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.