Introduction: Evolution and the Foundations of Biology

KEY CONCEPTS

1.1 Studying the diverse forms of life reveals common themes

1.2 The Core Theme: Evolution accounts for the unity and diversity of life

1.3 Biological inquiry entails forming and testing hypotheses based on observations of nature

▼ **Figure 1.1** What can this beach mouse teach us about biology?

Make Connections The study of life offers boundless opportunity for discovery, yet underlying it all are four Big Ideas.

Big Idea 1: The process of evolution drives the diversity and unity of life.

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis.

Big Idea 3: Living systems store, retrieve, transmit, and respond to information essential to life processes.

Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.

OVERVIEW

Inquiring About Life

The brilliant white sand dunes and sparse clumps of beach grass along the Florida seashore afford little cover for the beach mice that live there. However, a beach mouse's light, dappled fur acts as camouflage, allowing the mouse to blend into its surroundings **(Figure 1.1)**. Although mice of the same species (oldfield mice, *Peromyscus polionotus*) also inhabit nearby inland areas, the inland mice are much darker in color, matching the darker soil and vegetation where they live **(Figure 1.2)**. This close match of each mouse to its environment is vital for survival, since hawks, herons, and other sharp-eyed predators periodically scan the landscape for food. How has the color of each mouse come to be so well matched, or *adapted*, to the local background?

An organism's adaptations to its environment, such as camouflage that helps protect it from predators, are the result of **evolution**, the process of change that has transformed life from its beginnings to the astounding array of organisms today. Evolution is the fundamental principle of biology and the core theme of this book.

Although biologists know a great deal about life on Earth, many mysteries remain. The question of how the mice's coats have come to match the colors of their habitats is just one example. Posing questions about the living world and seeking answers through scientific inquiry are the central activities of **biology**, the scientific study of life. Biologists' questions can be ambitious. They may ask how a single tiny cell becomes a tree or a dog, how the human mind works, or how the different forms of life in a forest interact. When questions occur to you as you observe the living world, you are already thinking like a biologist.

How do biologists make sense of life's diversity and complexity? This opening chapter sets up a framework for answering this question. The first part of the chapter provides a panoramic view of the biological "landscape," organized around a set of unifying themes. We'll then focus on biology's core theme, evolution. Finally, we'll examine the process of scientific inquiry—how scientists ask and attempt to answer questions about the natural world.

▶ **Figure 1.2 An "inland" oldfield mouse (*Peromyscus polionotus*).** This mouse has a much darker back, side, and face than mice of the same species that inhabit sand dunes.

CONCEPT 1.1

Studying the diverse forms of life reveals common themes

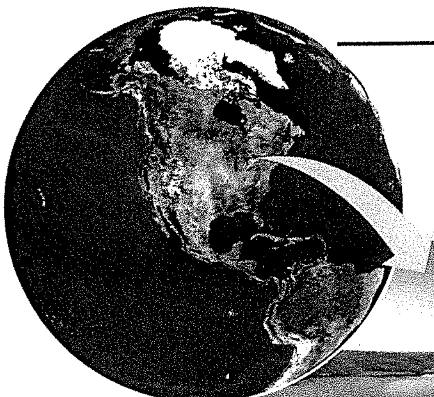
Biology is a subject of enormous scope, and exciting new biological discoveries are being made every day. How can you organize and make sense of all the information you'll encounter as you study biology? Focusing on a few big ideas—ways of thinking about life that will still hold true decades from now—will help. Here, we'll describe five unifying themes to serve as touchstones as you proceed through this book.

Theme: New Properties Emerge at Successive Levels of Biological Organization

ORGANIZATION The study of life extends from the microscopic scale of the molecules and cells that make up organisms to the global scale of the entire living planet. As biologists, we can divide this enormous range into different levels of biological organization.

Imagine zooming in from space to take a closer and closer look at life on Earth. It is spring in Ontario, Canada, and our destination is a local forest, where we will eventually narrow our focus down to the molecules that make up a maple leaf. **Figure 1.3** narrates this journey into life, as the numbers guide

▼ Figure 1.3 Exploring Levels of Biological Organization

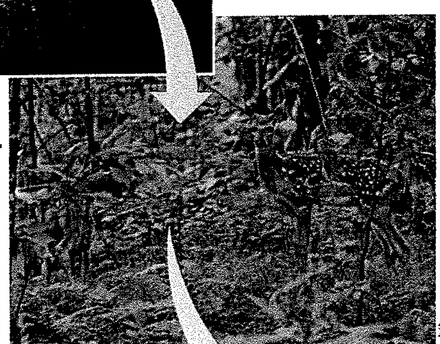


◀ 1 The Biosphere

Even from space, we can see signs of Earth's life—in the green mosaic of the forests, for example. We can also see the scale of the entire biosphere, which consists of all life on Earth and all the places where life exists: most regions of land, most bodies of water, the atmosphere to an altitude of several kilometers, and even sediments far below the ocean floor.

◀ 2 Ecosystems

Our first scale change brings us to a North American forest with many deciduous trees (trees that lose their leaves and grow new ones each year). A deciduous forest is an example of an ecosystem, as are grasslands, deserts, and coral reefs. An ecosystem consists of all the living things in a particular area, along with all the nonliving components of the environment with which life interacts, such as soil, water, atmospheric gases, and light.



▶ 3 Communities

The array of organisms inhabiting a particular ecosystem is called a biological community. The community in our forest ecosystem includes many kinds of trees and other plants, various animals, mushrooms and other fungi, and enormous numbers of diverse microorganisms, which are living forms, such as bacteria, that are too small to see without a microscope. Each of these forms of life is called a *species*.

▶ 4 Populations

A population consists of all the individuals of a species living within the bounds of a specified area. For example, our forest includes a population of sugar maple trees and a population of white-tailed deer. A community is therefore the set of populations that inhabit a particular area.

▲ 5 Organisms

Individual living things are called organisms. Each of the maple trees and other plants in the forest is an organism, and so is each deer, frog, beetle, and other forest animals. The soil teems with microorganisms such as bacteria.

you through photographs illustrating the hierarchy of biological organization.

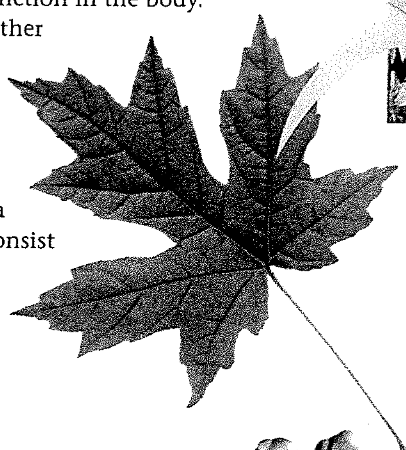
Zooming in at ever-finer resolution illustrates the principle of *reductionism*—the approach of reducing complex systems to simpler components that are more manageable to study. Reductionism is a powerful strategy in biology. For example, by studying the molecular structure of DNA that had been extracted from cells, James Watson and Francis Crick inferred the chemical basis of biological inheritance. However, although it has propelled many major discoveries, reductionism provides a necessarily incomplete view of life on Earth, as we'll discuss next.

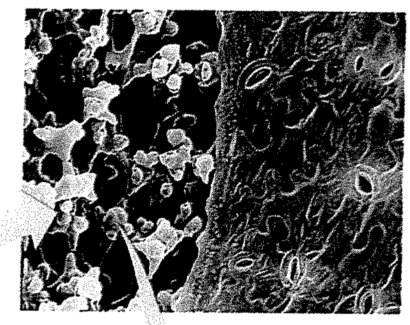
Emergent Properties

Let's reexamine Figure 1.3, beginning this time at the molecular level and then zooming out. Viewed this way, we see that at each level, novel properties emerge that are absent from the preceding one. These **emergent properties** are due to the arrangement and interactions of parts as complexity increases. For example, although photosynthesis occurs in an intact chloroplast, it will not take place in a disorganized test-tube mixture of chlorophyll and other chloroplast molecules. The coordinated processes of photosynthesis require a specific organization of these molecules in the chloroplast. Isolated components of living systems, acting as the objects of study in

▼ 6 Organs and Organ Systems

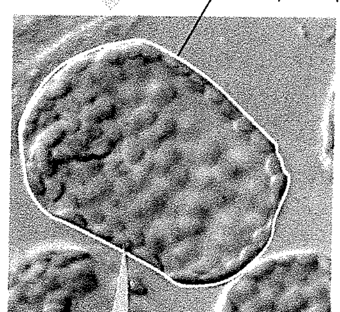
The structural hierarchy of life continues to unfold as we explore the architecture of more complex organisms. A maple leaf is an example of an organ, a body part that carries out a particular function in the body. Stems and roots are the other major organs of plants. The organs of complex animals and plants are organized into organ systems, each a team of organs that cooperate in a larger function. Organs consist of multiple tissues.





◀ 7 Tissues

To see the tissues of a leaf requires a microscope. Each tissue is a group of cells that work together, performing a specialized function. The leaf shown here has been cut on an angle. The honeycombed tissue in the interior of the leaf (left side of photo) is the main location of photosynthesis, the process that converts light energy to the chemical energy of sugar. The jigsaw puzzle–like "skin" on the surface of the leaf is a tissue called epidermis (right side of photo). The pores through the epidermis allow entry of the gas CO_2, a raw material for sugar production.

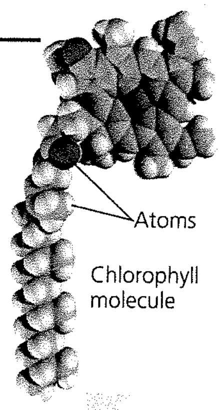


▲ 8 Cells

The cell is life's fundamental unit of structure and function. Some organisms are single cells, while others are multicellular. A single cell performs all the functions of life, while a multicellular organism has a division of labor among specialized cells. Here we see a magnified view of cells in a leaf tissue. One cell is about 40 micrometers (µm) across—about 500 of them would reach across a small coin. As tiny as these cells are, you can see that each contains numerous green structures called chloroplasts, which are responsible for photosynthesis.

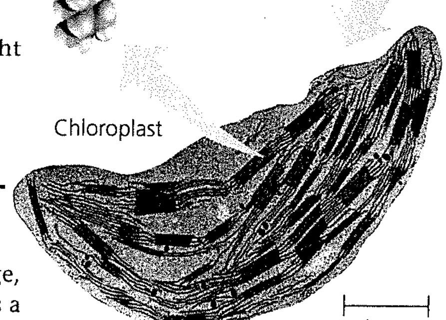
▶ 10 Molecules

Our last scale change drops us into a chloroplast for a view of life at the molecular level. A molecule is a chemical structure consisting of two or more units called atoms, represented as balls in this computer graphic of a chlorophyll molecule. Chlorophyll is the pigment molecule that makes a maple leaf green, and it absorbs sunlight during photosynthesis. Within each chloroplast, millions of chlorophyll molecules are organized into systems that convert light energy to the chemical energy of food.



▶ 9 Organelles

Chloroplasts are examples of organelles, the various functional components present in cells. This image, taken by a powerful microscope, shows a single chloroplast.



a reductionist approach to biology, typically lack some of the properties that emerge at higher levels of organization.

Emergent properties are not unique to life. A box of bicycle parts won't transport you anywhere, but if they are arranged in a certain way, you can pedal to your chosen destination. Compared to such nonliving examples, however, the unrivaled complexity of biological systems makes the emergent properties of life especially challenging to study.

To fully explore emergent properties, biologists today complement reductionism with **systems biology**, the exploration of a biological system by analyzing the interactions among its parts. A single leaf cell can be considered a system, as can a frog, an ant colony, or a desert ecosystem. By examining and modeling the dynamic behavior of an integrated network of components, systems biology enables us to pose new kinds of questions. For example, how does a drug that lowers blood pressure affect the functioning of organs throughout the body? At a larger scale, how does a gradual increase in atmospheric carbon dioxide alter ecosystems and the entire biosphere? Systems biology can be used to study life at all levels.

Structure and Function

At each level of the biological hierarchy, we find a correlation of structure and function. Consider the leaf in Figure 1.3: Its thin, flat shape maximizes the capture of sunlight by chloroplasts. More generally, analyzing a biological structure gives us clues about what it does and how it works. Conversely, knowing the function of something provides insight into its structure and organization. Many examples from the animal kingdom show a correlation between structure and function, including the hummingbird **(Figure 1.4)**. The hummingbird's anatomy allows the wings to rotate at the shoulder, so hummingbirds have the ability, unique among birds, to fly backward or hover in place. Hovering, the birds can extend their long slender beaks into flowers and feed on nectar. The elegant match of form and function in the structures of life is explained by natural selection, as we'll explore shortly.

▲ Figure 1.4 Form fits function in a hummingbird's body. The unusual bone structure of a hummingbird's wing allows the bird to rotate its wings in all directions, enabling it to fly backward and to hover while it feeds.

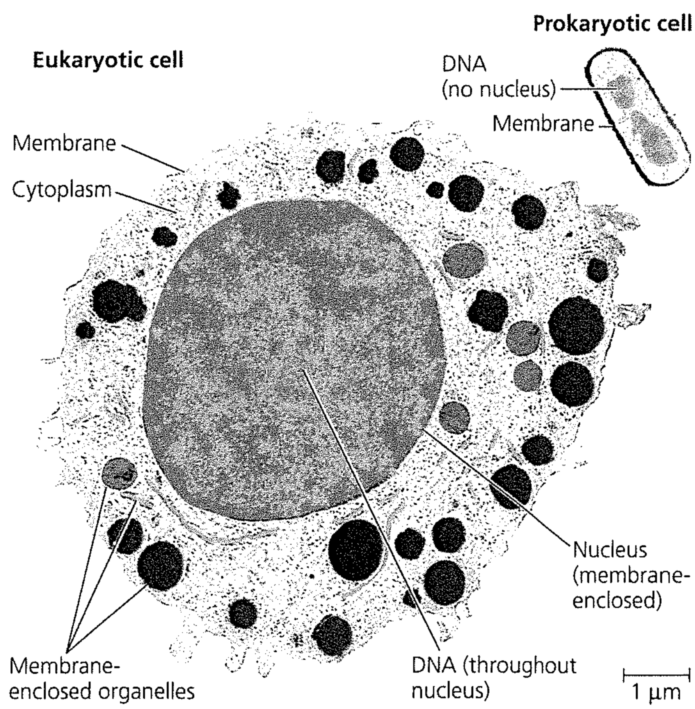
? *What other examples of form fitting function do you observe in this photograph?*

The Cell: An Organism's Basic Unit of Structure and Function

In life's structural hierarchy, the cell is the smallest unit of organization that can perform all required activities. In fact, the activities of organisms are all based on the activities of cells. For instance, the movement of your eyes as you read this sentence results from the activities of muscle and nerve cells. Even a process that occurs on a global scale, such as the recycling of carbon atoms, is the cumulative product of cellular functions, including the photosynthetic activity of chloroplasts in leaf cells.

All cells share certain characteristics. For instance, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. Nevertheless, we recognize two main forms of cells: prokaryotic and eukaryotic. The cells of two groups of single-celled microorganisms—bacteria (singular, *bacterium*) and archaea (singular, *archaean*)—are prokaryotic. All other forms of life, including plants and animals, are composed of eukaryotic cells.

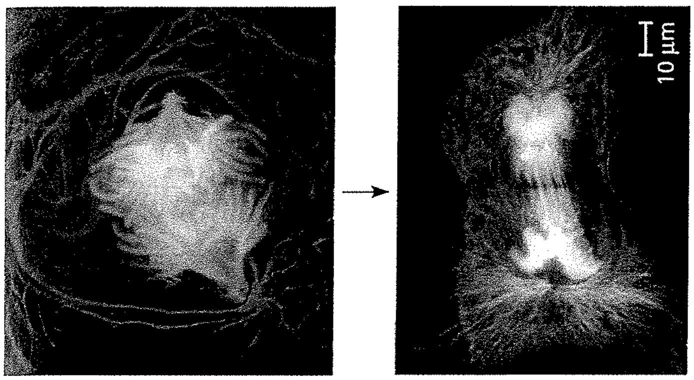
A **eukaryotic cell** contains membrane-enclosed organelles **(Figure 1.5)**. Some organelles, such as the DNA-containing nucleus, are found in the cells of all eukaryotes; other organelles are specific to particular cell types. For example, the chloroplast in Figure 1.3 is an organelle found only in eukaryotic cells that carry out photosynthesis. In contrast to eukaryotic cells, a **prokaryotic cell** lacks a nucleus or other membrane-enclosed organelles. Furthermore, prokaryotic cells are generally smaller than eukaryotic cells, as shown in Figure 1.5.



▲ Figure 1.5 Contrasting eukaryotic and prokaryotic cells in size and complexity.

Theme: Life's Processes Involve the Expression and Transmission of Genetic Information

INFORMATION Within cells, structures called chromosomes contain genetic material in the form of **DNA (deoxyribonucleic acid)**. In cells that are preparing to divide, the chromosomes may be made visible using a dye that appears blue when bound to the DNA **(Figure 1.6)**.



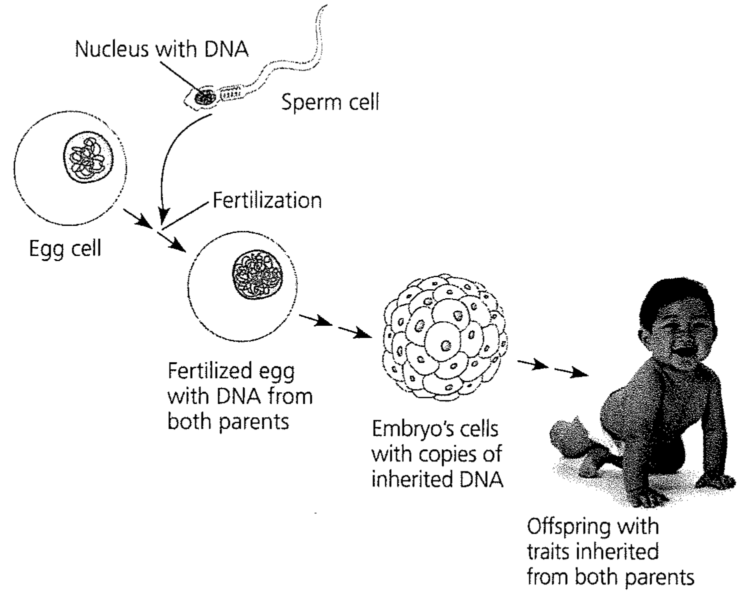
▲ **Figure 1.6 A lung cell from a newt divides into two smaller cells that will grow and divide again.**

DNA Structure and Function

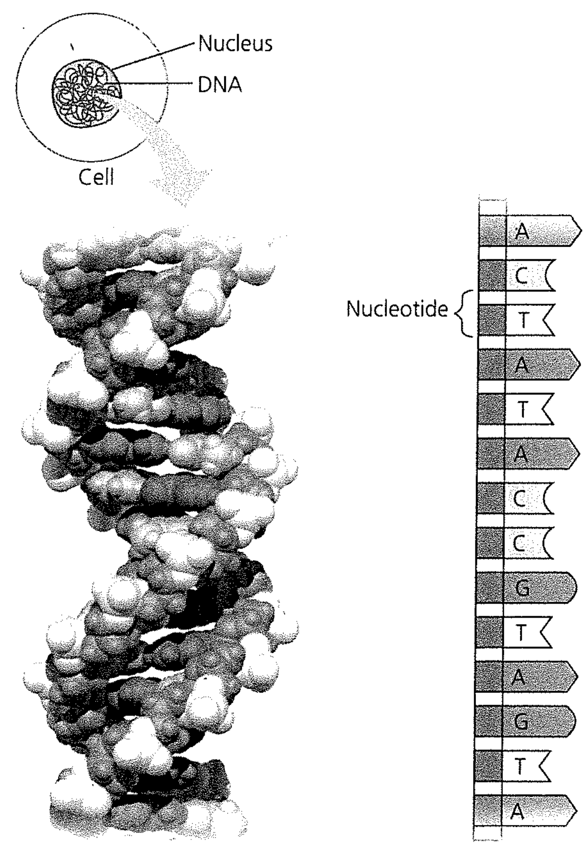
Each time a cell divides, the DNA is first *replicated*, or copied, and each of the two cellular offspring inherits a complete set of chromosomes, identical to that of the parent cell. Each chromosome contains one very long DNA molecule with hundreds or thousands of **genes**, each a stretch of DNA arranged along the chromosome. Transmitted from parents to offspring, genes are the units of inheritance. They encode the information necessary to build all of the molecules synthesized within a cell, which in turn establish that cell's identity and function. Each of us began as a single cell stocked with DNA inherited from our parents. The replication of that DNA during each round of cell division transmitted copies of the DNA to what eventually became the trillions of cells of the human body. As the cells grew and divided, the genetic information encoded by the DNA directed our development **(Figure 1.7)**.

The molecular structure of DNA accounts for its ability to store information. A DNA molecule is made up of two long chains, called strands, arranged in a double helix. Each chain is made up of four kinds of chemical building blocks called nucleotides, abbreviated A, T, C, and G **(Figure 1.8)**. The way DNA encodes information is analogous to how we arrange the letters of the alphabet into words and phrases with specific meanings. The word *rat*, for example, evokes a rodent; the words *tar* and *art*, which contain the same letters, mean very different things. We can think of nucleotides as a four-letter alphabet. Specific sequences of these four nucleotides encode the information in genes.

DNA provides the blueprints for making proteins, which are the major players in building and maintaining the cell and



▲ **Figure 1.7 Inherited DNA directs development of an organism.**



(a) DNA double helix. This model shows each atom in a segment of DNA. Made up of two long chains of building blocks called nucleotides, a DNA molecule takes the three-dimensional form of a double helix.

(b) Single strand of DNA. These geometric shapes and letters are simple symbols for the nucleotides in a small section of one chain of a DNA molecule. Genetic information is encoded in specific sequences of the four types of nucleotides. (Their names are abbreviated A, T, C, and G.)

▲ **Figure 1.8 DNA: The genetic material.**

carrying out its activities. For instance, a particular bacterial gene may specify a certain enzyme protein required to assemble the cell membrane, while a human gene may denote an antibody protein that helps fight off infection.

Genes control protein production indirectly, using a related molecule called RNA as an intermediary. The sequence of nucleotides along a gene is transcribed into RNA, which is then translated into a specific protein with a unique shape and function. This entire process, by which the information in a gene directs the manufacture of a cellular product, is called **gene expression**.

In translating genes into proteins, all forms of life employ essentially the same genetic code: A particular sequence of nucleotides says the same thing in one organism as it does in another. Differences between organisms reflect differences between their nucleotide sequences rather than between their genetic codes.

Not all RNA molecules in the cell are translated into protein; some RNAs carry out other important tasks. For example, we have known for decades that some types of RNA are actually components of the cellular machinery that manufactures proteins. Recently, scientists have discovered whole new classes of RNA that play other roles in the cell, such as regulating the functioning of protein-coding genes. All these RNAs are specified by genes, and the production of these RNAs is also referred to as gene expression. By carrying the instructions for making proteins and RNAs and by replicating with each cell division, DNA ensures faithful inheritance of genetic information from generation to generation.

Genomics: Large-Scale Analysis of DNA Sequences

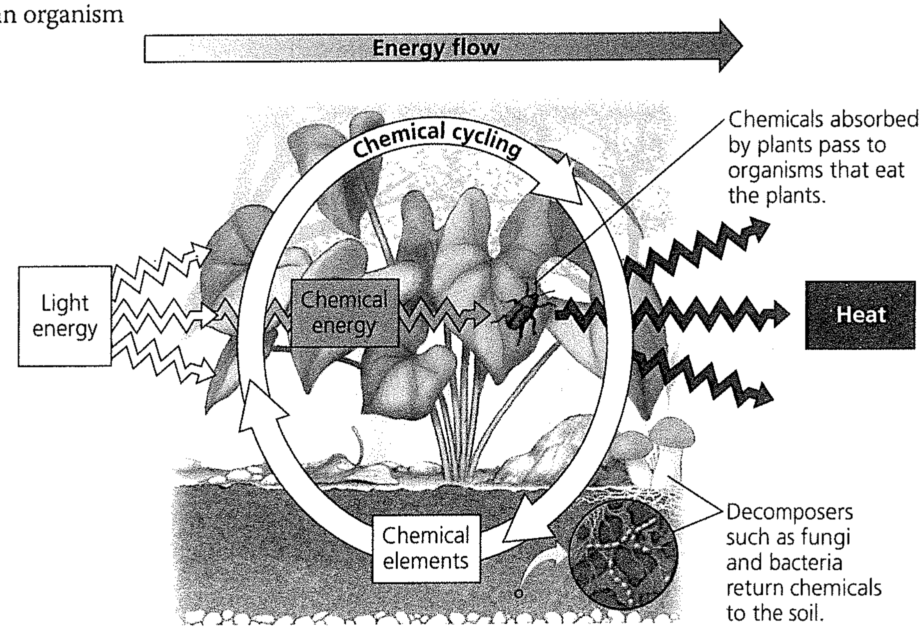
The entire "library" of genetic instructions that an organism inherits is called its **genome**. A typical human cell has two similar sets of chromosomes, and each set has approximately 3 billion nucleotide pairs of DNA. If the one-letter abbreviations for the nucleotides of one strand in a set were written in letters the size of those you are now reading, the genetic text would fill about 800 introductory biology textbooks.

Since the early 1990s, the pace at which researchers can determine the sequence of a genome has accelerated at an almost unbelievable rate, enabled by a revolution in technology. The entire sequence of nucleotides in the human genome is now known, along with the genome sequences of many other organisms, including other animals and numerous plants, fungi, bacteria, and archaea. To make sense of the deluge of data from genome-sequencing projects and the growing catalog of known gene functions, scientists are applying a systems biology approach at the cellular and molecular levels. Rather than investigating a single gene at a time, researchers study whole sets of genes in one or more species—an approach called **genomics**.

Three important research developments have made the genomic approach possible. One is "high-throughput" technology, tools that can analyze biological materials very rapidly. The second major development is **bioinformatics**, the use of computational tools to store, organize, and analyze the huge volume of data that results from high-throughput methods. The third key development is the formation of interdisciplinary research teams—melting pots of diverse specialists that may include computer scientists, mathematicians, engineers, chemists, physicists, and, of course, biologists from a variety of fields. Researchers in such teams aim to learn how the activities of all the proteins and nontranslated RNAs encoded by the DNA are coordinated in cells and in whole organisms.

Theme: Life Requires the Transfer and Transformation of Energy and Matter

ENERGY AND MATTER Moving, growing, reproducing, and the various cellular activities of life are work, and work requires energy. Input of energy, primarily from the sun, and transformation of energy from one form to another make life possible **(Figure 1.9)**. Chlorophyll molecules within plants' leaves convert the energy of sunlight to the chemical energy of food, the sugars produced during photosynthesis (see Figure 1.3). The chemical energy in sugar is then passed along by plants and other photosynthetic organisms (producers) to consumers. Consumers are organisms, such as animals, that feed on producers and other consumers.



▲ **Figure 1.9 Energy flow and chemical cycling.** There is a one-way flow of energy in an ecosystem: During photosynthesis, plants convert energy from sunlight to chemical energy (stored in sugars), which is used by plants and other organisms to do work and is eventually lost from the ecosystem as heat. In contrast, chemicals cycle between organisms and the physical environment.

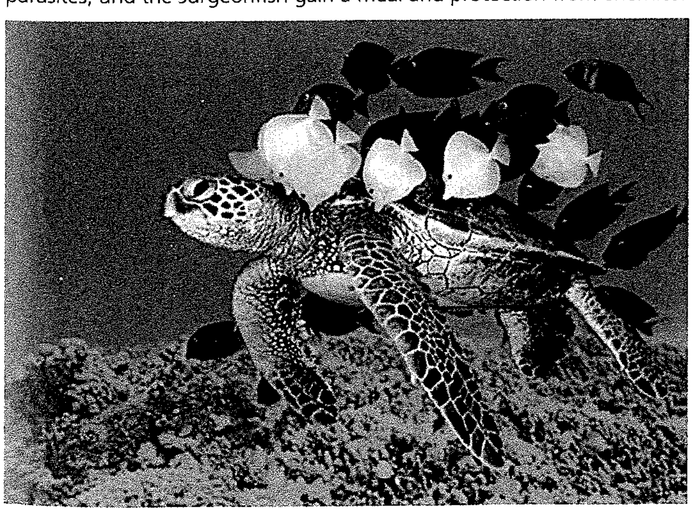
When an organism uses chemical energy to perform work, some of that energy is converted to thermal energy and is dissipated to the surroundings as heat. As a result, energy flows *through* an ecosystem, usually entering as light and exiting as heat. In contrast, chemical elements are recycled *within* an ecosystem (see Figure 1.9). Chemicals that a plant absorbs from the air or soil may be incorporated into the plant's body, then passed to an animal that eats the plant. Eventually, these chemicals will be returned to the environment by decomposers, such as bacteria and fungi, that break down waste products, organic debris, and the bodies of dead organisms. The chemicals are then available to be taken up by plants again, thereby completing the cycle.

Theme: Organisms Interact with Other Organisms and the Physical Environment

INTERACTIONS Turn again to Figure 1.3, this time focusing on the ecosystem, including the forest and its surroundings. Each organism interacts continuously with physical factors in its environment. The leaves of a tree, for example, absorb light from the sun, take in carbon dioxide from the air, and release oxygen to the air. The environment is also affected by the organisms living there. For example, a plant takes up water and minerals from the soil through its roots, and its roots break up rocks, thereby contributing to the formation of soil. On a global scale, plants and other photosynthetic organisms have generated all the oxygen in the atmosphere.

A tree also interacts with other organisms, such as soil microorganisms associated with its roots, insects that live in the tree, and animals that eat its leaves and fruit. Such interactions between organisms include those that are mutually beneficial (**Figure 1.10**); those in which one species benefits and the other is harmed (as when a lion kills and eats a zebra); and those in which both species are harmed (as when two plants compete for a soil resource that is in short supply). As we'll see, interactions between organisms not only affect the participants; they also affect how populations evolve over time.

▼ **Figure 1.10 An interaction between species that benefits both participants.** These surgeonfish feed on small organisms living on the sea turtle's skin. The sea turtle benefits from the removal of parasites, and the surgeonfish gain a meal and protection from enemies.



Evolution, the Core Theme of Biology

Having considered four of the unifying themes that run through this text, let's now turn to biology's core theme—evolution. Evolution makes sense of everything we know about living organisms. Life has been evolving on Earth for billions of years, resulting in a vast diversity of past and present organisms. But along with the diversity are many shared features. For example, while sea horses, jackrabbits, hummingbirds, crocodiles, and giraffes all look very different, their skeletons are basically similar. The scientific explanation for this unity and diversity—as well as for the adaptation of organisms to their environments—is evolution: the idea that the organisms living on Earth today are the modified descendants of common ancestors. In other words, we can explain traits shared by two organisms with the idea that they have descended from a common ancestor, and we can account for differences with the idea that heritable changes have occurred along the way. Many kinds of evidence support the occurrence of evolution and the theory that describes how it takes place. In the next section, we'll consider the fundamental concept of evolution in greater detail.

CONCEPT CHECK 1.1

1. For each biological level in Figure 1.3, write a sentence that includes components from the previous (lower) level of biological organization; for example: "A community consists of populations of the various species inhabiting a certain area."
2. Identify the theme or themes exemplified by (a) the sharp spines of a porcupine, (b) the cloning of a plant from a single cell, and (c) a hummingbird using sugar to power its flight.
3. **WHAT IF?** For each theme discussed in this section, give an example not mentioned in the text.

For suggested answers, see Appendix A.

CONCEPT 1.2

The Core Theme: Evolution accounts for the unity and diversity of life

EVOLUTION Diversity is a hallmark of life. To date, biologists have identified and named about 1.8 million species of organisms, and estimates of the number of living species range from about 10 million to over 100 million. The remarkably diverse forms of life on this planet arose by evolutionary processes. Before exploring the core theme of evolution further, let's first consider how biologists make sense of the great variety of lifeforms on this planet.

Classifying the Diversity of Life: The Three Domains of Life

Humans have a tendency to group diverse items according to their similarities and relationships to each other. Following this inclination, biologists have long used careful comparisons of form and function to classify life-forms into a hierarchy of increasingly inclusive groups. Consider, for example, the species known as the American black bear (*Ursus americanus*). Black bears belong to the same genus (*Ursus*) as the brown bear species and the polar bear species. Bringing together several similar genera forms a family, which in turn is a component of an order and then a class. For the black bear, this means being grouped with panda bears, raccoons, and others in the family Ursidae, with wolves in the order Carnivora, and with dolphins in the class Mammalia. These animals can be classified into still broader groupings: the phylum Chordata and the kingdom Animalia.

In the last few decades, new methods of assessing species relationships, especially comparisons of DNA sequences, have led to a reevaluation of the larger groupings. Although the reevaluation is ongoing, there is consensus among biologists that the kingdoms of life, whatever their number, can be further grouped into three so-called domains: Bacteria, Archaea, and Eukarya (**Figure 1.11**).

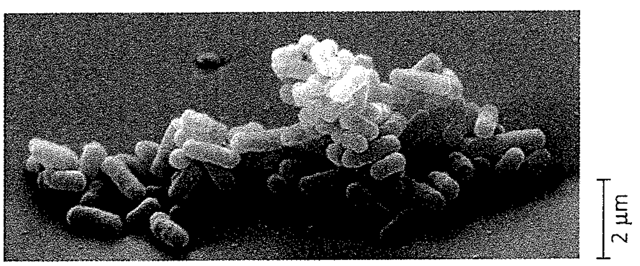
As you read earlier, the organisms making up two of the three domains—**Bacteria** and **Archaea**—are prokaryotic. All the eukaryotes (organisms with eukaryotic cells) are grouped in domain **Eukarya**. This domain includes three kingdoms of multicellular eukaryotes: Plantae, Fungi, and Animalia. These three kingdoms are distinguished partly by their modes of nutrition. Plants produce their own sugars and other food molecules by photosynthesis; fungi absorb dissolved nutrients from their surroundings; and animals obtain food by eating and digesting other organisms. Animalia is, of course, our own kingdom.

Unity in the Diversity of Life

As diverse as life is, it also displays remarkable unity. Earlier we mentioned both the similar skeletons of different vertebrate

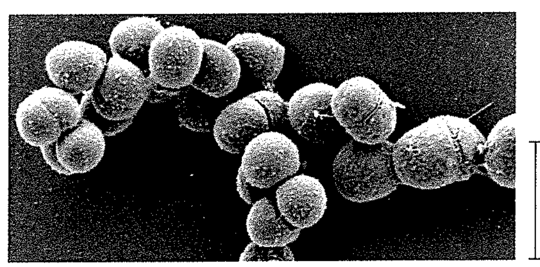
▼ **Figure 1.11 The three domains of life.**

(a) Domain Bacteria



Bacteria are the most diverse and widespread prokaryotes and are now classified into multiple kingdoms. Each rod-shaped structure in this photo is a bacterial cell.

(b) Domain Archaea



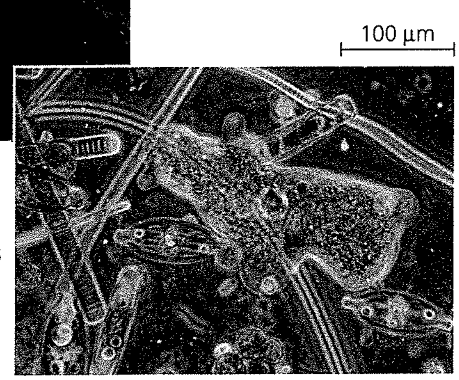
Some of the prokaryotes known as **archaea** live in Earth's extreme environments, such as salty lakes and boiling hot springs. Domain Archaea includes multiple kingdoms. Each round structure in this photo is an archaeal cell.

(c) Domain Eukarya

▲ **Kingdom Plantae** consists of terrestrial multicellular eukaryotes (land plants) that carry out photosynthesis, the conversion of light energy to the chemical energy in food.

▶ **Kingdom Fungi** is defined in part by the nutritional mode of its members (such as this mushroom), which absorb nutrients from outside their bodies.

◀ **Kingdom Animalia** consists of multicellular eukaryotes that ingest other organisms.



▶ **Protists** are mostly unicellular eukaryotes and some relatively simple multicellular relatives. Pictured here is an assortment of protists inhabiting pond water. Scientists are currently debating how to classify protists in a way that accurately reflects their evolutionary relationships.

animals and the universal genetic language of DNA (the genetic code). In fact, similarities between organisms are evident at all levels of the biological hierarchy.

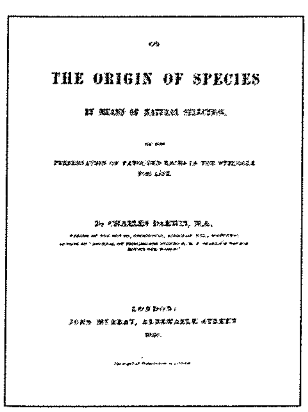
How can we account for life's dual nature of unity and diversity? The process of evolution, explained next, illuminates both the similarities and differences in the world of life and introduces another dimension of biology: the passage of time.

Charles Darwin and the Theory of Natural Selection

The history of life, as documented by fossils and other evidence, is the saga of a changing Earth billions of years old, inhabited by an evolving cast of living forms **(Figure 1.12)**. This view of life came into sharp focus in November 1859, when Charles Robert Darwin published one of the most influential books ever written, *On the Origin of Species by Means of Natural Selection* **(Figure 1.13)**.

▶ **Figure 1.12 Digging into the past.** Paleontologists carefully excavate the hind leg of a long-necked dinosaur (*Rapetosaurus krausei*) from rocks in Madagascar.

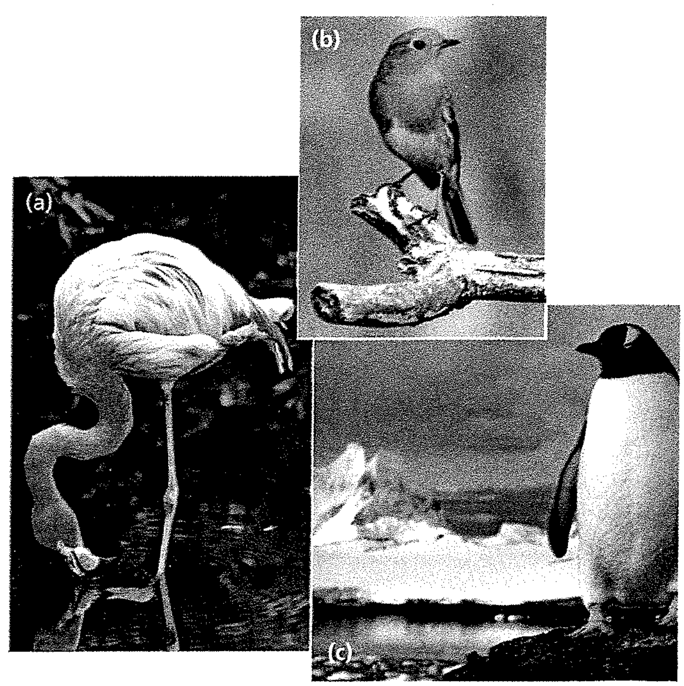
▶ **Figure 1.13 Charles Darwin in 1840.** His revolutionary book *The Origin of Species* was published in 1859.



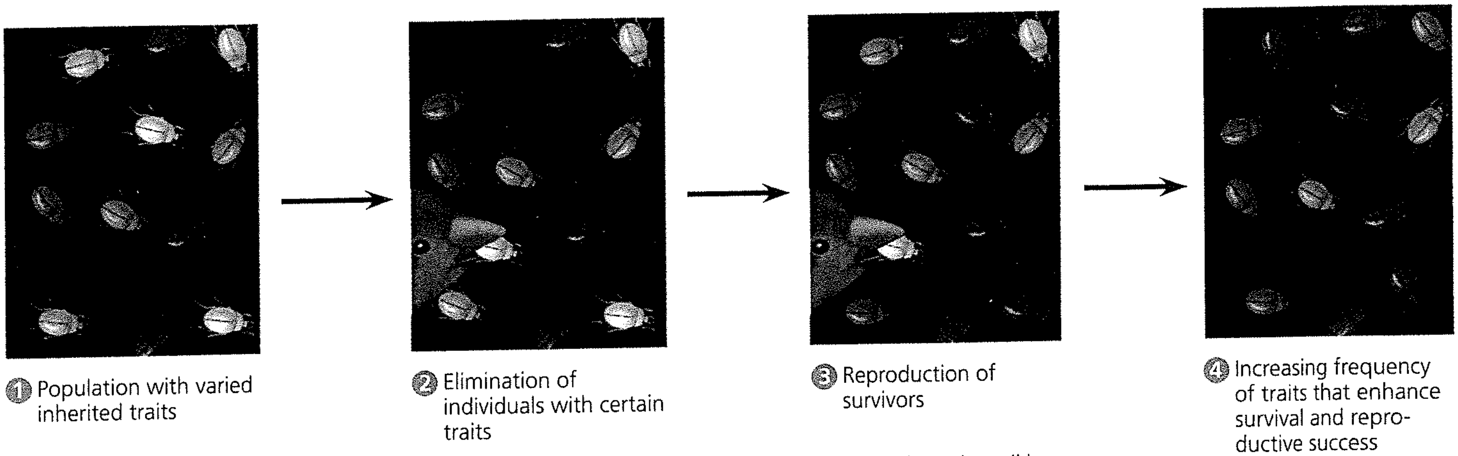
The Origin of Species articulated two main points. The first was that species have arisen from a succession of ancestors that differed from them. Darwin called this process "descent with modification." It was an insightful phrase, as it captured the duality of life's unity and diversity—unity in the kinship among species that descended from common ancestors, diver- sity in the modifications that evolved as species branched fron their common ancestors **(Figure 1.14)**. Darwin's second main point was his proposal that "natural selection" is a mechanism for descent with modification.

Darwin developed his theory of natural selection from observations that by themselves were not revolutionary. Others had described the pieces of the puzzle, but Darwin saw how they fit together. He started with the following three observations from nature: First, individuals in a population vary in their traits, many of which seem to be heritable, passed on from parents to offspring. Second, a population can produce far more offspring than can survive to produce offspring of their own. Competition is thus inevitable. Third, species generally are suited to their environments—in other words, they are adapted to their environments. For instance, various birds that feed on hard seeds tend to have especially strong beaks.

Darwin inferred that individuals with inherited traits that are better suited to the local environment are more likely to survive and reproduce than are less well-suited individuals. As a result, over many generations, a higher and higher proportion of individuals in a population will have the advantageous traits. Darwin called this mechanism of evolutionary



▲ **Figure 1.14 Unity and diversity among birds.** These three birds are variations on a common body plan. For example, each has feathers, a beak, and wings, but these features are highly specialized fo the birds' diverse lifestyles.



▲ **Figure 1.15 Natural selection.** This imaginary beetle population has colonized a locale where the soil has been blackened by a recent brush fire. Initially, the population varies extensively in the inherited coloration of the individuals, from very light gray to charcoal. For birds that prey on the beetles, it is easiest to spot the lighter ones.

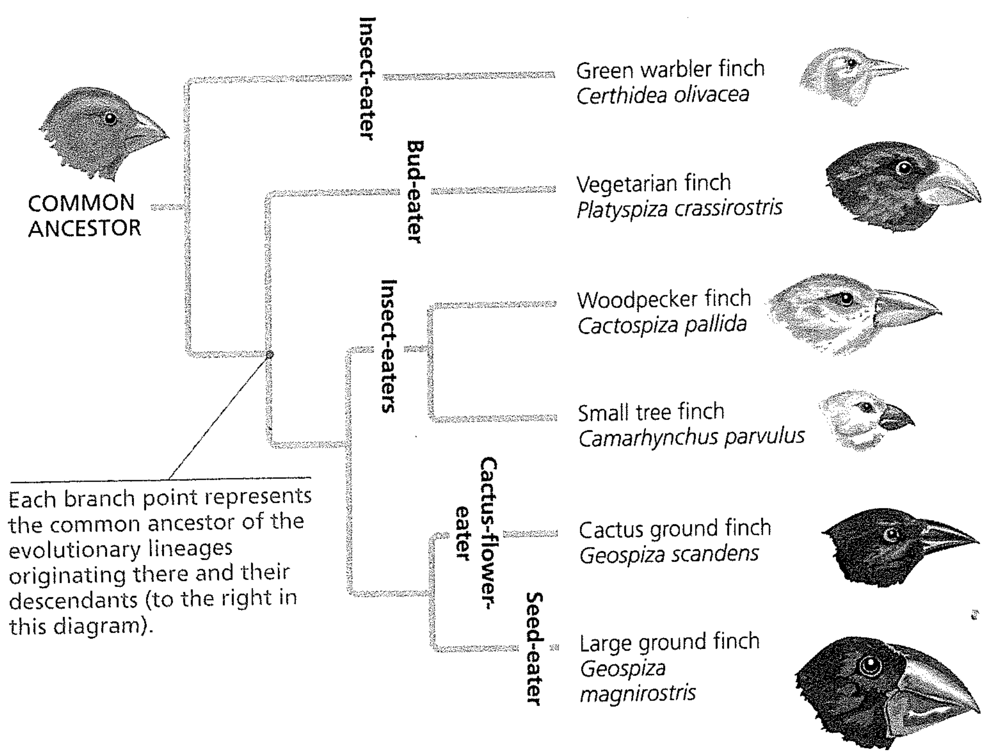
adaptation **natural selection** because the natural environment "selects" for the propagation of certain traits among naturally occurring variant traits in the population **(Figure 1.15)**.

The Tree of Life

For another example of unity and diversity, consider the human arm. Your forelimb has the same bones, joints, nerves, and blood vessels found in other limbs as diverse as the foreleg of a horse, the flipper of a whale, and the wing of a bat. Indeed, all mammalian forelimbs are anatomical variations of a common architecture. According to the Darwinian concept of descent with modification, the shared anatomy of mammalian limbs reflects inheritance of the limb structure from a common ancestor—the "prototype" mammal from which all other mammals descended. The diversity of mammalian forelimbs results from modification by natural selection operating over millions of years in different environmental contexts.

Darwin proposed that natural selection, by its cumulative effects over time, could cause an ancestral species to give rise to two or more descendant species. This could occur, for example, if one population of organisms fragmented into several subpopulations isolated in different environments. In these separate arenas of natural selection, a species could gradually radiate into multiple species as the geographically isolated populations adapted over many generations to different environmental conditions.

The "family tree" of six finch species in **Figure 1.16** illustrates a famous example of this process of radiation. Darwin collected specimens of these birds during his 1835 visit to the remote Galápagos Islands, 900 kilometers (km) off the Pacific coast of South America. The Galápagos finches are believed to have descended from an ancestral finch species that reached the archipelago from South America or the Caribbean. Over time, the Galápagos finches diversified from their ancestor as they adapted to different food sources on the various islands. Years after Darwin collected the finches, researchers began to sort out their evolutionary relationships, first from anatomical and geographic data and more recently using DNA sequence comparisons.



▲ **Figure 1.16 Descent with modification: finches on the Galápagos Islands.** This "tree" diagram illustrates a current model for the evolutionary relationships among some of the finches on the Galápagos. Note the different beaks, which are adapted to food sources on the different islands.

Biologists' diagrams of such evolutionary relationships generally take treelike forms, though the trees are often turned sideways as in Figure 1.16. Tree diagrams make sense: Just as an individual has a genealogy that can be diagrammed as a family tree, each species is one twig of a branching tree of life extending back in time through ancestral species more and more remote. Species that are very similar, such as the Galápagos finches, share a relatively recent common ancestor. But through an ancestor that lived much farther back in time, finches are related to sparrows, hawks, penguins, and all other birds. And birds, mammals, and all other vertebrates share a common ancestor even more ancient. Trace life back far enough, and we reach the early prokaryotes that inhabited Earth 3.5 billion years ago. We can recognize their vestiges in our own cells—in the universal genetic code, for example. Indeed, all of life is connected through its long evolutionary history.

CONCEPT CHECK 1.2

1. How is a mailing address analogous to biology's hierarchical classification system?
2. Explain why "editing" is an appropriate metaphor for how natural selection acts on a population's heritable variation.
3. **WHAT IF?** Recent evidence indicates that fungi and animals are more closely related to each other than either of these kingdoms is to plants. Draw a simple branching pattern that symbolizes the proposed relationship between these three kingdoms of multicellular eukaryotes.

For suggested answers, see Appendix A.

CONCEPT 1.3

Biological inquiry entails forming and testing hypotheses based on observations of 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 developed out of our human curiosity about ourselves, other life-forms, our planet, and the universe. Striving to make sense of our experiences seems to be one of our basic urges.

At the heart of science is **inquiry**, a search for information and explanations of natural phenomena. There is no formula for successful scientific inquiry, no single scientific method that researchers must rigidly follow. As in all quests, science includes elements of challenge, adventure, and luck, along with careful planning, reasoning, creativity, patience, and the persistence to overcome setbacks. Such diverse elements of inquiry make science far less structured than most people realize. That said, it is possible to distill certain characteristics that help to distinguish science from other ways of describing and explaining nature.

Scientists use a process of inquiry that includes making observations, forming logical hypotheses, and testing them. The process is necessarily repetitive: In testing a hypothesis, our observations may lead to conclusions that inspire revision of the original hypothesis or formation of a new one, thus leading to further testing. In this way, scientists circle closer and closer to their best estimation of the laws governing nature.

Making Observations

In the course of their work, scientists describe natural structures and processes as accurately as possible through careful observation and analysis of data. Observation is the use of the senses to gather information either directly or indirectly, such as with the help of microscopes or other tools that extend our senses. Recorded observations are called **data**. Put another way, data are items of information on which scientific inquiry is based.

The term *data* implies numbers to many people. But some data are *qualitative*, often in the form of recorded descriptions. For example, British primate researcher Jane Goodall spent decades recording her observations of chimpanzee behavior during field research in a Tanzanian jungle **(Figure 1.17)**. She also documented her observations with photographs and movies. Along with these qualitative data, Goodall also gathered and recorded volumes of *quantitative* data, a type of information generally expressed as numerical measurements and often organized into tables or graphs.

Collecting and analyzing observations can lead to important conclusions based on a type of logic called **inductive reasoning**. Through induction, we derive generalizations from a large number of specific observations. The generalization "All

▲ **Figure 1.17 Jane Goodall collecting qualitative data on chimpanzee behavior.** Goodall recorded her observations in field notebooks, often with sketches of the animals' behavior.

organisms are made of cells" was based on two centuries of microscopic observations made by biologists examining cells in diverse biological specimens. Careful observations and data analyses, along with the generalizations reached by induction, are fundamental to our understanding of nature.

Forming and Testing Hypotheses

Our innate curiosity often stimulates us to pose questions about the natural basis for the phenomena we observe in the world. What *caused* the diversification of finches on the Galápagos Islands? What *explains* the variation in coat color among mice of a single species, such as the beach and inland mice pictured in Figures 1.1 and 1.2? In science, answering such questions usually involves proposing and testing hypothetical explanations—that is, hypotheses.

In science, a **hypothesis** is a tentative answer to a well-framed question; it is an explanation on trial. The hypothesis is usually a rational accounting for a set of observations, based on the available data and guided by inductive reasoning. A scientific hypothesis leads to predictions that can be tested by making additional observations or by performing experiments.

We all use hypotheses in solving everyday problems. Let's say, for example, that your flashlight fails during a camp-out. That's an observation. The question is obvious: Why doesn't the flashlight work? Two reasonable hypotheses based on your experience are that (1) the batteries in the flashlight are dead or (2) the bulb is burnt out. Each of these alternative hypotheses leads to predictions you can test with experiments. For example, the dead-battery hypothesis predicts that replacing the batteries will fix the problem. Figuring things out in this way by trial and error is a hypothesis-based approach.

Deductive Reasoning

A type of logic called deduction is also built into the use of hypotheses in science. While induction entails reasoning from a set of specific observations to reach a general conclusion, **deductive reasoning** involves logic that flows in the opposite direction, from the general to the specific. From general premises, we extrapolate to the specific results we should expect if the premises are true. In the scientific process, deductions usually take the form of predictions of results that will be found if a particular hypothesis (premise) is correct. We then test the hypothesis by carrying out experiments or observations to see whether or not the results are as predicted. This deductive testing takes the form of "*If*. . . *then*" logic. In the case of the flashlight example: *If* the dead-battery hypothesis is correct, *then* the flashlight should work when you replace the batteries with new ones.

The flashlight inquiry demonstrates two other key points about the use of hypotheses in science. First, the initial observations may give rise to multiple hypotheses. The ideal is to design experiments to test all these candidate explanations. For instance, another of the many possible alternative hypotheses to explain our dead flashlight is that *both* the batteries *and* the bulb are bad, and you could design an experiment to test this. Second, we can never *prove* that a hypothesis is true. The dead-battery hypothesis stands out as the most likely explanation, but testing supports that hypothesis *not* by proving that it is correct, but rather by not eliminating it through falsification (proving it false). Replacing the batteries might have fixed the flashlight, but perhaps the endpiece had simply not been screwed on tight enough in the first place. No amount of experimental testing can prove a hypothesis beyond a shadow of doubt, because it is impossible to test *all* alternative hypotheses. A hypothesis gains credibility by surviving multiple attempts to falsify it while alternative hypotheses are eliminated (falsified) by testing.

Questions That Can and Cannot Be Addressed by Science

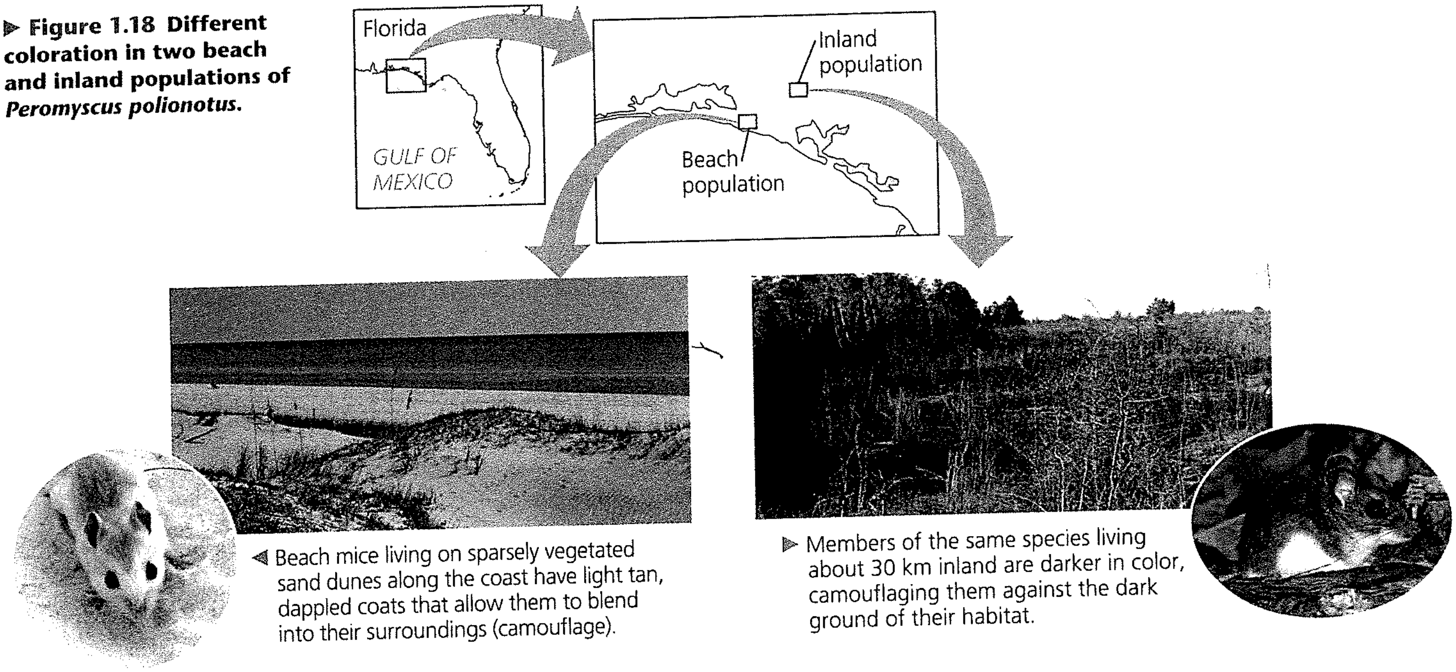
Scientific inquiry is a powerful way to learn about nature, but there are limitations to the kinds of questions it can answer. A scientific hypothesis must be falsifiable; there must be some observation or experiment that could reveal if such an idea is actually *not* true. The hypothesis that dead batteries are the sole cause of the broken flashlight could be falsified by replacing the old batteries with new ones and finding that the flashlight still doesn't work.

Not all hypotheses meet the criteria of science: You wouldn't be able to falsify the hypothesis that invisible campground ghosts are fooling with your flashlight! Because science requires natural explanations for natural phenomena, it can neither support nor falsify hypotheses that angels, ghosts, or spirits, whether benevolent or evil, cause storms, rainbows, illnesses, and cures. Such supernatural explanations are simply outside the bounds of science, as are religious matters, which are issues of personal faith.

A Case Study in Scientific Inquiry: Investigating Coat Coloration in Mouse Populations

Now that we have highlighted the key features of scientific inquiry—making observations and forming and testing hypotheses—you should be able to recognize these features in a case study of actual scientific research.

The story begins with a set of observations and inductive generalizations. Color patterns of animals vary widely in nature, sometimes even between members of the same species. What accounts for such variation? As you may recall, the two mice depicted at the beginning of this chapter are members of the same species (*Peromyscus polionotus*), but they reside in very different habitats. Beach mice live along the ocean on white sand dunes, whereas "inland" mice live on darker, loamy soil away from the shore **(Figure 1.18)**. Even a brief glance at the photographs in Figure 1.18 reveals a striking match of mouse coloration to environment. The natural predators of these mice, including hawks, owls, foxes, and coyotes, are all visual hunters



▶ **Figure 1.18 Different coloration in two beach and inland populations of *Peromyscus polionotus*.**

◀ Beach mice living on sparsely vegetated sand dunes along the coast have light tan, dappled coats that allow them to blend into their surroundings (camouflage).

▶ Members of the same species living about 30 km inland are darker in color, camouflaging them against the dark ground of their habitat.

(they use their eyes to look for prey). It was logical, therefore, for Francis Bertody Sumner, a naturalist studying populations of these mice in the 1920s, to hypothesize that their color patterns had evolved as adaptations that camouflage the mice in their native environments, protecting them from predation.

As obvious as the camouflage hypothesis may seem, it still required testing. In 2010, biologist Hopi Hoekstra of Harvard University and a group of her students headed to Florida to test the prediction that mice with coloration that did not match their habitat would be preyed on more heavily than the native, well-matched mice. **Figure 1.19** summarizes this field experiment, introducing a format we will use throughout the book to walk through other examples of biological inquiry.

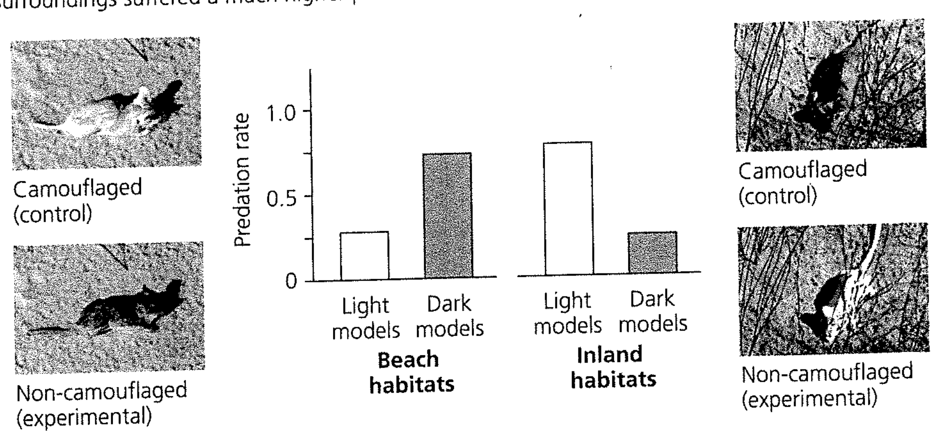
The researchers built hundreds of silicone models of mice and spray-painted them to resemble either beach or inland mice, so that the models differed only in their color patterns. The researchers placed equal numbers of these model mice randomly in both habitats and left them overnight. The mouse models resembling the native

▼ **Figure 1.19 Inquiry**

Does camouflage affect predation rates on two populations of mice?

Experiment Hopi Hoekstra and colleagues tested the hypothesis that coloration of beach and inland populations of oldfield mice (*Peromyscus polionotus*) provides camouflage that protects them from predation in their respective habitats. The researchers made mouse models with either light or dark color patterns that matched those of the beach and inland mice, then placed models with both patterns in each of the habitats. The next morning, they counted damaged or missing mice.

Results The researchers calculated the proportion of attacked mice that were camouflaged or non-camouflaged for each habitat. In both cases, the mice whose pattern did not match their surroundings suffered a much higher predation rate than did the camouflaged mice.



Conclusion The results do not falsify the researchers' prediction that mouse models with camouflage coloration would be preyed on less often than non-camouflaged mouse models. Thus, the experiment supports the camouflage hypothesis.

Source S. N. Vignieri, J. G. Larson, and H. E. Hoekstra, The selective advantage of crypsis in mice, *Evolution* 64:2153–2158 (2010).

WHAT IF? If you found a habitat with reddish, iron-rich soil, what would you predict with respect to the coat color of resident mice? What prediction would you make about the predation rate on beach mice and inland mice if you placed them in this new habitat?

ice in the habitat were the *control* group (for instance, light-lored beach mice in the dune habitat), while the mice with e non-native coloration were the *experimental* group (for ample, the darker mainland mice in the dunes). The follow-g morning, the team counted and recorded signs of preda-on events, which ranged from bites and gouge marks on me models to the outright disappearance of others. Judging the shape of the predator's bites and the tracks surround-g the experimental sites, the predators appeared to be split rly evenly between mammals (such as foxes and coyotes) d birds (such as owls, herons, and hawks).

For each environment, the researchers then calculated the ction of predation events that targeted camouflaged mice. e results were clear-cut: Camouflaged mice showed much wer predation rates than those lacking camouflage in both e dune habitat (where light mice were less vulnerable) and the ainland habitat (where dark mice were less vulnerable). The ta thus fit the key prediction of the camouflage hypothesis.

perimental Controls

e mouse camouflage experiment described in Figure 1.19 is example of a **controlled experiment**, one that is designed compare an experimental group (the non-camouflaged ice, in this case) with a control group (the camouflaged mice rmally resident in that area). Ideally, the experimental and ntrol groups differ only in the one factor the experiment is signed to test—in our example, the effect of mouse color-on on the behavior of predators. Without the control group, e researchers would not have been able to rule out other ctors as causes of the more frequent attacks on the non-mouflaged mice—such as different numbers of predators or ferent temperatures in the different test areas. The clever ex-rimental design left coloration as the only factor that could count for the low predation rate on the camouflaged mice iced in their normal environment. It was not the absolute mber of attacks on the non-camouflaged mice that counted, t the difference between that number and the number of at-cks on the camouflaged mice.

A common misconception is that the term *controlled ex-riment* means that scientists control the experimental envi-nment to keep everything constant except the one variable ing tested. But that's impossible in field research and not alistic even in highly regulated laboratory environments. Re-archers usually "control" unwanted variables not by *eliminat-g* them by regulating the environment, but by *canceling out* eir effects using control groups.

ieories in Science

's just a theory!" Our everyday use of the term *theory* often plies an untested speculation. But the term *theory* has a dif-ent meaning in science. What is a scientific theory, and how t different from a hypothesis or from mere speculation?

First, a scientific **theory** is much broader in scope than a pothesis. *This* is a hypothesis: "A match of the coloration of a mouse's coat to its environment is an adaptation that protects mice from predators." But *this* is a theory: "Evolutionary adaptations arise by natural selection." Darwin's theory of natural selection accounts for an enormous diversity of adaptations, of which coat color in mice is one example.

Second, a theory is general enough to spin off many new, testable hypotheses. For example, the theory of natural selection motivated two researchers at Princeton University, Peter and Rosemary Grant, to test the specific hypothesis that the beaks of Galápagos finches evolve in response to changes in the types of available food. (For the results, see the Chapter 21 Overview.)

And third, compared to any one hypothesis, a theory is generally supported by a much greater body of evidence. Those theories that become widely adopted in science (such as the theory of natural selection) explain a great diversity of observations and are supported by a vast accumulation of evidence.

In spite of the body of evidence supporting a widely accepted theory, scientists must sometimes modify or even reject theories when new research methods produce results that don't fit. For example, biologists once lumped bacteria and archaea together as a kingdom of prokaryotes. When new methods for comparing cells and molecules could be used to test such relationships, the evidence led scientists to reject the theory that bacteria and archaea are members of the same kingdom. If there is "truth" in science, it is conditional, based on the weight of available evidence.

Science as a Social Process: Community and Diversity

The great scientist Sir Isaac Newton once said: "To explain all nature is too difficult a task for any one man or even for any one age. 'Tis much better to do a little with certainty, and leave the rest for others that come after you. . . ." Anyone who becomes a scientist, driven by curiosity about nature, is sure to benefit from the rich storehouse of discoveries by others who have come before. In fact, while movies and cartoons sometimes portray scientists as loners working in isolated labs, science is an intensely social activity. Most scientists work in teams, which often include graduate and undergraduate students **(Figure 1.20)**.

▲ **Figure 1.20 Science as a social process.** Lab members help each other interpret data, troubleshoot experiments, and plan future research.

Science is rarely perfectly objective, but it is continuously vetted through the expectation that observations and experiments be repeatable and hypotheses be falsifiable. Scientists working in the same research field often check one another's claims by attempting to confirm observations or repeat experiments. In fact, Hopi Hoekstra's experiment benefited from the work of another researcher, D. W. Kaufman, 40 years earlier. You can study the design of Kaufman's experiment and interpret the results in the **Scientific Skills Exercise**.

If experimental results cannot be repeated by scientific colleagues, this failure may reflect some underlying weakness in the original claim, which will then have to be revised. In this sense, science polices itself. Integrity and adherence to high professional standards in reporting results are central to the scientific endeavor. After all, the validity of experimental data is key to designing further lines of inquiry.

Biologists may approach questions from different angles. Some biologists focus on ecosystems, while others study natural phenomena at the level of organisms or cells. This text is divided into units that focus on biology at different levels. Yet any given problem can be addressed from many perspectives, which in fact complement each other. For example, Hoekstra's work uncovered at least one genetic mutation that underlies the differences between beach and inland mouse coloration. Her lab includes biologists with different specialties, allowing discoveries on topics that range from evolutionary adaptations to their molecular basis in DNA.

The research community is part of society at large. The relationship of science to society becomes clearer when we add technology to the picture. The goal of **technology** is to *apply* scientific knowledge for some specific purpose. Because scientists put new technology to work in their research, science and technology are interdependent.

In centuries past, many major technological innovations originated along trade routes, where a rich mix of different cultures ignited new ideas. For example, the printing press was invented by Johannes Gutenberg around 1440, living in what is now Germany. This invention relied on several innovations from China,

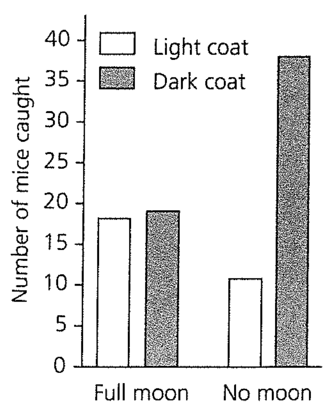
Scientific Skills Exercise

Interpreting a Pair of Bar Graphs

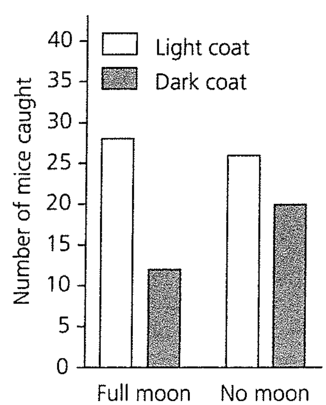
How Much Does Camouflage Affect Predation on Mice by Owls with and without Moonlight? Nearly half a century ago, D. W. Kaufman investigated the effect of prey camouflage on predation. Kaufman tested the hypothesis that the amount of contrast between the coat color of a mouse and the color of its surroundings would affect the rate of nighttime predation by owls. He also hypothesized that the color contrast would be affected by the amount of moonlight. In this exercise, you will analyze data from his owl-mouse predation studies.

How the Experiment Was Done Pairs of mice (*Peromyscus polionotus*) with different coat colors, one light brown and one dark brown, were released simultaneously into an enclosure that contained a hungry owl. The researcher recorded the color of the mouse that was first caught by the owl. If the owl did not catch either mouse within 15 minutes, the test was recorded as a zero. The release trials were repeated multiple times in enclosures with either a dark-colored soil surface or a light-colored soil surface. The presence or absence of moonlight during each assay was recorded.

Data from the Experiment



A: Light-colored soil



B: Dark-colored soil

Interpret the Data

1. First, make sure you understand how the graphs are set up. Graph A shows data from the light-colored soil enclosure and Graph B from the dark-colored enclosure, but in all other respects the graphs are the same. (a) There is more than one independent variable in these graphs. What are the independent variables, the variables that were tested by the researcher? Which axis of the graphs has the independent variables? (b) What is the dependent variable, the response to the variables being tested? Which axis of the graphs has the dependent variable?
2. (a) How many dark brown mice were caught in the light-colored soil enclosure on a moonlit night? (b) How many dark brown mice were caught in the dark-colored soil enclosure on a moonlit night? (c) On a moonlit night, would a dark brown mouse be more likely to escape predation by owls on dark- or light-colored soil? Explain your answer.
3. (a) Is a dark brown mouse on dark-colored soil more likely to escape predation under a full moon or with no moon? (b) A light brown mouse on light-colored soil? Explain.
4. (a) Under which conditions would a dark brown mouse be most likely to escape predation at night? (b) A light brown mouse?
5. (a) What combination of independent variables led to the highest predation level in enclosures with light-colored soil? (b) What combination of independent variables led to the highest predation level in enclosures with dark-colored soil? (c) What relationship, if any, do you see in your answers to parts (a) and (b)?
6. What conditions are most deadly for both colors of mice?
7. Combining the data shown in both graphs, estimate the total number of mice caught in moonlight versus no-moonlight conditions. Which condition is optimal for predation by the owl on mice? Explain your answer.

Data from D. W. Kaufman, Adaptive coloration in *Peromyscus polionotus*: Experimental selection by owls, *Journal of Mammalogy* 55:271–283 (1974).

(MB) A version of this Scientific Skills Exercise can be assigned in MasteringBiology.

including paper and ink, and from Iraq, where technology was developed for the mass production of paper. Like technology, science stands to gain much from embracing a diversity of backgrounds and viewpoints among its practitioners.

The scientific community reflects the customs and behaviors of society at large. It is therefore not surprising that until recently, women and certain minorities have faced huge obstacles in their pursuit to become professional scientists. Over the past 50 years, changing attitudes about career choices have increased the proportion of women in biology and several other sciences, and now women constitute roughly half of undergraduate biology majors and biology Ph.D. students. The pace has been slow at higher levels in the profession, however, and women and many racial and ethnic groups are still significantly underrepresented in many branches of science. This lack of diversity hampers the progress of science. The more voices that are heard at the table, the more robust and productive the scientific conversation will be. The authors of this textbook welcome all students to the community of biologists, wishing you the joys and satisfactions of this exciting field of science.

CONCEPT CHECK 1.3

1. Contrast inductive reasoning with deductive reasoning.
2. What variable was tested in Hoekstra's mouse experiment?
3. Why is natural selection called a theory rather than a hypothesis?
4. How does science differ from technology?

For suggested answers, see Appendix A.

1 Chapter Review

SUMMARY OF KEY CONCEPTS

CONCEPT 1.1

Studying the diverse forms of life reveals common themes (pp. 2–7)

Theme: Organization

- The hierarchy of life unfolds as follows: biosphere > ecosystem > community > population > organism > organ system > organ > tissue > cell > organelle > molecule > atom. With each step up, new properties emerge (**emergent properties**) as a result of interactions among components at the lower levels.
- Structure and function are correlated at all levels of biological organization. The cell is the lowest level of organization that can perform all activities required for life. Cells are either prokaryotic or eukaryotic. **Eukaryotic cells** have a DNA-containing nucleus and other membrane-enclosed organelles. **Prokaryotic cells** lack such organelles.

Theme: Information

- Genetic information is encoded in the nucleotide sequences of **DNA**. It is DNA that transmits heritable information from parents to offspring. DNA sequences (called **genes**) program a cell's protein production by being transcribed into RNA and then translated into specific proteins, a process called **gene expression**. Gene expression also produces RNAs that are not translated into protein but serve other important functions.

Theme: Energy and Matter

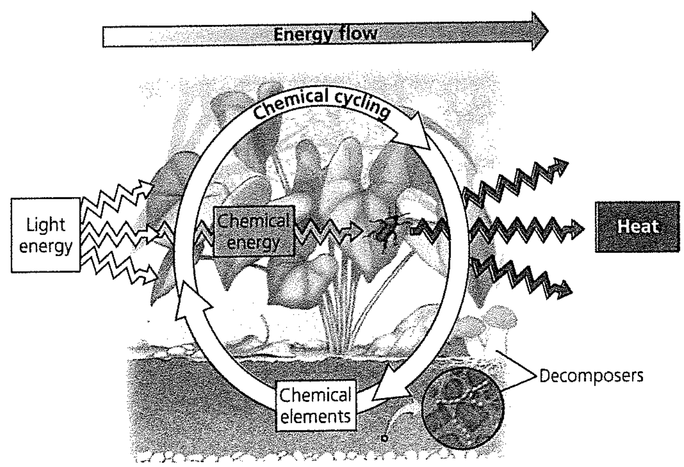
- Energy flows through an ecosystem. All organisms must perform work, which requires energy. Producers convert energy from sunlight to chemical energy, some of which is then passed on to consumers (the rest is lost from the ecosystem as heat). Chemicals cycle between organisms and the environment.

Theme: Interactions

- Organisms interact continuously with physical factors. Plants take up nutrients from the soil and chemicals from the air and use energy from the sun. Interactions among plants, animals, and other organisms affect the participants in varying ways.

Core Theme: Evolution

- Evolution accounts for the unity and diversity of life and also for the match of organisms to their environments.

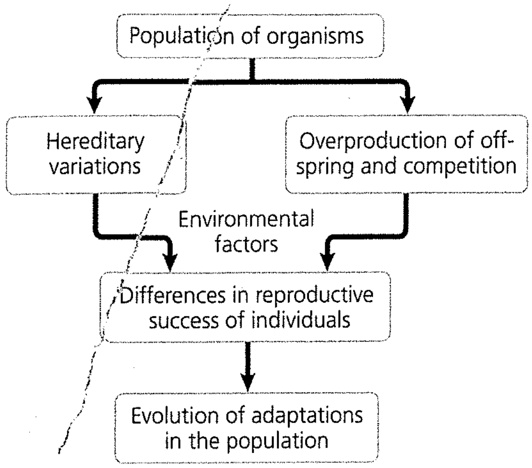


❓ *Thinking about the muscles and nerves in your hand, how does the activity of text messaging reflect the five unifying themes of biology described in this chapter?*

CONCEPT 1.2

The Core Theme: Evolution accounts for the unity and diversity of life (pp. 7–11)

- Biologists classify species according to a system of broader and broader groups. Domain **Bacteria** and domain **Archaea** consist of prokaryotes. Domain **Eukarya**, the eukaryotes, includes various groups of protists as well as plants, fungi, and animals. As diverse as life is, there is also evidence of remarkable unity, which is revealed in the similarities between different kinds of organisms.
- Darwin proposed **natural selection** as the mechanism for evolutionary adaptation of populations to their environments. Each species is one twig of a branching tree of life extending back in time through ancestral species more and more remote. All of life is connected through its long evolutionary history.



How could natural selection have led to the evolution of adaptations such as camouflaging coat color in beach mice?

CONCEPT 1.3

Biological inquiry entails forming and testing hypotheses based on observations of nature (pp. 11–16)

- In scientific **inquiry**, scientists make observations (collect **data**) and use **inductive reasoning** to draw a general conclusion, which can be developed into a testable **hypothesis**. **Deductive reasoning** makes predictions that can be used to test hypotheses. Scientific hypotheses must be falsifiable.
- **Controlled experiments**, such as the study investigating coat color in mouse populations, are designed to demonstrate the effect of one variable by testing control groups and experimental groups that differ in only that one variable.
- A scientific **theory** is broad in scope, generates new hypotheses, and is supported by a large body of evidence.
- Scientists must be able to repeat each other's results, so integrity is key. Biologists approach questions at different levels; their approaches complement each other. **Technology** is a method or device that applies scientific knowledge for some specific purpose that affects society as well as for scientific research. Diversity among scientists promotes progress in science.

What are the roles of inductive and deductive reasoning in scientific inquiry?

TEST YOUR UNDERSTANDING

Level 1: Knowledge/Comprehension

1. All the organisms on your campus make up
   (A) an ecosystem.
   (B) a community.
   (C) a population.
   (D) an experimental group.

2. Which of the following best demonstrates the unity among all organisms?
   (A) identical DNA sequences
   (B) descent with modification
   (C) the structure and function of DNA
   (D) natural selection

3. A controlled experiment is one that
   (A) proceeds slowly enough that a scientist can make careful records of the results.
   (B) tests experimental and control groups in parallel.
   (C) is repeated many times to make sure the results are accurate.
   (D) keeps all variables constant.

4. Which of the following statements best distinguishes hypotheses from theories in science?
   (A) Theories are hypotheses that have been proved.
   (B) Hypotheses are guesses; theories are correct answers.
   (C) Hypotheses usually are relatively narrow in scope; theories have broad explanatory power.
   (D) Hypotheses and theories are essentially the same thing.

Level 2: Application/Analysis

5. Which of the following is an example of qualitative data?
   (A) The temperature decreased from 20°C to 15°C.
   (B) The plant's height is 25 centimeters (cm).
   (C) The fish swam in a zigzag motion.
   (D) The six pairs of robins hatched an average of three chicks.

6. Which of the following best describes the logic of scientific inquiry?
   (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 support my hypothesis.
   (D) If my hypothesis is correct, I can expect certain test results.

7. **DRAW IT** With rough sketches, **draw** a biological hierarchy similar to the one in Figure 1.3 but using a coral reef as the ecosystem, a fish as the organism, its stomach as the organ, and DNA as the molecule. Include all levels in the hierarchy.

Level 3: Synthesis/Evaluation

8. **SCIENTIFIC INQUIRY/Science Practice 4**
   Based on the results of the mouse coloration case study, **propose a hypothesis** to extend the investigation.

9. **FOCUS ON BIG IDEA 1**
   In a short essay (100–150 words), **describe** Darwin's view of natural selection and how it resulted in both unity and diversity of life on Earth. Include in your discussion some of his evidence. (A suggested grading rubric and tips for writing good essays can be found in the Study Area of MasteringBiology.)

10. **FOCUS ON BIG IDEA 3**
    A typical prokaryotic cell has about 3,000 genes in its DNA, while a human cell has about 20,500 genes. About 1,000 of these genes are present in both types of cells.
    (a) Based on your understanding of evolution, **explain** how such different organisms could have this same subset of genes.
    (b) What sorts of functions might these shared genes have? **Justify** your choices.

For selected answers, see Appendix A.

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