Chapter 1Evolution, the Themes of Biology, and Scientific Inquiry Figure 1.1 A beach mouse (Peromyscuspolionotus) peers through beach grass; the mouse has white face and light tan body. The light, dappled color of this beach mouse (Peromyscus polionotus) allows it to blend into its habitat—brilliant white sand dunes dotted with sparse clumps of beach grass along the Florida seashore. Mice of the same species that inhabit nearby inland areas are much darker, blending with the soil and vegetation where they live. How do several given mice illustrate the unifying themes of biology? 1.1-1 Full Alternative Text Key Concepts 1. 1.1 The study of life reveals unifying themes 2. 1.2 The Core Theme: Evolution accounts for the unity and diversity of life 3. 1.3 In studying nature, scientists form and test hypotheses 4. 1.4 Science benefits from a cooperative approach and diverse viewpoints Study Tip Make a table: List the five unifying themes of biology across the top. Enter at least three examples of each theme as you read this chapter. One example is filled in for you. To help you focus on these big ideas, continue adding examples throughout your study of biology. A chart has columns labeled Evolution, Organization, and then 3 blanks. Under evolution is as follows. Beach mouse's coat color matches its sandy habitat. Highlights of Mastering Biology For Students Watch Figure 1-8 Walkthrough: Gene expression: cells use information encoded in a gene to synthesize a functional protein An embedded video is located here in your eText. Reference it when you have a chance. Watch Video: Galápagos Biodiversity by Peter and Rosemary Grant An embedded video is located here in your eText. Reference it when you have a chance. For Instructors to Assign (in Item Library) Scientific Skills Exercise: Interpreting a Pair of Bar Graphs Tutorial: The Scientific Method Learning Objectives After studying this chapter, you should be able to do the following: 1. 1.1 Use examples to illustrate each theme of this book. 2. 1.2 Summarize how evolution accounts for the unity and diversity of life. 3. 1.3 Discuss the scientific process. 4. 1.4 Evaluate the contribution of diversity among scientists to scientific progress.

Concept 1.1 The study of life reveals unifying themes At the most fundamental level, we may ask: What is life? Even a child realizes that a dog or a plant is alive, while a rock or a car is not. Yet the phenomenon we call life defies a simple definition. We recognize life by what living things do. Figure 1.2 highlights some of the properties and processes we associate with life. Figure 1.2 Some properties of life. Photos and descriptions of properties of life: order, evolutionary adaptation, regulation, energy processing, growth and development, response to the environment, and reproduction. Figure 1.2 Full Alternative Text Watch Animation: Signs of Life An embedded video is located here in your eText. Reference it when you have a chance. Watch Video: Sea Horse Camouflage An embedded video is located here in your eText. Reference it when you have a chance. Biology, the scientific study of life, is a subject of enormous scope, and exciting new biological discoveries are being made every day. How can you organize into a comprehensible framework all the information you'll encounter as you study biology? Focusing on a few big ideas will help. Here are five unifying themes—ways of thinking about life that will still be useful decades from now. Organization Information Energy and Matter Interactions Evolution In this section and the next, we'll briefly explore each theme. Theme: New Properties Emerge at Successive Levels of Biological Organization ORGANIZATION The study of life on Earth 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. In Figure 1.3, we zoom in from space to take a closer and closer look at life in a mountain meadow. This journey, depicted as a series of numbered steps, highlights the hierarchy of biological organization. Figure 1.3 Exploring Levels of Biological Organization. Exploring levels of biological organization. 1.1-3 Full Alternative Text Zooming in at ever-finer resolution illustrates the principle that underlies reductionism, an approach that reduces 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. Despite its importance, reductionism provides an incomplete view of life on Earth, as you'll see next. Emergent Properties Let's reexamine Figure 1.3, beginning this time at the molecular level and then zooming out. This approach allows us to see novel properties emerge at each level 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 if chlorophyll and other chloroplast molecules are simply mixed in a test tube. The coordinated processes of photosynthesis require a specific organization of these molecules in the chloroplast. Isolated components of living systems—the objects of study in a reductionist approach—lack a number of significant 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 with such nonliving examples, however, biological systems are far more complex, making 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. In this context, 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 do networks of molecular interactions in our bodies generate our 24-hour cycle of wakefulness and sleep? 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 between structure and function. Consider the leaf in Figure 1.3: Its broad, flat shape maximizes the capture of sunlight by chloroplasts. Because such correlations of structure and function are common in all living things, analyzing a biological structure gives us clues about what it does and how it works. For example, the hummingbird's anatomy allows its wings to rotate at the shoulder, so hummingbirds have the ability, unique among birds, to fly backward or hover in place. While 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, which we'll explore shortly. A hummingbird. The Cell: An Organism's Basic Unit of Structure and Function The cell is the smallest unit of organization that can perform all activities required for life. The so-called Cell Theory was first developed in the 1800s, based on the observations of many scientists. The theory states that all living organisms are made of cells, which are the basic unit of life. In fact, the actions 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 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 distinguish two main forms of cells: prokaryotic and eukaryotic. Prokaryotic cells are found in two groups of single-celled microorganisms, bacteria (singular, bacterium) and archaea (singular, archaean). All other forms of life, including plants and animals, are composed of eukaryotic cells. A eukaryotic cell contains membrane-enclosed organelles (Figure 1.4). 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 1.4. Figure 1.4 Contrasting eukaryotic and prokaryotic cells in size and complexity. A eukaryotic cell next to a prokaryotic cell. On the scale of the micrometer, the eukaryotic cell is approximately ten times larger and contains many membrane-bound organelles. The cells are shown to scale here; to see a larger magnification of a prokaryotic cell, see Figure 6.5. Figure 1.4 Full Alternative Text VISUAL SKILLS Measure the scale bar, the length of the prokaryotic cell, and the diameter of the eukaryotic cell. Knowing that this scale bar represents 1 µm, calculate the length of the prokaryotic cell and the diameter of the eukaryotic cell in µm.

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 1.5). Figure 1.5 A lung cell from a newt divides into two smaller cells that will grow and divide again. A lung cell from a newt divides into two smaller cells that will grow and divide again. Chromosomes are shown dividing between the two daughter cells. (Scale: 25 micrometers). DNA, the Genetic Material Each chromosome contains one very long DNA molecule with hundreds or thousands of genes, each a section of the DNA of 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. You began as a single cell stocked with DNA inherited from your parents. The replication of that DNA prior to each cell division transmitted copies of the DNA to what eventually became the trillions of cells of your body. As the cells grew and divided, the genetic information encoded by the DNA directed your development (Figure 1.6). Figure 1.6 Inherited DNA directs the development of an organism. A fertilized egg resulting from a sperm and egg cell with nuclei containing D N A develops into an embryo and then a human infant with traits inherited from both parents. 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 1.7). Specific sequences of these four nucleotides encode the information in genes. 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. Figure 1.7 DNA: the genetic material. D N A is diagrammed two ways. Figure 1.7 Full Alternative Text Watch Animation: Heritable Information: DNA An embedded video is located here in your eText. Reference it when you have a chance. For many genes, the sequence provides the blueprint for making a protein. For instance, a given bacterial gene may specify a particular protein (such as an enzyme) required to break down a certain sugar molecule, while one particular human gene may denote an enzyme, and another gene a different protein (an antibody, perhaps) that helps fight off infection. Overall, proteins are major players in building and maintaining the cell and carrying out its activities. Protein-encoding genes control protein production indirectly, using a related molecule called RNA as an intermediary. The sequence of nucleotides along a gene is transcribed into mRNA, which is then translated into a linked series of protein building blocks called amino acids. Once completed, the amino acid chain forms a specific protein with a unique shape and function. The entire process by which the information in a gene directs the manufacture of a cellular product is called gene expression (Figure 1.8). Figure 1.8 Gene expression: Cells use information encoded in a gene to synthesize a functional protein. Part a. The lens of the eye (behind the pupil) is able to focus light because lens cells are tightly packed with transparent proteins called crystallin. Part b describes how lens cells make crystallin proteins. Figure 1.8 Full Alternative Text Watch Figure 1-8 Walkthrough: Gene expression: cells use information encoded in a gene to synthesize a functional protein An embedded video is located here in your eText. Reference it when you have a chance. In carrying out gene expression, all forms of life employ essentially the same genetic code: A particular sequence of nucleotides means 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. This universality of the genetic code is a strong piece of evidence that all life is related. Comparing the sequences in several species for a gene that codes for a particular protein can provide valuable information both about the protein and about the relationship of the species to each other. Molecules of mRNA, like the one in Figure 1.8, are translated into proteins, but other cellular RNAs function differently. For example, we have known for decades that some types of RNA are actually components of the cellular machinery that manufactures proteins. In the last few decades, scientists have discovered new classes of RNA that play other roles in the cell, such as regulating the function of protein-coding genes. Genes specify these RNAs as well, and their production 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 a set were written in letters the size of those you are now reading, the genomic text would fill about 700 biology textbooks. Since the early 1990s, the pace at which researchers can determine the sequence of a genome has accelerated at an astounding rate, enabled by a revolution in technology. The genome sequence—the entire sequence of nucleotides for a representative member of a species—is now known for humans and many other animals, as well as 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 (or other DNA) in one or more species—an approach called genomics. Likewise, the term proteomics refers to the study of sets of proteins and their properties. (The entire set of proteins expressed by a given cell, tissue, or organism is called a proteome.) Three important research developments have made the genomic and proteomic approaches possible. One is “high-throughput” technology, tools that can analyze many biological samples 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 development is the formation of interdisciplinary research teams—groups 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 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. The input of energy, primarily from the sun, and the transformation of energy from one form to another make life possible (Figure 1.9). When a plant’s leaves absorb sunlight in the process of photosynthesis, molecules within the leaves convert the energy of sunlight to the chemical energy of food, such as sugars. The chemical energy in the food molecules is then passed along from plants and other photosynthetic organisms (producers) to consumers. A consumer is an organism that feeds on other organisms or their remains. Figure 1.9 Energy flow and chemical cycling. 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 food molecules such as 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. Figure 1.9 Full Alternative Text When an organism uses chemical energy to perform work, such as muscle contraction or cell division, some of that energy is lost to the surroundings as heat. As a result, energy flows through an ecosystem in one direction, usually entering as light and exiting as heat. In contrast, chemicals cycle within an ecosystem, where they are used and then recycled (see Figure 1.9). Chemicals that a plant absorbs from the air or soil may be incorporated into the plant’s body and 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, leaf litter, and the bodies of dead organisms. The chemicals are then available to be taken up by plants again, thereby completing the cycle.

Theme: From Molecules to Ecosystems, Interactions Are Important in Biological Systems INTERACTIONS At any level of the biological hierarchy, interactions between the components of the system ensure smooth integration of all the parts, such that they function as a whole. This holds true equally well for molecules in a cell and the components of an ecosystem; we’ll look at both as examples. Molecules: Interactions Within Organisms At lower levels of organization, the interactions between components that make up living organisms—organs, tissues, cells, and molecules—are crucial to their smooth operation. Consider the regulation of blood sugar level, for instance. Cells in the body must match the supply of fuel (sugar) to demand, regulating the opposing processes of sugar breakdown and storage. The key is the ability of many biological processes to self-regulate by a mechanism called feedback. In feedback regulation, the output or product of a process regulates that very process. The most common form of regulation in living systems is negative feedback, a loop in which the response reduces the initial stimulus. As seen in the example of insulin signaling (Figure 1.10), after a meal the level of the sugar glucose in your blood rises, which stimulates cells of the pancreas to secrete insulin. Insulin, in turn, causes body cells to take up glucose and liver cells to store it, thus decreasing the blood glucose level. This eliminates the stimulus for insulin secretion, shutting off the pathway. Thus, the output of the process (insulin) negatively regulates that process. Figure 1.10 Feedback regulation. Figure 1.10 Full Alternative Text VISUAL SKILLS In this example, what is the response to insulin? What is the initial stimulus that is reduced by the response? Though less common than processes regulated by negative feedback, there are also many biological processes regulated by positive feedback, in which an end product speeds up its own production. The clotting of your blood in response to injury is an example. When a blood vessel is damaged, structures in the blood called platelets begin to aggregate at the site. Positive feedback occurs as chemicals released by the platelets attract more platelets. The platelet pileup then initiates a complex process that seals the wound with a clot. Ecosystems: An Organism’s Interactions with Other Organisms and the Physical Environment At the ecosystem level, every organism interacts with other organisms. For instance, an acacia tree interacts with soil microorganisms associated with its roots, insects that live on it, and animals that eat its leaves and fruit (Figure 1.11). Interactions between organisms include those that are mutually beneficial (as when cleaner fish” eat small parasites on a turtle) and those in which one species benefits and the other is harmed (as when a lion kills and eats a zebra). In some interactions between species, both are harmed—for example, when two plants compete for a soil resource that is in short supply. Interactions among organisms help regulate the functioning of the ecosystem as a whole. Figure 1.11 Interactions of an African acacia tree with other organisms and the physical environment. Figure 1.11 Full Alternative Text Each organism also 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 (see Figure 1.11). The environment is also affected by organisms. For instance, in addition to taking up water and minerals from the soil, the roots of a plant break up rocks as they grow, contributing to the formation of soil. On a global scale, plants and other photosynthetic organisms have generated all the oxygen in the atmosphere. Like other organisms, we humans interact with our environment. Our interactions sometimes have dire consequences: For example, over the past 150 years, humans have greatly increased the burning of fossil fuels (coal, oil, and gas). This practice releases large amounts of carbon dioxide <math xmlns=\"http://www.w3.org/1998/Math/MathML\"><mrow><mo>(</mo><mrow><mtext>CO</mtext></mrow><msub><mrow></mrow><mn>2</mn></msub><mo>)</mo></mrow></math> and other gases into the atmosphere, causing heat to be trapped close to Earth’s surface (see Figure 56.29). Scientists calculate that the <math xmlns=\"http://www.w3.org/1998/Math/MathML\"><mrow><mrow><mtext>CO</mtext></mrow><msub><mrow></mrow><mn>2</mn></msub></mrow></math> added to the atmosphere by human activities has increased the average temperature of the planet by about

<math xmlns=\"http://www.w3.org/1998/Math/MathML\"><mrow><mn>1</mn><mtext>°</mtext><mtext>C</mtext></mrow></math> since 1900. At the current rates that <math xmlns=\"http://www.w3.org/1998/Math/MathML\"><mrow><mrow><mtext>CO</mtext></mrow><msub><mrow></mrow><mn>2</mn></msub></mrow></math> and other gases are being added to the atmosphere, global models predict an additional rise of at least <math xmlns=\"http://www.w3.org/1998/Math/MathML\"><mrow><mn>3</mn><mtext>°</mtext><mtext>C</mtext></mrow></math> before the end of this century. This ongoing global warming is a major aspect of climate change, a directional change to the global climate that lasts for three decades or more (as opposed to short-term changes in the weather). But global warming is not the only way the climate is changing: Wind and precipitation patterns are also shifting, and extreme weather events such as storms and droughts are occurring more often. Climate change has already affected organisms and their habitats all over the planet. For example, polar bears have lost much of the ice platform from which they hunt, leading to food shortages and increased mortality rates. As habitats deteriorate, hundreds of plant and animal species are shifting their ranges to more suitable locations—but for some, there is insufficient suitable habitat, or they may not be able to migrate quickly enough. As a result, the populations of many species are shrinking in size or even disappearing (Figure 1.12). (For more examples of how climate change is affecting life on Earth, see Make Connections Figure 56.30.) Figure 1.12 Threatened by global warming. The loss of populations due to climate change can ultimately result in extinction, the permanent loss of a species. As we'll explore in greater detail in Concept 56.4, the consequences of these changes for humans and other organisms may be profound. Having considered four of the unifying themes (organization, information, energy and matter, and interactions), let's now turn to evolution. There is consensus among biologists that evolution is the core theme of biology, and it is discussed in detail in the next section. Concept Check 1.1: The study of life reveals unifying themes 1. Starting with the molecular level in Figure 1.3, write a sentence that includes components from the previous (lower) level of biological organization, for example: "A molecule consists of atoms bonded together." Continue with organelles, moving up the biological hierarchy. 2. Identify the theme or themes exemplified by (a) the sharp quills of a porcupine, (b) the development of a multicellular organism from a single fertilized egg, 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 An understanding of evolution helps us to make sense of everything we know about life on Earth. As the fossil record clearly shows, life has been evolving for billions of years, resulting in a vast diversity of past and present organisms. But along with the diversity there is also unity, in the form of shared features. For example, while sea horses, jackrabbits, hummingbirds, and giraffes all look very different, their skeletons are organized in the same basic way. The scientific explanation for the unity and diversity of organisms is evolution: a process of biological change in which species accumulate differences from their ancestors as they adapt to different environments over time. Thus, we can account for differences between two species (diversity) with the idea that certain heritable changes occurred after the two species diverged from their common ancestor. However, they also share certain traits (unity) simply because

they have descended from a common ancestor. An abundance of evidence of different types supports the occurrence of evolution and the mechanisms that describe how it takes place, which we'll explore in detail in Chapters 22, 23, 24 and 25. To quote one of the founders of modern evolutionary theory, Theodosius Dobzhansky, Nothing in biology makes sense except in the light of evolution." To understand this statement, we need to examine how biologists think about the vast diversity of life on the planet.
Classifying the Diversity of Life Diversity is a hallmark of life. Biologists have so far identified and named about 1.8 million species of organisms. Each species is given a two-part name: The first part is the name of the genus (plural, genera) to which the species belongs, and the second part is unique to the species within the genus. (For example, Homo sapiens is the name of our species.) To date, known species include at least 100,000 species of fungi, 290,000 plant species, 57,000 vertebrate species (animals with backbones), and 1 million insect species (more than half of all known forms of life)—not to mention the myriad types of single-celled organisms. Researchers identify thousands of additional species each year. Estimates of the total number of species range from about 10 million to over 100 million. Whatever the actual number, the enormous variety of life gives biology a very broad scope. Biologists face a major challenge in attempting to make sense of this variety. The Three Domains of Life Humans tend to group diverse items according to their similarities and relationships to each other. Consequently, biologists have long used careful comparisons of structure, function, and other obvious features to classify forms of life into groups. In the last few decades, new methods of assessing species relationships, such as comparisons of DNA sequences, have led to a reevaluation of the classification of life. Although this reevaluation is ongoing, biologists currently place all organisms into three groups called domains: Bacteria, Archaea, and Eukarya (Figure 1.13). Figure 1.13 The three domains of life. The three domains of life are given. Figure 1.13 Full Alternative Text Two of the three domains—Bacteria and Archaea—consist of single-celled prokaryotic organisms. All the eukaryotes (organisms with eukaryotic cells) are in domain Eukarya. This domain includes four subgroups: kingdom Plantae, kingdom Fungi, kingdom Animalia, and the protists. The three kingdoms are distinguished partly by their modes of nutrition: Plants produce their own sugars and other food molecules by photosynthesis, fungi absorb nutrients in dissolved form from their surroundings, and animals obtain food by eating and digesting other organisms. Animalia is, of course, the kingdom to which we belong. The most numerous and diverse eukaryotes are the protists, which are mostly single-celled organisms. Although protists were once placed in a single kingdom, they are now classified into several groups. One major reason for this change is the recent DNA evidence showing that some protists are less closely related to other protists than they are to plants, animals, or fungi.
Unity in the Diversity of Life As diverse as life is, there is also remarkable unity among forms of life. Consider, for example, the similar skeletons of different animals and the universal genetic language of DNA (the genetic code), both mentioned earlier. In fact, similarities between organisms are evident at all levels of the biological hierarchy. For example, unity is obvious in many features of cell structure, even among distantly related organisms (Figure 1.14). Figure 1.14 An example of unity underlying the diversity of life: the architecture of cilia in eukaryotes. Cilia are compared. Cilia (singular, cilium) are extensions of cells that function in locomotion. They occur in eukaryotes as diverse as Paramecium (found in pond water) and humans. Even organisms so different share a common architecture for their cilia, which have an elaborate

system of tubules that is striking in cross-sectional views. Figure 1.14 Full Alternative Text 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. It also introduces another important dimension of biology: the passage of time. The history of life, as documented by fossils and other evidence, is the saga of an ever-changing Earth billions of years old, inhabited by an evolving cast of living forms (Figure 1.15). Figure 1.15 Studying the history of life. Researchers reconfigure a skeleton. Researchers in South Africa reconstruct skeletons of Homo naledi, an extinct relative of Homo sapiens. The fossils were discovered in an underground cave that may have been a burial chamber.

Charles Darwin and the Theory of Natural Selection An evolutionary view of life came into sharp focus in November 1859, when Charles Darwin published one of the most important and influential books ever written, On the Origin of Species by Means of Natural Selection (Figure 1.16). The Origin of Species articulated two main points. The first point was that, as species adapt to different environments over time, they accumulate differences from their ancestors. Darwin called this process descent with modification." This insightful phrase captured the duality of life's unity and diversity—unity in the kinship among species that descended from common ancestors and diversity in the modifications that evolved as species branched from their common ancestors (Figure 1.17). Darwin's second main point was his proposal that "natural selection" is a primary cause of descent with modification. Figure 1.16 Charles Darwin. A portrait of Darwin next to a copy of The Origins of Species. The portrait shows Darwin in about 1840, well before the 1859 publication of his revolutionary book, commonly referred to as The Origin of Species. Figure 1.17 Unity and diversity among birds. Four different species of birds. These four birds are variations on a common body plan. For example, each has feathers, a beak, and wings. However, these common features are highly specialized for the birds' diverse lifestyles. Figure 1.17 Full Alternative Text Darwin developed his theory of natural selection from observations that by themselves were neither new nor profound. However, although others had described the pieces of the puzzle, it was Darwin who 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. With more individuals than the environment is able to support, competition is inevitable. Third, species generally are suited to their environments—in other words, they are adapted to their circumstances. For instance, a common adaptation among birds that eat hard seeds is an especially strong beak. By making inferences from these three observations, Darwin developed a scientific explanation for how evolution occurs. He reasoned that individuals with inherited traits that are better suited to the local environment are more likely to survive and reproduce than less well-suited individuals. Over many generations, a higher and higher proportion of individuals in a population will have the advantageous traits. Evolution occurs as the unequal reproductive success of individuals ultimately leads to adaptation to their environment, as long as the environment remains the same. Darwin called this mechanism of evolutionary adaptation natural selection because the natural environment consistently "selects" for the propagation of certain traits among naturally occurring variant traits in the population. The example in Figure 1.18 illustrates the ability of natural selection to "edit" an insect population's heritable variations in coloration. We see the products of natural selection in the exquisite adaptations of various organisms to the special circumstances of their way of life and their environment. The wings of the bat shown in Figure 1.19 are an excellent example of adaptation. Figure 1.18 Natural selection. Natural selection amongst a beetle population. 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 hungry birds that prey on the beetles, it is easiest to spot the beetles that are lightest in color. Figure 1.18 Full Alternative Text DRAW IT Over time, the soil will gradually become lighter in color. Draw another step to show how the soil, when lightened to medium color, would affect natural selection. Write a caption for this new step 5. Then explain how the population would change over time as the soil becomes lighter. Watch HHMI BioInteractive Video: The Making of The Fittest: Natural Selection and Adaptation (Rock Pocket Mouse) An embedded video is located here in your eText. Reference it when you have a chance. For more resources from HHMI BioInteractive, go to www.hhmi.org/biointeractive. Figure 1.19 Evolutionary adaptation. Bat flapping its webbed wings. This mammal has small dog-like head with two tiny pointed ears Bats, the only mammals capable of active flight, have wings with webbing between extended “fingers.” Darwin proposed that such adaptations are refined over time by natural selection.

The Tree of Life Take another look at the skeletal architecture of the bat’s wings in Figure 1.19. These wings are not like those of feathered birds; the bat is a mammal. The bones, joints, nerves, and blood vessels in the bat’s forelimbs, though adapted for flight, are very similar to those in the human arm, the foreleg of a horse, and the flipper of a whale. 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. Fossils and other evidence corroborate anatomical unity in supporting this view of mammalian descent from a common ancestor. Darwin proposed that natural selection, by its cumulative effects over long periods of 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 became fragmented into several subpopulations isolated in different environments. In these separate arenas of natural selection, one species could gradually radiate into multiple species as the geographically isolated populations adapted over many generations to different environmental conditions. The Galápagos finches are a famous example of the process of radiation of new species from a common ancestor. 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. These relatively young volcanic islands are home to many species of plants and animals found nowhere else in the world, though many Galápagos organisms are clearly related to species on the South American mainland. The Galápagos finches are thought 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 populations became adapted to different food sources on their particular islands. Years after Darwin collected the finches, researchers began to sort out their evolutionary relationships, first from anatomical and geographic data and more recently with the help of DNA sequence comparisons. Watch Video: Galápagos Biodiversity by Peter and Rosemary Grant An embedded video is located here in your eText. Reference it when you have a chance. Biologists' diagrams of evolutionary relationships generally take treelike forms, though the trees are often turned sideways as in Figure 1.20. 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. Through an ancestor that lived much further back in time, finches are related to sparrows, hawks, penguins, and all other birds. Furthermore, finches and other birds are related to us through a common ancestor even more ancient. Trace life back far enough, and we reach the early prokaryotes that inhabited Earth over 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. Figure 1.20 Descent with modification: adaptive radiation of finches on the Galápagos Islands. Figure 1.20 Full Alternative Text Watch HHMI BioInteractive Video: The Origin of Species: The Making of The Fittest An embedded video is located here in your eText. Reference it when you have a chance. For more resources from HHMI BioInteractive, go to www.hhmi.org/biointeractive. Concept Check 1.2: The Core Theme: Evolution accounts for the unity and diversity of life 1. Explain why "editing" is a metaphor for how natural selection acts on a population's heritable variation. 2. Referring to Figure 1.20, provide a possible explanation for how, over a very long time, the green warbler finch came to have a slender beak. 3. DRAW IT The three domains you learned about in Concept 1.2 can be represented in the tree of life as the three main branches, with three subbranches on the eukaryotic branch being the kingdoms Plantae, Fungi, and Animalia. What if fungi and animals are more closely related to each other than either of these kingdoms is to plants—as recent evidence strongly suggests? Draw a simple branching pattern that symbolizes the proposed relationship between these three eukaryotic kingdoms. For suggested answers, see Appendix A.