instance, the organs of the nervous system are the brain, the spinal cord, and the nerves. A lemur's nervous system controls its actions, such as climbing trees.

An **organ** is made up of several different **tissues**, each made up of a group of similar cells that perform a specific function. A **cell** is the fundamental unit of life. In the nerve cell shown here, you can see several organelles, such as the nucleus. An **organelle** is a membrane-enclosed structure that performs a specific function in a cell.

Finally, we reach the level of molecules in the hierarchy. A **molecule** is a cluster of small chemical units called atoms held together by chemical bonds. Our example in Figure 1.2 is a computer graphic of a section of DNA (deoxyribonucleic acid)—the molecule of inheritance.

Now let's work our way in the opposite direction in Figure 1.2, moving up life's hierarchy from molecules to the biosphere. It takes many molecules to build organelles, numerous organelles to make a cell, many cells to make a tissue, and so on. At each new level, there are novel properties that arise, properties that were not present at the preceding level. For example, life emerges at the level of the cell—a test tube full of organelles is not alive. Such **emergent properties** represent an important theme of biology. The familiar saying that "the whole is greater than the sum of its parts" captures this idea. The emergent properties of each level result from the specific arrangement and interactions of its parts.

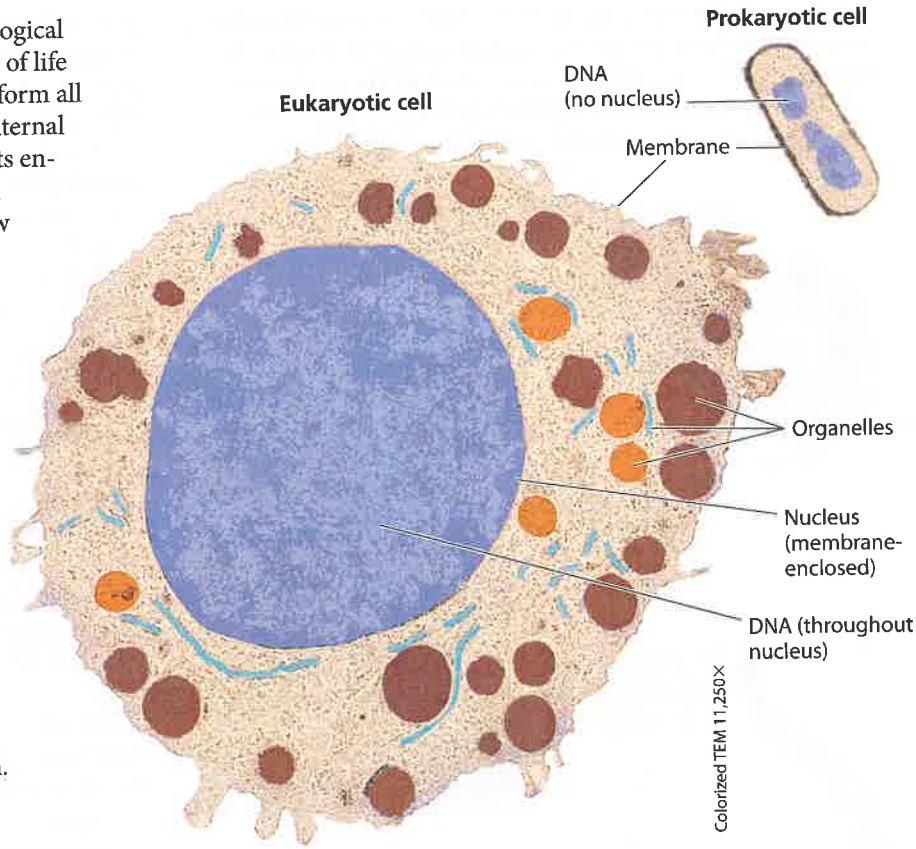
? **Which of these levels of biological organization includes all others in the list: cell, molecule, organ, tissue?**

1.3 Cells are the structural and functional units of life

The cell has a special place in the hierarchy of biological organization. It is the level at which the properties of life emerge—the lowest level of structure that can perform all activities required for life. A cell can regulate its internal environment, take in and use energy, respond to its environment, and develop and maintain its complex organization. The ability of cells to give rise to new cells is the basis for all reproduction and for the growth and repair of multicellular organisms.

All organisms are composed of cells. They occur singly as a great variety of unicellular (single-celled) organisms, such as amoebas and most bacteria. And cells are the subunits that make up multicellular organisms, such as lemurs and trees. Your body consists of trillions of cells of many different kinds.

All cells share many characteristics. For example, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. And every cell uses DNA as its genetic information. There are two basic types of cells. **Prokaryotic cells** were the first to evolve and were Earth's sole inhabitants for about the first 1.5 billion years of life on Earth. Fossil evidence indicates that **eukaryotic cells** evolved about 2.1 billion years ago.



▲ **Figure 1.3** Contrasting the size and complexity of prokaryotic and eukaryotic cells (shown here approximately 11,250 times their real size)

Figure 1.3 shows these two types of cells as artificially colored photographs taken with an electron microscope. A prokaryotic cell is much simpler and usually much smaller than a eukaryotic cell. The cells of the microorganisms we call bacteria are prokaryotic. Plants, animals, fungi, and protists are all composed of eukaryotic cells. As you can see in Figure 1.3, a eukaryotic cell is subdivided by membranes into many functional compartments, called organelles. These include a nucleus, which houses the cell's DNA.

The properties of life emerge from the ordered arrangement and interactions of the structures of a cell. Such a combination of components forms a more complex organization that we can call a *system*. Cells are examples of biological systems, as are organisms and ecosystems. Systems and their emergent properties are not unique to life. Consider a box of bicycle parts. When all of the individual parts are properly assembled, the result is a mechanical system you can use for exercise or transportation.

The emergent properties of life, however, are particularly challenging to study because of the unrivaled complexity of biological systems. At the cutting edge of large-scale research today is an approach called **systems biology**. The goal of systems biology is to construct models for the dynamic behavior of whole systems based on studying the interactions among the parts. Biological systems can range from the functioning of the biosphere to the molecular machinery of an organelle.

Cells illustrate another theme of biology: the correlation of structure and function. Experience shows you that form generally fits function. A screwdriver tightens or loosens screws, a hammer pounds nails. Because of their form, these tools can't do each other's jobs. Applied to biology, this theme of form fitting function is a guide to the structure of life at all its organizational levels. For example, the long extension of the nerve cell shown in Figure 1.2 enables it to transmit impulses across long distances in the body. Often, analyzing a biological structure gives us clues about what it does and how it works.

The activities of organisms are all based on cells. For example, your every thought is based on the actions of nerve cells, and your movements depend on muscle cells. Even a global process such as the cycling of carbon is the result of cellular activities, including the photosynthesis of plant cells and the cellular respiration of nearly all cells, a process that uses oxygen to break down sugar for energy and releases carbon dioxide. In the next module, we explore these processes and how they relate to the theme of organisms interacting with their environments.

? **Why are cells considered the basic units of life?**

They are the lowest level in the hierarchy of biological organization at which the properties of life emerge.

1.4 Organisms interact with their environment, exchanging matter and energy

An organism interacts with its environment, which includes other organisms as well as physical factors. **Figure 1.4** is a simplified diagram of such interactions taking place in a forest ecosystem in Madagascar. Plants are the *producers* that provide the food for a typical ecosystem. A tree, for example, absorbs water (H_2O) and minerals from the soil through its roots, and its leaves take in carbon dioxide (CO_2) from the air. In photosynthesis, a tree's leaves use energy from sunlight to convert CO_2 and H_2O to sugar and oxygen (O_2). The leaves release O_2 to the air, and the roots help form soil by breaking up rocks. Thus, both organism and environment are affected by the interactions between them.

The *consumers* of the ecosystem eat plants and other animals. The lemur in Figure 1.4 eats the leaves and fruits of the tamarind tree. To release the energy in food, animals (as well as plants and most other organisms) take in O_2 from the air and release CO_2. An animal's wastes return other chemicals to the environment.

Another vital part of the ecosystem includes the small animals, fungi, and bacteria in the soil that decompose wastes and the remains of dead organisms. These *decomposers* act as recyclers, changing complex matter into simpler mineral nutrients that plants can absorb and use.

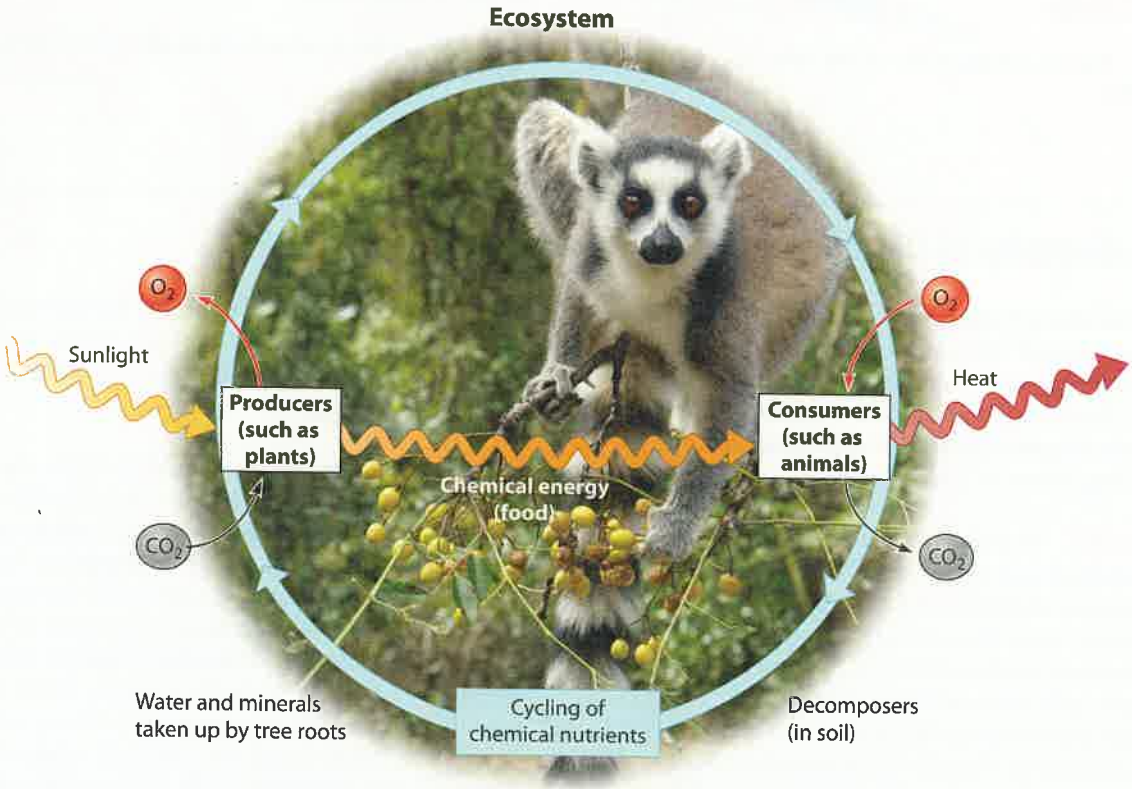
The dynamics of ecosystems include two major processes—the recycling of chemical nutrients and the flow of energy. These processes are illustrated in Figure 1.4. The most basic chemicals necessary for life—carbon dioxide, oxygen, water, and various minerals—cycle within an ecosystem from the air and soil to plants, to animals and decomposers, and back to the air and soil (blue arrows in the figure).

By contrast, an ecosystem gains and loses energy constantly. Energy flows into the ecosystem when plants and other photosynthesizers absorb light energy from the sun (yellow arrow) and convert it to the chemical energy of sugars and other complex molecules. Chemical energy (orange arrow) is then passed through a series of consumers and, eventually, decomposers, powering each organism in turn. In the process of these energy conversions between and within organisms, some energy is converted to heat, which is then lost from the system (red arrow). In contrast to chemical nutrients, which recycle within an ecosystem, energy flows through an ecosystem, entering as light and exiting as heat.

In this first section, we have touched on several themes of biology, from emergent properties in the biological hierarchy of organization, to cells as the structural and functional units of life, to the exchange of matter and energy as organisms interact with their environment. In the next section, we begin our exploration of evolution, the core theme of biology.

? **Explain how the photosynthesis of plants functions in both cycling of chemical nutrients and the flow of energy in an ecosystem.**

Photosynthesis uses light energy to convert carbon dioxide and water to energy-rich food, making it the pathway by which both chemical nutrients and energy become available to most organisms.

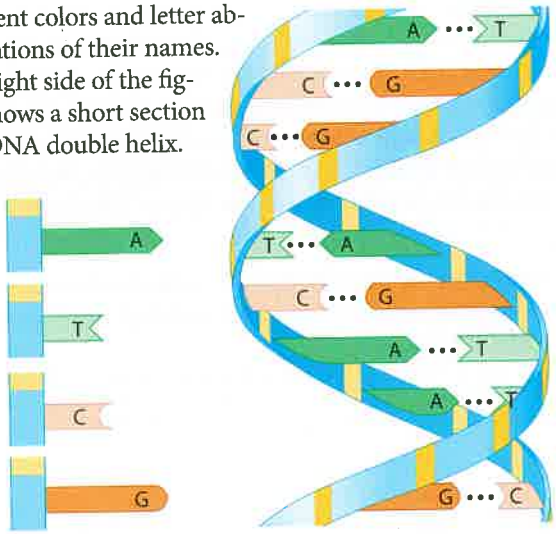


▲ **Figure 1.4** The cycling of nutrients and flow of energy in an ecosystem

Evolution, the Core Theme of Biology

1.5 The unity of life is based on DNA and a common genetic code

All cells have DNA, and the continuity of life depends on this universal genetic material. DNA is the chemical substance of **genes**, the units of inheritance that transmit information from parents to offspring. Genes, which are grouped into very long DNA molecules called chromosomes, also control all the activities of a cell. The molecular structure of DNA accounts for these functions. Let us explain: Each DNA molecule is made up of two long chains coiled together into what is called a double helix. The chains are made up of four kinds of chemical building blocks. **Figure 1.5** illustrates these four building blocks, called nucleotides, with different colors and letter abbreviations of their names. The right side of the figure shows a short section of a DNA double helix.



▲ **Figure 1.5** The four building blocks of DNA (left); part of a DNA double helix (right)

The way DNA encodes a cell's information is analogous to the way we arrange letters of the alphabet into precise sequences with specific meanings. The word *rat*, for example, conjures up an image of a rodent; *tar* and *art*, which contain the same letters, mean very different things. We can think of the four building blocks as the alphabet of inheritance. Specific sequential arrangements of these four chemical letters encode precise information in genes, which are typically hundreds or thousands of "letters" long.

The DNA of genes provides the blueprints for making proteins, and proteins serve as the tools that actually build and maintain the cell and carry out its activities. A bacterial gene may direct the cell to "Make a yellow pigment." A particular human gene may mean "Make the hormone insulin." All forms of life use essentially the same genetic code to translate the information stored in DNA into proteins. This makes it possible to engineer cells to produce proteins normally found only in some other organism. Thus, bacteria can be used to produce insulin for the treatment of diabetes by inserting a gene for human insulin into bacterial cells.

The diversity of life arises from differences in DNA sequences—in other words, from variations on the common theme of storing genetic information in DNA. Bacteria and humans are different because they have different genes. But both sets of instructions are written in the same language.

In the next module, we see how biologists attempt to organize the diversity of life.

? What is the chemical basis for all of life's kinship?

DNA is the genetic material.

1.6 The diversity of life can be arranged into three domains

We can think of biology's enormous scope as having two dimensions. The "vertical" dimension, which we examined in Module 1.2, is the size scale that stretches from molecules to the biosphere. But biology also has a "horizontal" dimension, spanning across the great diversity of organisms existing now and over the long history of life on Earth.

Grouping Species Diversity is a hallmark of life. Biologists have so far identified and named about 1.8 million species, and thousands more are identified each year. Estimates of the total number of species range from 10 million to over 100 million. Whatever the actual number, biologists face a major challenge in attempting to make sense of this enormous variety of life.

There seems to be a human tendency to group diverse items according to similarities. We may speak of bears or butterflies, though we recognize that each group includes many different species. We may even sort groups into broader categories, such as mammals and insects. Taxonomy, the branch of biology that names and classifies species, arranges species into a hierarchy of broader and broader groups, from genus, family, order, class, and phylum, to kingdom.

The Three Domains of Life Until the 1990s, most biologists used a taxonomic scheme that divided all of life into five kingdoms. But new methods for assessing evolutionary relationships, such as comparison of DNA sequences, have led to an ongoing reevaluation of the number and boundaries of kingdoms. As that debate continues, however, there is consensus that life can be organized into three higher levels called **domains**. **Figure 1.6**, on the facing page, shows representatives of the three domains: Bacteria, Archaea, and Eukarya.

Domains **Bacteria** and **Archaea** both consist of prokaryotes, organisms with prokaryotic cells. Most prokaryotes are single-celled and microscopic. The photos of the prokaryotes in Figure

1.6 were made with an electron microscope, and the number along the side indicates the magnification of the image. (We will discuss microscopy in Chapter 4.) Bacteria and archaea were once combined in a single kingdom. But much evidence indicates that they represent two very distinct branches of life, each of which includes multiple kingdoms.

Bacteria are the most diverse and widespread prokaryotes. In the photo of bacteria in Figure 1.6, each of the rod-shaped structures is a bacterial cell.

Many of the prokaryotes known as archaea live in Earth's extreme environments, such as salty lakes and boiling hot springs. Each round structure in the photo of archaea in Figure 1.6 is an archaeal cell.

All the eukaryotes, organisms with eukaryotic cells, are grouped in domain **Eukarya**. As you learned in Module 1.3, eukaryotic cells have a nucleus and other internal structures called organelles.

Protists are a diverse collection of mostly single-celled organisms and some relatively simple multicellular relatives. Pictured in Figure 1.6 is an assortment of protists in a drop of pond water. Although protists were once placed in a single kingdom, it is now clear that they do not form a single natural group of species. Biologists are currently debating how to split the protists into groups that accurately reflect their evolutionary relationships.

The three remaining groups within Eukarya contain multicellular eukaryotes. These kingdoms are distinguished partly by their modes of nutrition. Kingdom Plantae consists of plants, which produce their own food by photosynthesis. The representative of kingdom Plantae in Figure 1.6 is a tropical bromeliad, a plant native to the Americas.

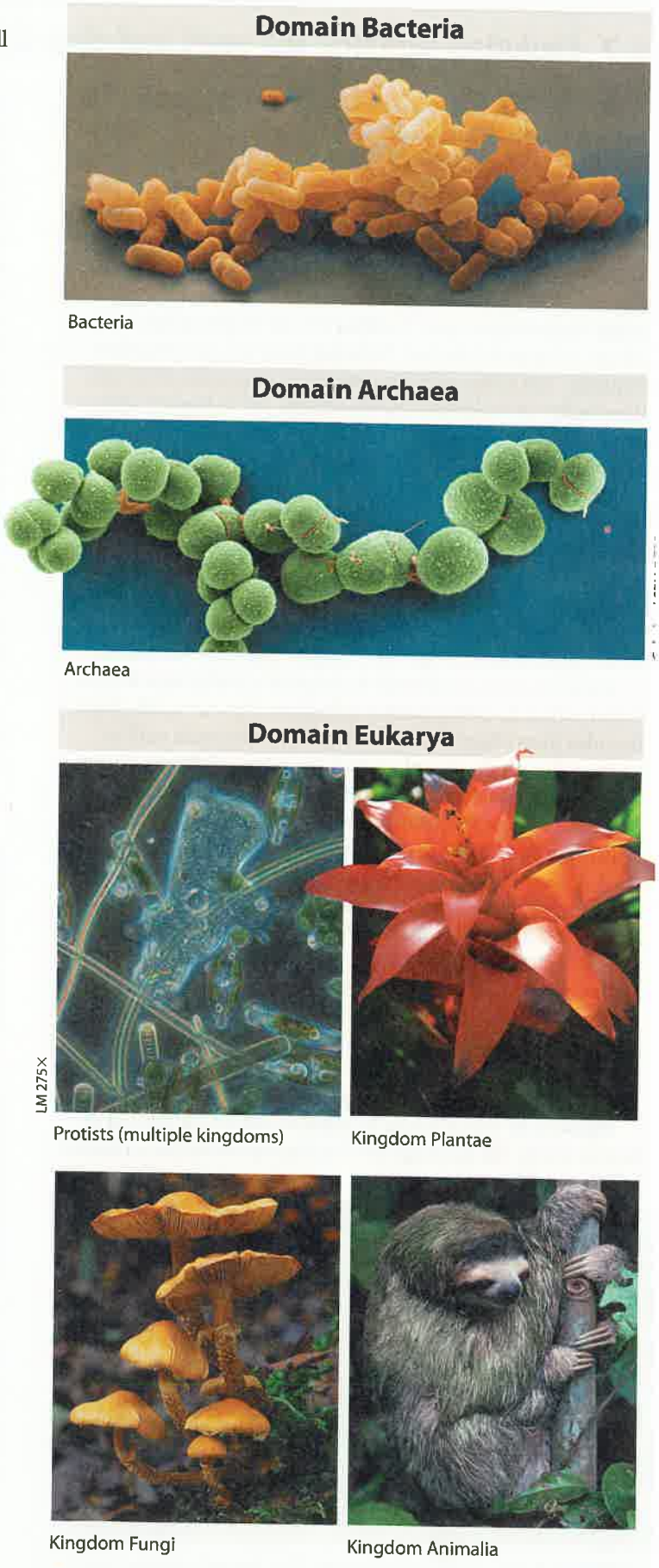
Kingdom Fungi, represented by the mushrooms in Figure 1.6, is a diverse group, whose members mostly decompose the remains of dead organisms and organic wastes and absorb the nutrients into their cells.

Animals obtain food by ingestion, which means they eat other organisms. Representing kingdom Animalia, the sloth in Figure 1.6 resides in the trees of Central and South American rain forests. There are actually members of two other groups in the sloth photo. The sloth is clinging to a tree (kingdom Plantae), and the greenish tinge in the animal's hair is a luxuriant growth of photosynthetic prokaryotes (domain Bacteria). This photograph exemplifies a theme reflected in our book's title: connections between living things. The sloth depends on trees for food and shelter; the tree uses nutrients from the decomposition of the sloth's feces; the prokaryotes gain access to the sunlight necessary for photosynthesis by living on the sloth; and the sloth is camouflaged from predators by its green coat.

The diversity of life and its interconnectedness are evident almost everywhere. Earlier we looked at life's unity in its shared properties, two basic types of cell structure, and common genetic code. And now we have briefly surveyed its diversity. In the next module, we explore how evolution explains both the unity and the diversity of life.

? **To which of the three domains of life do we belong?**

Eukarya



▲ **Figure 1.6** The three domains of life

1.7 Evolution explains the unity and diversity of life

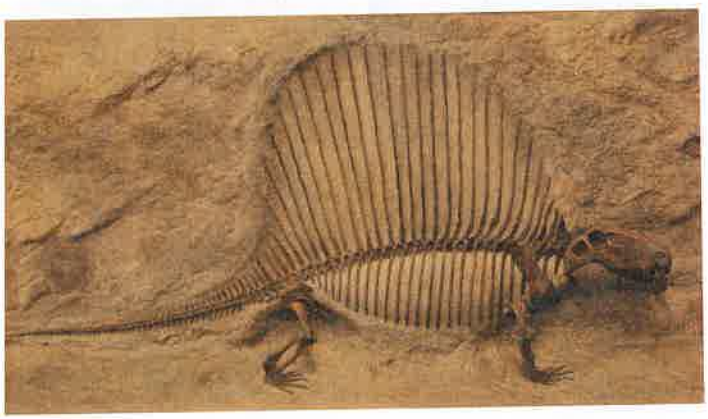
The history of life, as documented by fossils, is a saga of a changing Earth billions of years old, inhabited by an evolving cast of living forms (Figure 1.7A). And yet, there is relatedness among these diverse forms, and patterns of ancestry can be traced through the fossil record and other evidence. Evolution accounts for life's dual nature of kinship and diversity.

In November 1859, the English naturalist Charles Darwin (Figure 1.7B) published one of the most important and influential books ever written. Entitled *On the Origin of Species by Means of Natural Selection*, Darwin's book was an immediate bestseller and soon made his name almost synonymous with the concept of evolution. Darwin stands out in history with people like Newton and Einstein, scientists who synthesized comprehensive theories with great explanatory power.

The Origin of Species articulated two main points. First, Darwin presented a large amount of evidence to support the idea of **evolution**—that species living today are descendants of ancestral species. Darwin called his evolutionary theory "descent with modification." It was an insightful phrase, as it captured both the unity of life (descent from a common ancestor) and the diversity of life (modification as species diverged from their ancestors).

Darwin's second point was to propose a mechanism for evolution, which he called **natural selection**. Darwin synthesized this idea from observations that by themselves were neither profound nor original. Others had the pieces of the puzzle, but Darwin saw how they fit together. He started with the following two observations: (1) Individuals in a population vary in their traits, many of which are passed on from parents to offspring. (2) A population can produce far more offspring than the environment can support. From these two observations, Darwin inferred that those individuals with heritable traits best suited to the environment are more likely to survive and reproduce than are less well-suited individuals. As a result of this unequal reproductive success over many generations, a higher and higher proportion of individuals will have the advantageous traits. The result of natural selection is evolutionary adaptation, the accumulation of favorable traits in a population over time.

Figure 1.7C uses a simple example to show how natural selection works. (1) An imaginary beetle population has colonized an area where the soil has been blackened by a recent brush fire. Initially, the population varies extensively in the inherited coloration of individuals, from very light gray to charcoal. (2) A bird eats the beetles it sees most easily, the light-colored ones. This selective predation reduces the number of light-colored beetles and favors the survival and reproductive success of the darker beetles. (3) The surviving beetles reproduce. After several generations, the population is quite different from the original one. As a result of natural selection, the frequencies of the darker-colored beetles in the population have increased.



▲ **Figure 1.7A** Fossil of *Dimetrodon*. This 3-m-long carnivore was more closely related to mammals than to reptiles.

▲ **Figure 1.7B** Charles Darwin in 1859

Darwin realized that numerous small changes in populations caused by natural selection could eventually lead to major alterations of species. He proposed that new species could evolve as a result of the gradual accumulation of changes over long periods of time. (We'll explore evolution and natural selection in more detail in Chapters 13 and 14.)

We see the exquisite results of natural selection in every kind of organism. Each species has its own set of evolutionary adaptations that have evolved over time. Consider the two very

(1) Population with varied inherited traits

(2) Elimination of individuals with certain traits

(3) Reproduction of survivors

▲ **Figure 1.7C** An example of natural selection in action

▲ **Figure 1.7D** Examples of adaptations to different environments

different mammals shown in **Figure 1.7D**. The ground pangolin, found in southern and eastern Africa, has a tough body armor of overlapping scales, protecting it from most predators. The pangolin uses its unusually long tongue to prod ants out of their nests. The killer whale is a mammal adapted for life at sea. It breathes air through nostrils on the top of its head and communicates with its companions by emitting clicking sounds that carry in water. Killer whales use sound echoes to detect schools of fish or other prey. The pangolin's armor and the killer whale's echolocating ability arose over many, many generations as individuals with heritable traits that made them better adapted to the environment had greater reproductive success. Evolution—descent with modification—explains both how these two mammals are related and how they differ. Evolution is the core theme that makes sense of everything we know and learn about life.

? **How does natural selection adapt a population of organisms to its environment?**

On average, those individuals with heritable traits best suited to the local environment produce the greatest number of offspring. This unequal reproductive success increases the frequency of those traits in the population.

The Process of Science

1.8 Scientific inquiry is used to ask and answer questions about nature

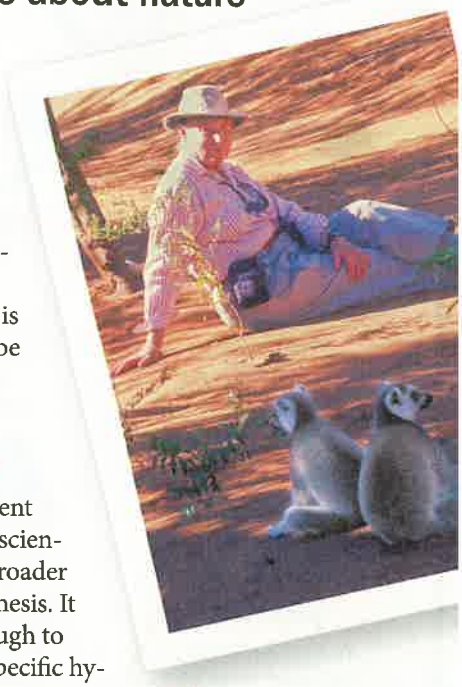
The word *science* is derived from a Latin verb meaning "to know." Science is a way of knowing—an approach to understanding the natural world. It stems from our curiosity about ourselves and the world around us. And it involves the process of inquiry—a search for information, explanations, and answers to specific questions. Scientific inquiry involves making observations, forming hypotheses, and testing predictions.

Recorded observations and measurements are the data of science. Some data are *quantitative*, such as numerical measurements. Other data may be descriptive, or *qualitative*. For example, primatologist Alison Jolly has spent over 40 years making observations of lemur behavior during field research in Madagascar, amassing data that is mostly qualitative **(Figure 1.8)**.

Collecting and analyzing observations can lead to conclusions based on a type of logic called **inductive reasoning**. This kind of reasoning derives generalizations from a large number of specific observations. "All organisms are made of cells" is an inductive conclusion based on the discovery of cells in every biological specimen observed over two centuries of time. Careful observations and the inductive conclusions they lead to are fundamental to understanding nature.

Observations often stimulate us to seek natural causes and explanations. Such inquiry usually involves the forming and testing of hypotheses. A **hypothesis** is a proposed explanation for a set of observations. A good hypothesis leads to predictions that scientists can test by recording additional observations or by designing experiments.

Deduction is the type of logic used to come up with ways to test hypotheses. In **deductive reasoning**, the logic flows from general premises to the specific results we should expect if the premises are true. If all organisms are made of cells (premise 1), and humans are organisms (premise 2), then humans are composed of cells (deduction). This deduction is a prediction that can be tested by examining human tissues.



▲ **Figure 1.8** Alison Jolly with her research subjects, ring-tailed lemurs

Theories in Science

How is a theory different from a hypothesis? A scientific **theory** is much broader in scope than a hypothesis. It is usually general enough to generate many new, specific hypotheses that can then be tested. And a theory is supported by a large and usually growing body of evidence. Theories that become widely adopted (such as the theory of evolution) explain a great diversity of observations and are supported by a vast accumulation of evidence.

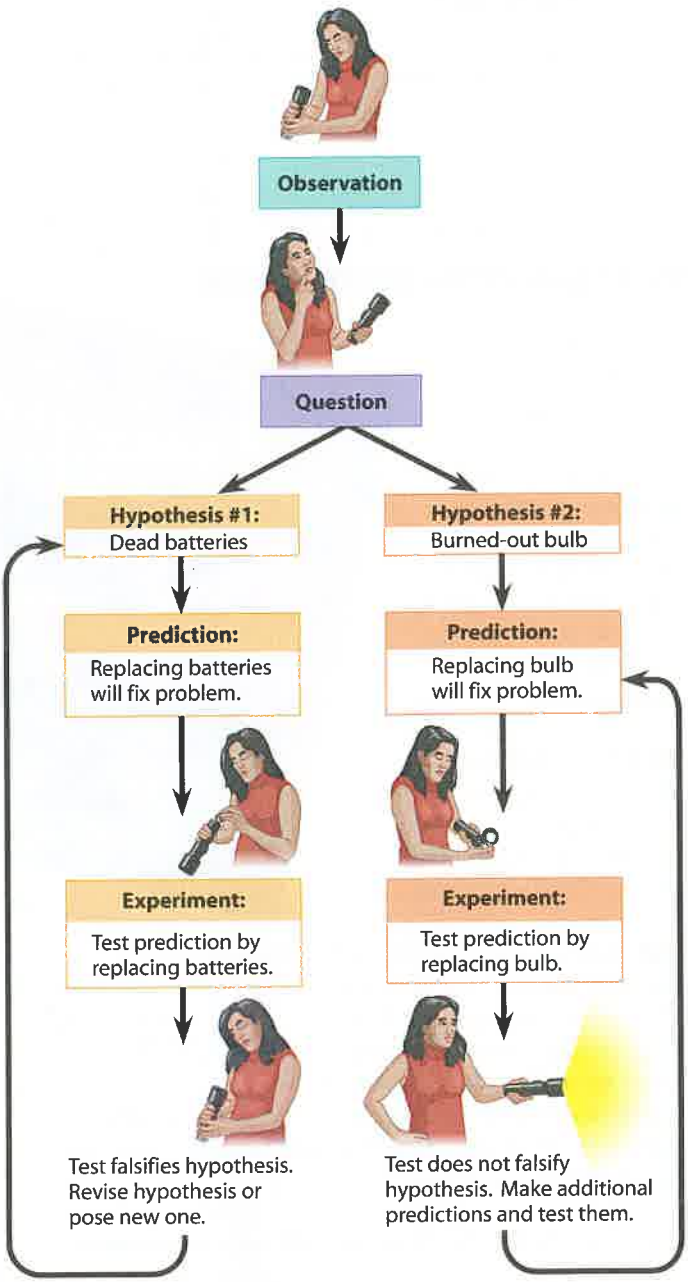
? **Contrast inductive reasoning with deductive reasoning.**

Inductive reasoning derives a generalization from many observations; deductive reasoning predicts specific outcomes from a general premise.

1.9 Scientists form and test hypotheses and share their results

Let's explore the elements of scientific inquiry with two case studies, one from everyday life and one from a research project.

A Case Study from Everyday Life We all use hypotheses in solving everyday problems. Let's say, for example, that your flashlight fails during a campout. That's an observation. The question is obvious: Why doesn't the flashlight work? Two reasonable hypotheses based on past experience are that either the batteries in the flashlight are dead or the bulb is burned out. Each of these hypotheses leads to predictions you can test with experiments or further observations. For example, the dead-battery hypothesis predicts that replacing the batteries with new ones will fix the problem. **Figure 1.9A** diagrams this campground inquiry.



▲ **Figure 1.9A** An example of hypothesis-based science

The flashlight example illustrates two important points. First, a hypothesis must be *testable*—there must be some way to check its validity. Second, a hypothesis must be *falsifiable*—there must be some observation or experiment that could show that it is not true. As shown on the left in Figure 1.9A, the hypothesis that dead batteries are the sole cause of the problem was falsified by replacing the batteries with new ones. As shown on the right, the burned-out-bulb hypothesis is the more likely explanation. Notice that testing supports a hypothesis not by proving that it is correct but by not eliminating it through falsification. Perhaps the bulb was simply loose and the new bulb was inserted correctly. Testing cannot *prove* a hypothesis beyond a shadow of doubt, because it is impossible to exhaust all alternative hypotheses. A hypothesis gains credibility by surviving multiple attempts to falsify it, while alternative hypotheses are eliminated by testing.

A Case Study from Science To learn more about how science works, let's examine some actual scientific research.

The story begins with a set of observations and generalizations. Many poisonous animals are brightly colored, often with distinctive patterns. This so-called warning coloration apparently says "dangerous species" to potential predators. But there are also mimics. These imposters resemble poisonous species but are actually harmless. A question that follows from these observations is: What is the function of mimicry? A reasonable hypothesis is that mimicry is an evolutionary adaptation that reduces the harmless animal's risk of being eaten.

In 2001, biologists David and Karin Pfennig, along with William Harcombe, one of their undergraduate students, designed an elegant set of field experiments to test the hypothesis that mimics benefit because predators confuse them with the harmful species. A venomous snake called the eastern coral snake has warning coloration: bold, alternating rings of red, yellow, and black (**Figure 1.9B,** on the facing page). (A *venomous* species delivers its poison by stinging, stabbing, or biting.) Predators rarely attack these snakes. The predators do not learn this avoidance behavior by trial and error; a first encounter with a coral snake would usually be deadly. Natural selection has apparently increased the frequency of predators that inherit an instinctive avoidance of the coral snake's coloration.

The nonvenomous scarlet king snake mimics the ringed coloration of the coral snake **(Figure 1.9C)**. Both types of snakes live in North and South Carolina, but king snakes are also found in regions that have no coral snakes.

The geographic distribution of these snakes made it possible for the researchers to test a key prediction of the mimicry hypothesis: Mimicry should help protect king snakes from predators, but only in regions where coral snakes also live. Avoiding snakes with warning coloration is an adaptation of predator populations that evolved in areas where coral snakes are present. Therefore, predators adapted to the warning coloration of coral snakes will attack king snakes less frequently than will predators in areas where coral snakes are absent.

▲ **Figure 1.9B** Eastern coral snake (venomous)

▲ **Figure 1.9C** Scarlet king snake (nonvenomous)

To test this prediction, Harcombe made hundreds of artificial snakes out of wire covered with a claylike substance called plasticine. He made two versions of fake snakes: an *experimental group* with the color pattern of king snakes and a *control group* of plain brown snakes as a basis of comparison.

The researchers placed equal numbers of the two types of artificial snakes in field sites throughout North and South Carolina, including the region where coral snakes are absent. After four weeks, they retrieved the snakes and recorded how many had been attacked by looking for bite or claw marks. The most common predators were foxes, coyotes, and raccoons, but black bears also attacked some of the snakes **(Figure 1.9D)**.

The data fit the key prediction of the mimicry hypothesis. The artificial king snakes were attacked less frequently than the artificial brown snakes only in field sites within the geographic range of the venomous coral snakes. The bar graph in **Figure 1.9E** summarizes the results.

This case study is an example of a **controlled experiment**, one that is designed to compare an experimental group (the artificial king snakes, in this case) with a control group (the artificial brown snakes). Ideally, the experimental and control groups differ only in the one factor the experiment is designed to test—in our example, the effect of the snakes' coloration on the behavior of predators. Without the control group, the researchers would not have been able to rule out other variables, such as the number of predators in the different test areas. The experimental design left coloration as the only factor that could account for the low predation rate on the artificial king snakes placed within the range of coral snakes.

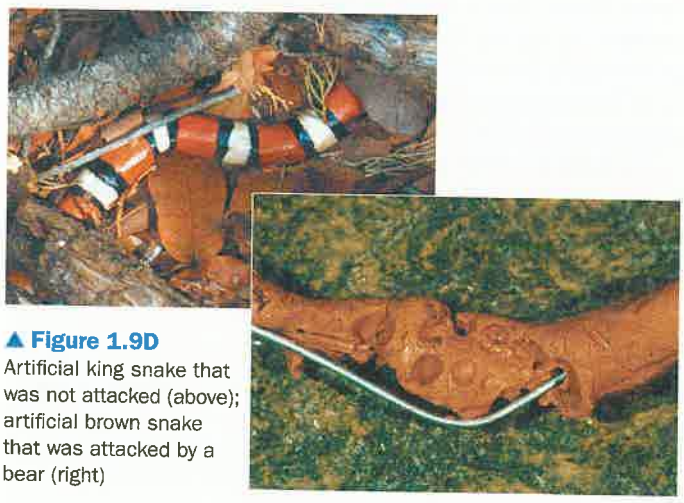
The Culture of Science Science is a social activity, with most scientists working in teams, which often include graduate and undergraduate students. Scientists share information through publications, seminars, meetings, and personal communication. The Internet has added a new medium for this exchange of ideas and data. Scientists build on what has been learned from earlier research and often check each other's claims by attempting to confirm observations or repeat experiments.

Science seeks natural causes for natural phenomena. Thus, the scope of science is limited to the study of structures and processes that we can directly observe and measure. Science can neither support nor falsify hypotheses about supernatural forces or explanations, for such questions are outside the bounds of science.

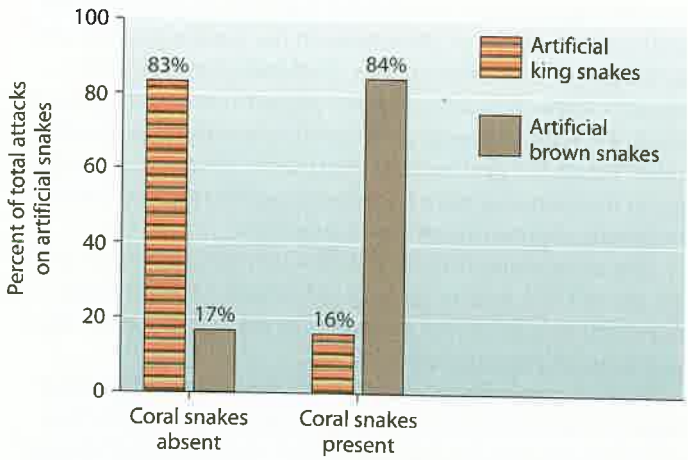
The process of science is necessarily repetitive: In testing a hypothesis, researchers may make observations that call for rejection of the hypothesis or at least revision and further testing. This process allows biologists to circle closer and closer to their best estimation of how nature works. As in all quests, science includes elements of challenge, adventure, and luck, along with careful planning, reasoning, creativity, cooperation, competition, patience, and persistence.

? **Why is it difficult to draw a conclusion from an experiment that does not include a control group?**

Without a control group, you don't know if the experimental outcome is due to the variable you are trying to test or to some other variable.



▲ **Figure 1.9D** Artificial king snake that was not attacked (above); artificial brown snake that was attacked by a bear (right)



▲ **Figure 1.9E** Results of mimicry experiment

Biology and Everyday Life

CONNECTION

1.10 Biology, technology, and society are connected in important ways

Many issues facing society are related to biology (Figure 1.10). Most of these issues also involve our expanding technology. Science and technology are interdependent, but their basic goals differ. The goal of science is to understand natural phenomena. In contrast, the goal of **technology** is to apply scientific knowledge for some specific purpose. Scientists often speak of "discoveries," while engineers more often speak of "inventions." The beneficiaries of those inventions also include scientists, who use new technology in their research. And scientific discoveries often lead to the development of new technologies.

Technology depends less on the curiosity that drives basic science than on the needs and wants of people and on the social environment of the times. Debates about technology center more on "should we do it" than "can we do it." Should insurance companies have access to individuals' DNA information? Should we permit research with embryonic stem cells?

Technology has improved our standard of living in many ways, but not without adverse consequences. Technology that keeps people healthier has enabled Earth's population to grow 10-fold in the past three centuries and to more than double to 6.8 billion in just the past 40 years. The environmental effects of this growth can be devastating. Global climate change, toxic wastes, deforestation, nuclear accidents, and extinction of species are just some of the repercussions of more and more people wielding more and more technology. Science can help us identify such problems and provide insight into what course of action may prevent further damage. But solutions to these problems have as much to do with politics, economics, and cultural values as with science and technology. Now that science and technology have become such powerful aspects of society, every citizen has a responsibility to develop a reasonable amount of scientific literacy. The crucial science-technology-society relationship is a theme that adds to the significance of any biology course.

▲ **Figure 1.10** Biology and technology in the news

? **How do science and technology interact?**

New scientific discoveries may lead to new technologies; new technologies may increase the ability of scientists to search for new knowledge.

EVOLUTION CONNECTION

1.11 Evolution is connected to our everyday lives

Evolution is the core theme of biology. To emphasize the centrality of evolution to biology, we include an Evolution Connection module in each chapter in this book. But is evolution connected to your everyday life? And if so, in what ways?

Biologists now recognize that differences in DNA among individuals, populations, and species reflect the patterns of evolutionary change. The new technology of automatic DNA-sequencing machines has enabled scientists to determine the order of the billions of DNA bases in the human genome and in the genomes of other species. Comparisons of those sequences allow us to identify genes shared across many species, study the actions of such genes in other species, and, in some cases, search for new medical treatments. Identifying beneficial genes in relatives of our crop plants has permitted the breeding or genetic engineering of enhanced crops.

The recognition that DNA differs between people has led to the use of DNA tests to identify individuals. DNA profiling is now used to help convict or exonerate the accused, determine paternity, and identify remains.

Evolution teaches us that the environment is a powerful selective force for traits that best adapt populations to their environment. We are major agents of environmental change when we take drugs to combat infection or grow crops in pesticide-dependent monocultures or alter Earth's habitats. We have seen the effects of such environmental changes in antibiotic-resistant bacteria, pesticide-resistant pests, endangered species, and increasing rates of extinction.

How can evolutionary theory help? It can help us be more judicious in our use of antibiotics and pesticides and help us develop strategies for conservation efforts. It can help us create flu vaccines and HIV drugs by tracking the rapid evolution of these viruses. It can identify new sources of drugs. For example, by tracing the evolutionary history of the endangered Pacific Yew tree, once the only source of the cancer drug Taxol, scientists have discovered similar compounds in more common trees.

We hope this book will help you develop an appreciation for evolution and biology and help you apply your new knowledge to evaluating issues ranging from your personal health to the well-being of the whole world. Biology offers us a deeper understanding of ourselves and our planet and a chance to more fully appreciate life in all of its diversity.

? **How might an understanding of evolution contribute to the development of new drugs?**

As one example, we can find organisms that share our genes and similar cellular processes and test the actions of potential drugs in these organisms.

CHAPTER 1 REVIEW

For Practice Quizzes, BioFlix, MP3 Tutors, and Activities, go to www.masteringbiology.com.

Reviewing the Concepts

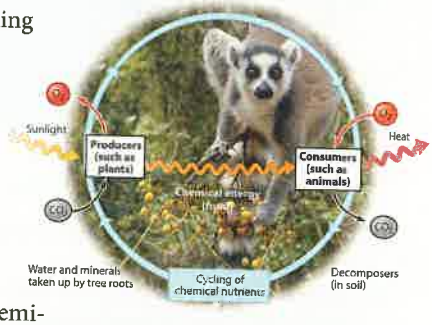
Themes in the Study of Biology (1.1–1.4)

1.1 All forms of life share common properties. Biology is the scientific study of life. Properties of life include order, reproduction, growth and development, energy processing, response to the environment, regulation, and evolutionary adaptation.

1.2 In life's hierarchy of organization, new properties emerge at each level. Biological organization unfolds as follows: biosphere > ecosystem > community > population > organism > organ system > organ > tissue > cell > organelle > molecule. Emergent properties result from the interactions among component parts.

1.3 Cells are the structural and functional units of life. Eukaryotic cells contain membrane-enclosed organelles, including a nucleus containing DNA. Prokaryotic cells are smaller and lack such organelles. Structure is related to function at all levels of biological organization. Systems biology models the complex interactions of biological systems, such as the molecular interactions within a cell.

1.4 Organisms interact with their environment, exchanging matter and energy. Ecosystems are characterized by the cycling of chemical nutrients from the atmosphere and soil through producers, consumers, decomposers, and back to the environment. Energy flows one way through an ecosystem—entering as sunlight, converted to chemical energy by producers, passed on to consumers, and exiting as heat.

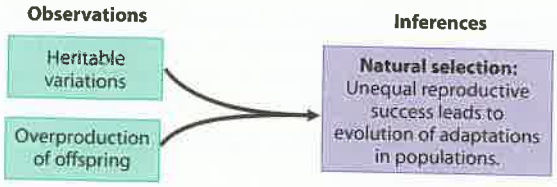


Evolution, the Core Theme of Biology (1.5–1.7)

1.5 The unity of life is based on DNA and a common genetic code. DNA is responsible for heredity and for programming the activities of a cell. A species' genes are coded in the sequences of the four building blocks making up DNA's double helix.

1.6 The diversity of life can be arranged into three domains. Taxonomy names species and classifies them into a system of broader groups. Domains Bacteria and Archaea consist of prokaryotes. The eukaryotic domain, Eukarya, includes various protists and the kingdoms Fungi, Plantae, and Animalia.

1.7 Evolution explains the unity and diversity of life. Darwin synthesized the theory of evolution by natural selection.



The Process of Science (1.8–1.9)

1.8 Scientific inquiry is used to ask and answer questions about nature. Scientists use inductive reasoning to draw general conclusions from many observations. They form hypotheses and use deductive reasoning to make predictions. Data may be qualitative or quantitative. A scientific theory is broad in scope, generates new hypotheses, and is supported by a large body of evidence.

1.9 Scientists form and test hypotheses and share their results. Predictions can be tested with experiments, and results can either falsify or support the hypothesis. In a controlled experiment, the use of control and experimental groups helps to demonstrate the effect of a single variable. Science is a social process: scientists share information and review each other's results.

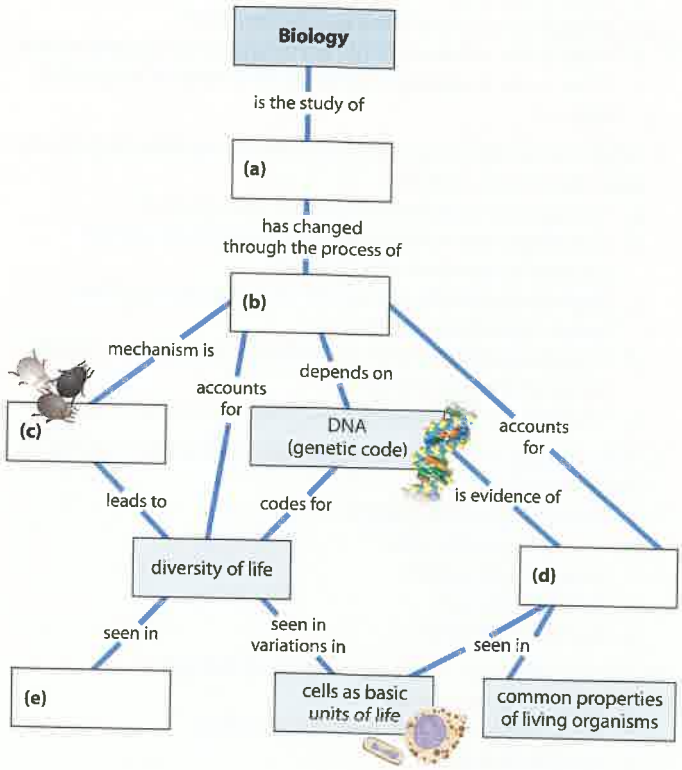
Biology and Everyday Life (1.10–1.11)

1.10 Biology, technology, and society are connected in important ways. Technological advances stem from scientific research, and research benefits from new technologies.

1.11 Evolution is connected to our everyday lives. Evolutionary theory is useful in medicine, agriculture, forensics, and conservation. Human-caused environmental changes are powerful selective forces that affect the evolution of many species.

Connecting the Concepts

1. Biology can be described as having both a vertical scale and a horizontal scale. Explain what that means.
2. Complete the following map organizing some of biology's major concepts.



Testing Your Knowledge

Multiple Choice

3. Which of the following best describes the logic of the scientific process?
   a. If I generate a testable hypothesis, tests and observations will support it.
   b. If my prediction is correct, it will lead to a testable hypothesis.
   c. If my observations are accurate, they will not falsify my hypothesis.
   d. If my hypothesis is correct, I can make predictions and my results will not falsify my hypothesis.
   e. If my predictions are good and my tests are right, they will prove my hypothesis.

4. Single-celled amoebas and bacteria are grouped into different domains because
   a. amoebas eat bacteria.
   b. bacteria are not made of cells.
   c. bacterial cells lack a membrane-enclosed nucleus.
   d. bacteria decompose amoebas.
   e. amoebas are motile; bacteria are not.

5. A biologist studying interactions among the protists in an ecosystem could *not* be working at which level in life's hierarchy? (*Choose carefully and explain your answer.*)
   a. the population level
   b. the molecular level
   c. the community level
   d. the organism level
   e. the organ level

6. Which of the following questions is outside the realm of science?
   a. Which organisms play the most important role in energy input to a forest?
   b. What percentage of music majors take a biology course?
   c. What is the physical nature of the universe?
   d. What is the influence of the supernatural on current events?
   e. What is the dominance hierarchy in a troop of ring-tailed lemurs?

7. Which of the following statements best distinguishes hypotheses from theories in science?
   a. Theories are hypotheses that have been proved.
   b. Hypotheses are tentative guesses; theories are correct answers to questions about nature.
   c. Hypotheses usually are narrow in scope; theories have broad explanatory power.
   d. Hypotheses and theories are different terms for essentially the same thing in science.
   e. Theories cannot be falsified; hypotheses can be falsified.

8. Which of the following best demonstrates the unity among all living organisms?
   a. descent with modification
   b. common genetic code
   c. emergent properties
   d. natural selection
   e. the three domains

9. The core idea that makes sense of all of biology is
   a. the process of science.
   b. the correlation of function with structure.
   c. systems biology.
   d. evolution.
   e. the emergence of life at the level of the cell.

Describing, Comparing, and Explaining

10. In an ecosystem, how is the movement of energy similar to that of chemical nutrients, and how is it different?

11. Explain the role of heritable variations in Darwin's theory of natural selection.

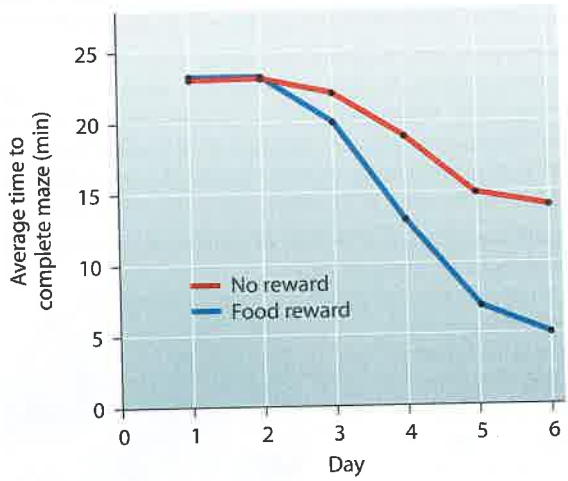
12. Explain what is meant by this statement: The scientific process is not a rigid method.

13. Contrast technology with science. Give an example of each to illustrate the difference.

14. Explain what is meant by this statement: Natural selection is an editing mechanism rather than a creative process.

Applying the Concepts

15. The graph below shows the results of an experiment in which mice learned to run through a maze.



   a. State the hypothesis and prediction that you think this experiment tested.
   b. Which was the control group and which the experimental? Why was a control group needed?
   c. List some variables that must have been controlled so as not to affect the results.
   d. Do the data support the hypothesis? Explain.

16. In an experiment similar to the mimicry experiment described in Module 1.9, a researcher counted more predator attacks on artificial king snakes in areas with coral snakes than in areas outside the range of coral snakes. From those numbers, the researcher concluded that the mimicry hypothesis is false. Do you think this conclusion is justified? Why or why not?

17. The fruits of wild species of tomato are tiny compared to the giant beefsteak tomatoes available today. This difference in fruit size is almost entirely due to the larger number of cells in the domesticated fruits. Plant biologists have recently discovered genes that are responsible for controlling cell division in tomatoes. Why would such a discovery be important to producers of other kinds of fruits and vegetables? To the study of human development and disease? To our basic understanding of biology?

18. The news media and popular magazines frequently report stories that are connected to biology. In the next 24 hours, record the ones you hear or read about in three different sources and briefly describe the biological connections in each story.

Answers to all questions can be found in Appendix 4.