CHAPTER 1

Introduction: Evolution and the Foundations of Biology

Key Concepts

1.1 The study of life reveals unifying themes

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

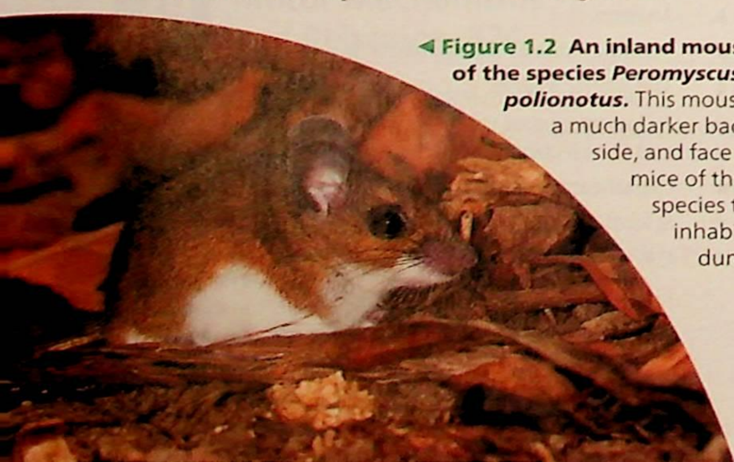
1.3 In studying nature, scientists form and test hypotheses

Figure 1.1 What can this beach mouse (*Peromyscus polionotus*) teach us about biology?

Overview

Inquiring About Life

There are few hiding places for a mouse among the sparse clumps of beach grass that dot the brilliant white sand dunes along the Florida seashore. However, the beach mice that live there have light, dappled fur, allowing them to blend into their surroundings **(Figure 1.1)**. Mice of the same species (*Peromyscus polionotus*) also inhabit nearby inland areas. These mice are much darker in color, as are the soil and vegetation where they live **(Figure 1.2)**. For both beach mice and inland mice, the close color match of coat (fur) and environment is vital for survival, since hawks, herons, and other sharp-eyed predators periodically scan the landscape for prey. How has the color of each group of mice come to be so well matched, or *adapted*, to the local background?



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

An organism's adaptations to its environment, such as the mouse's protective camouflage, are the result of *evolution*, the process of change over time that has resulted in the astounding array of organisms found on Earth. Evolution is the fundamental principle of biology and the core theme of this book.

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 cell becomes a tree or a dog, how the human mind works, or how the different forms of life in a forest interact. When such questions occur to you as you observe the living world, you are thinking like a biologist.

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

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CONCEPT 1.1

The study of life reveals unifying 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 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 chapter, we'll briefly define and 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 in the figure as a series of numbered steps, highlights the hierarchy of biological organization.

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, 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 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. In general, 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 complement reductionism with **systems biology**, the exploration of the network of interactions that underlie the emergent properties of a system. 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 biological organization, we find a correlation between structure and function. Consider a 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. A good example from the animal kingdom is the hummingbird. 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. Such an elegant match of form and function in the structures of life is explained by natural selection, as we'll explore shortly.

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. In fact, the actions of an organism are all based on the activities of its 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

▼ Figure 1.3 Exploring Levels of Biological Organization

◀ 1 The Biosphere

Even from space, we can see signs of Earth's life—in the mosaic of greens indicating forests, for example. We can also see the **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 mountain meadow, which is an example of an ecosystem, as are a tropical forest, grassland, desert, and coral reef. 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 meadow ecosystem includes many kinds of plants, various animals, mushrooms and other fungi, and enormous numbers of diverse microorganisms, such as bacteria, that are too small to see without a microscope. Each of these forms of life belongs to a *species*—a group whose members can only reproduce with other members of the group.

▶ 4 Populations

A **population** consists of all the individuals of a species living within the bounds of a specified area. For example, our meadow includes a population of lupines (some of which are shown here) and a population of mule deer. A community is therefore the set of populations that inhabit a particular area.

▲ 5 Organisms

Individual living things are called **organisms**. Each plant in the meadow is an organism, and so is each animal, fungus, and bacterium.

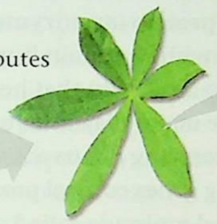
atoms, is the cumulative product of cellular functions, including the photosynthetic activity of chloroplasts in leaf cells.

All cells share certain characteristics, such as being 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 and archaea. 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.

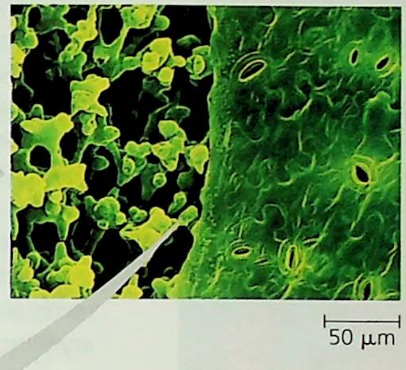
▼ 6 Organs

The structural hierarchy of life continues to unfold as we explore the architecture of a complex organism. A leaf is an example of an **organ**, a body part that is made up of multiple tissues and has specific functions in the body. Leaves, stems, and roots are the major organs of plants. Within an organ, each tissue has a distinct arrangement and contributes particular properties to organ function.

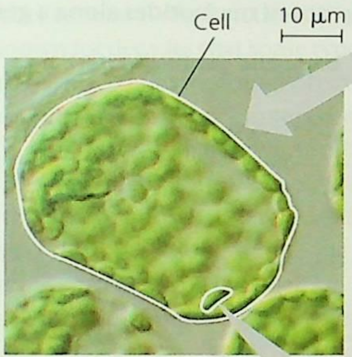


▼ 7 Tissues

Viewing 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 (right side of photo) is a tissue called epidermis. The pores through the epidermis allow entry of the gas CO_2, a raw material for sugar production.



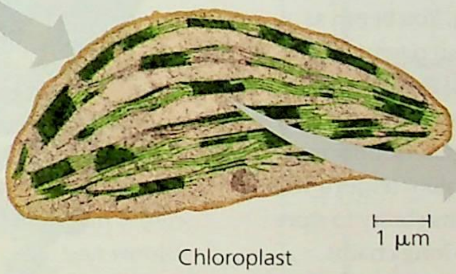
▶ 8 Cells



The **cell** is life's fundamental unit of structure and function. Some organisms consist of a single cell, which performs all the functions of life. Other organisms are multicellular and feature a division of labor among specialized cells. Here we see a magnified view of a cell in a leaf tissue. This cell is about 40 micrometers (μm) across—about 500 of them would reach across a small coin. Within these tiny cells are even smaller green structures called chloroplasts, which are responsible for photosynthesis.

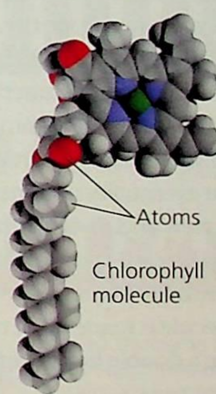
▼ 9 Organelles

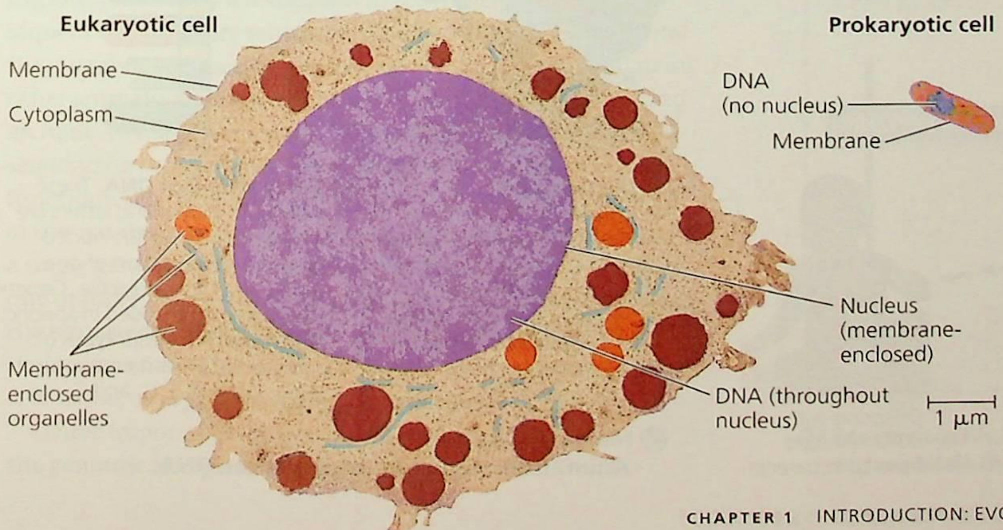
Chloroplasts are examples of **organelles**, the various functional components present in cells. The image below, taken by a powerful microscope, shows a single chloroplast.



▼ 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 that makes a 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.





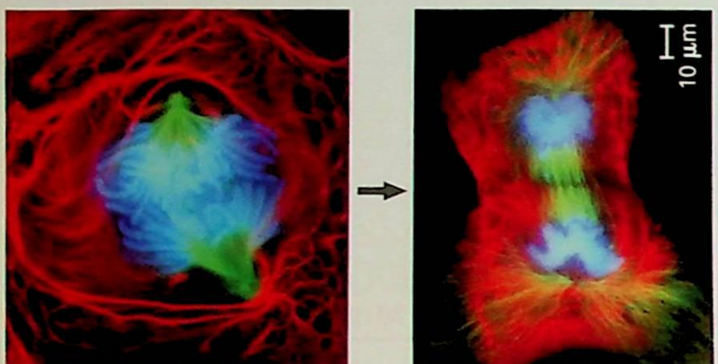
◀ **Figure 1.4 Contrasting eukaryotic and prokaryotic cells in size and complexity.** Cells vary in size, but eukaryotic cells are generally much larger than prokaryotic cells. The cells are shown to scale here; to see a larger magnification of a prokaryotic cell, see Figure 4.4.

VISUAL SKILLS *Measure the scale bar and use its length to estimate the length of the prokaryotic cell and the approximate diameter of the eukaryotic cell.*

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)**.

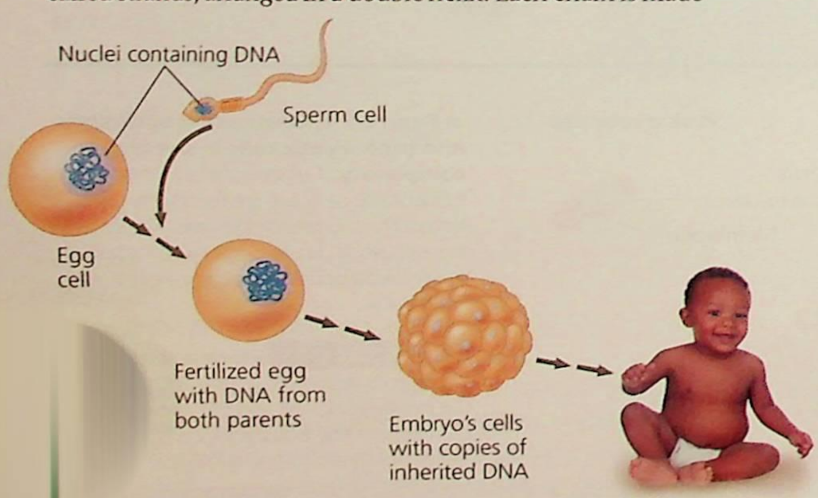
▼ **Figure 1.5 A lung cell from a newt divides into two smaller cells that will grow and divide again.**



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)**.

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



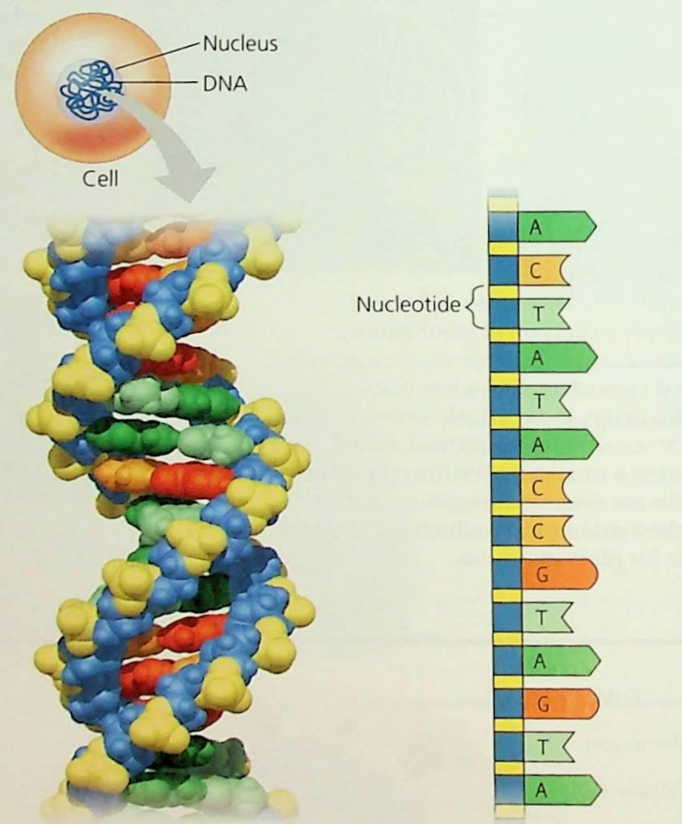
▲ **Figure 1.6 Inherited DNA directs the development of an organism.**

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 the set of nucleotides as a four-letter alphabet.

For many genes, the sequence provides the blueprint for making a protein. For instance, a given bacterial gene may specify a particular protein (an enzyme) required to assemble the cell membrane, while a certain human gene may denote a different protein (an antibody) that helps fight off infection. Overall, proteins are major players in building and maintaining the cell and in carrying out its activities.

Protein-encoding genes control protein production indirectly, using a related molecule called mRNA as an intermediary. The sequence of nucleotides along a gene is transcribed

▼ **Figure 1.7 DNA: The genetic material.**



(a) DNA double helix. This model shows the atoms in a segment of DNA. Made up of two long chains (strands) 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 strand 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.

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Animation: Heritable Information: DNA

into mRNA, which is then translated into a chain 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 production of a cellular product is called **gene expression** (**Figure 1.8**).

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 evolutionary 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. Recently, scientists have discovered whole new classes of RNA that play other roles in the cell, such as regulating the function of protein-coding genes. Genes also specify all of these RNAs, 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.

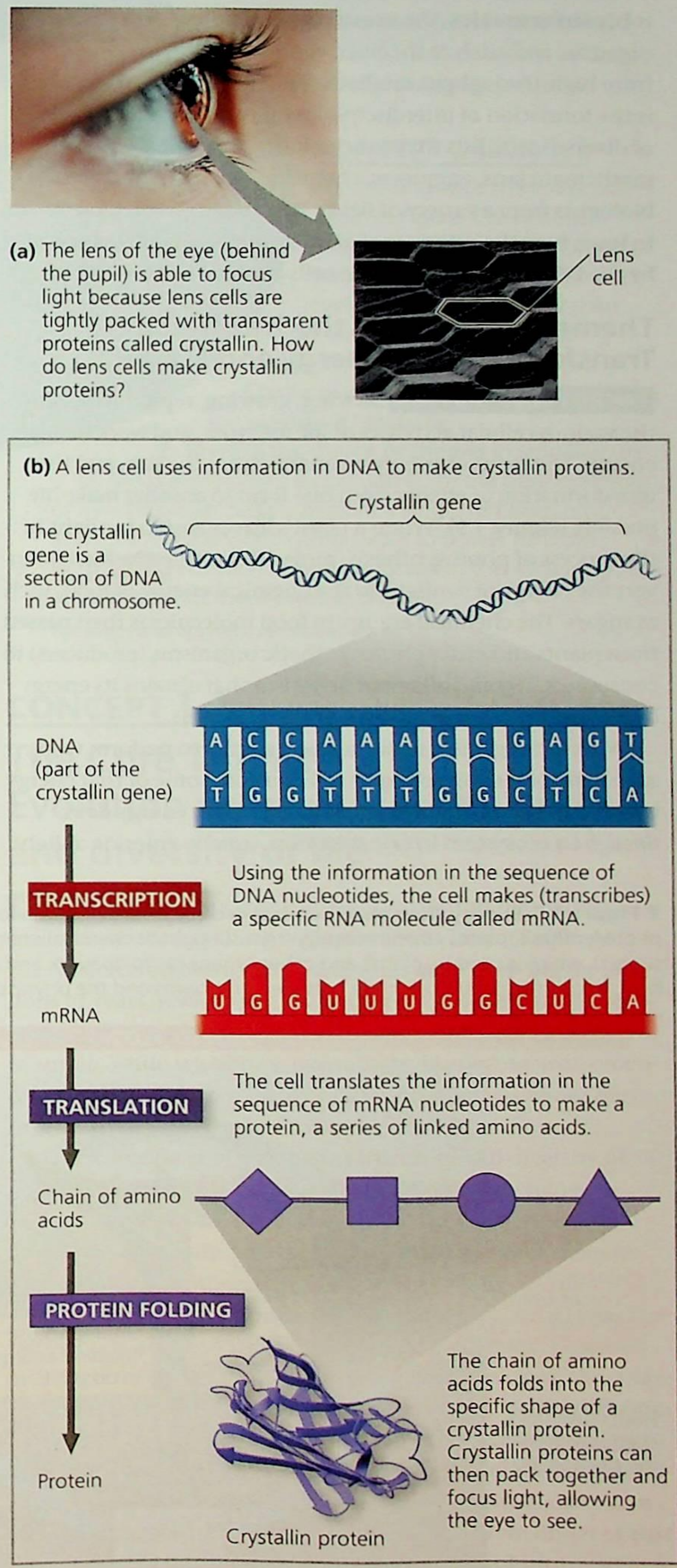
Genomics: Large-Scale Analysis of DNA Sequences

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 one strand in 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 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

▼ **Figure 1.8 Gene expression: Cells use information encoded in a gene to synthesize a functional protein.**



Mastering Biology
Figure Walkthrough

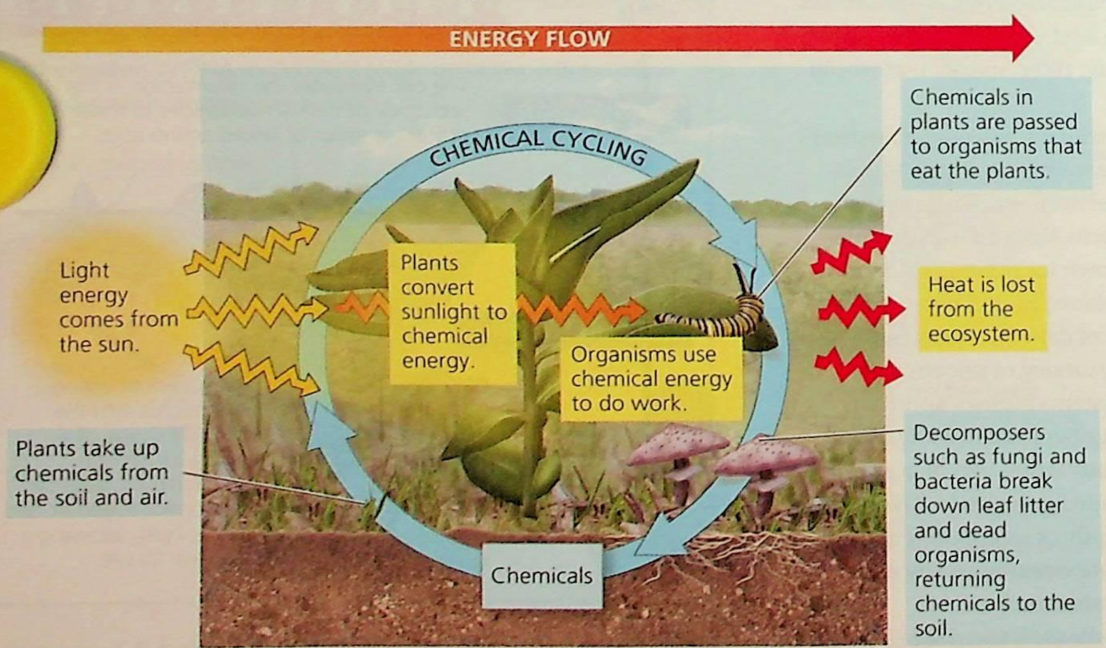
"high-throughput" technology, tools that can analyze many biological samples very rapidly. The second major development is **bioinformatics**, the use of computational tools to store, organize, and analyze the huge volume of data that results from high-throughput methods. The third key development is 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 food molecules is then passed from plants and other photosynthetic organisms (producers) to consumers. A consumer is an organism that obtains its energy by feeding on other organisms or their remains.

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, organic debris, and the bodies of dead organisms. The chemicals are then available to be taken up by plants again, thereby completing the cycle.

▼ **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 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.

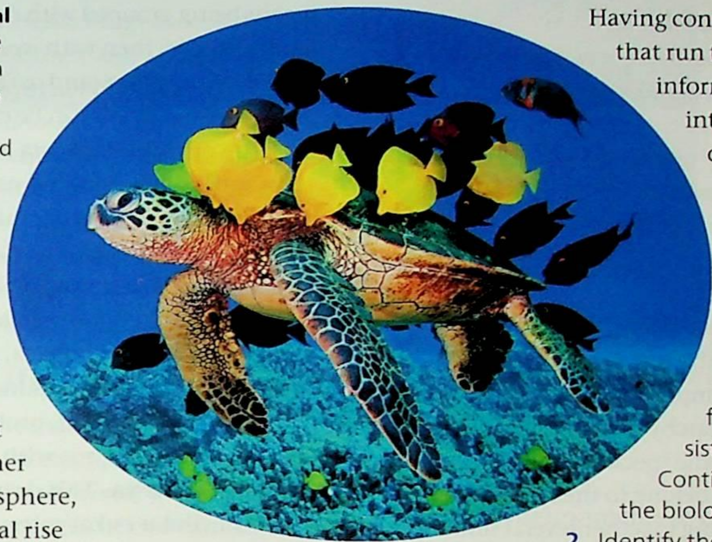


Theme: Organisms Interact with Other Organisms and the Physical Environment

INTERACTIONS Every organism in an ecosystem interacts with other organisms. A flowering plant, for example, interacts with soil microorganisms associated with its roots, insects that pollinate its flowers, and animals that eat its leaves and petals. Interactions between organisms include those that are mutually beneficial (as when fish eat small parasites on a turtle, shown in **Figure 1.10**), 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 (as when two plants compete for a soil resource that is in short supply).

Each organism in an ecosystem also interacts continuously with physical factors in its environment. The leaves of a flowering plant, 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.

Like other organisms, we humans interact with our environment. Unfortunately, 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 (CO_2) and other gases into the atmosphere. About half of this CO_2 stays in the atmosphere, causing heat to be trapped close to Earth's surface (see Figure 43.26). Scientists calculate that the CO_2 added to the atmosphere

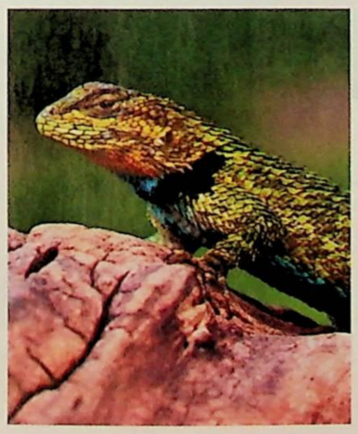


▶ **Figure 1.10 A mutually beneficial interaction between species.** These fish feed on small organisms living on the sea turtle's skin and shell. The sea turtle benefits from the removal of parasites, and the fish gain a meal and protection from enemies. For more examples of mutually beneficial relationships (mutualisms), see Make Connections Figure 29.11.

by human activities has increased the average temperature of the planet by about 1°C since 1900. At the current rates that CO_2 and other gases are being added to the atmosphere, global models predict an additional rise of at least 3°C 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 1.11)**. (For more examples of how climate change is affecting life on Earth, see Make Connections Figure 43.28.)

The loss of populations due to climate change can ultimately result in *extinction*, the permanent loss of a species. As we'll discuss in greater detail in Concept 43.4, the consequences of these changes for humans and other organisms may be profound.



▶ **Figure 1.11 Threatened by global warming.** A warmer environment causes lizards in the genus *Sceloporus* to spend more time in refuges from the heat, reducing the time available for foraging. The lizards' food intake drops, decreasing their reproductive success. Surveys of 200 *Sceloporus* populations in Mexico show that 12% of these populations have disappeared since 1975.

Having considered four of the unifying themes that run through this text (organization, information, energy and matter, and interactions), let's now turn to biology's core theme—evolution.

CONCEPT CHECK 1.1

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. For example, while sea horses, jackrabbits, hummingbirds, crocodiles, 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, although these two species differ in some ways, 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 discuss in detail in Chapters 19–23. Meanwhile, for the remainder of this section, we'll continue our introduction to evolution and how it has led to the unity and diversity of life.

Classifying the Diversity of Life

Diversity is a hallmark of life. 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. These remarkably diverse forms of life arose by evolutionary processes. Before exploring how evolution occurs, however, let's first consider how biologists organize the enormous variety of life-forms on this planet into manageable and informative groupings.

Humans have a tendency to group diverse items according to their similarities and relationships to each other. Consequently, 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 leopard (*Panthera pardus*). Leopards belong to the same genus (*Panthera*) as tigers and lions. Bringing together several similar genera (the plural of genus) forms a family, which in turn is a component of an order and then a class. For the leopard, this means being grouped with cougars, cheetahs, and others in the family Felidae, then with wolves in the order Carnivora, and then with dolphins (and us) in the class Mammalia (see Figure 20.3). 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, such as comparisons of DNA sequences, have led to a reevaluation of the larger groupings. Although this reevaluation is ongoing, biologists currently place all of the kingdoms of life into three higher levels of classification called domains: Bacteria, Archaea, and Eukarya (**Figure 1.12**).

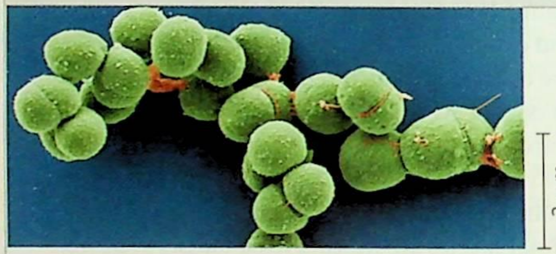
Two of the three domains—**Bacteria** and **Archaea**—consist of single-celled, prokaryotic organisms. All the eukaryotes (organisms with eukaryotic cells) are grouped in domain **Eukarya**. This domain includes three kingdoms of multicellular eukaryotes: Plantae, Fungi, and Animalia. These three kingdoms are distinguished partly by their modes of nutrition. Plants produce their own sugars and

▼ Figure 1.12 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.

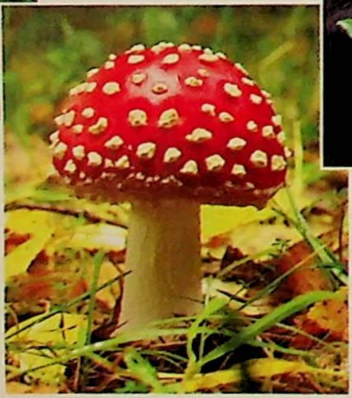
(b) Domain Archaea



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

(c) Domain Eukarya

▲ Kingdom Plantae (plants) consists of multicellular eukaryotes that carry out photosynthesis, the conversion of light energy to the chemical energy in food. Most plant species live on land.



▶ Kingdom Fungi is characterized 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.

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, the kingdom to which we belong.

The most numerous and diverse eukaryotes are the mostly single-celled protists. Although protists once were 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

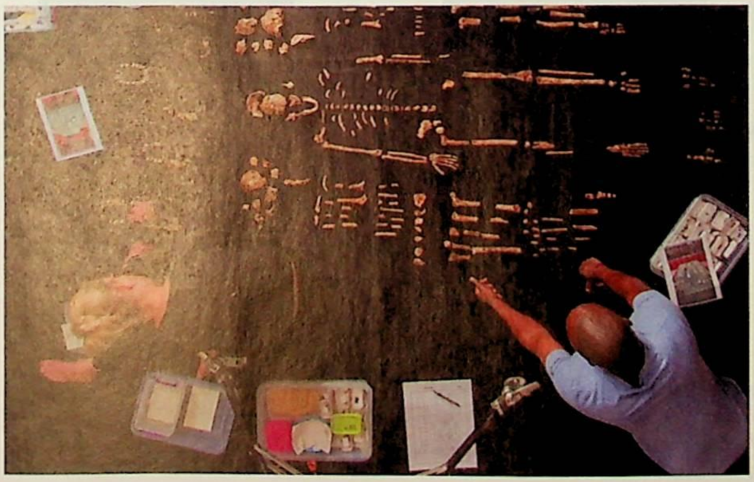
Although diversity is apparent in the many forms of life, there is also remarkable unity. Consider, for example, the similar skeletons of different animals and the universal genetic language of DNA (the genetic code), both mentioned earlier. In fact, similarities between organisms are evident at all levels of the biological hierarchy.

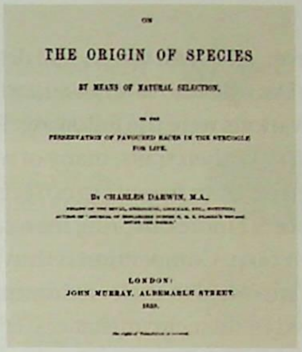
How can we account for life's dual nature of unity and diversity? The process of evolution, explained next, illuminates both the similarities and differences in the world of life. It also introduces another dimension of biology: the passage of time. The history of life, as documented by fossils and other evidence, is the saga of an ever-changing Earth billions of years old, inhabited by an evolving cast of living forms **(Figure 1.13)**.

Charles Darwin and the Theory of Natural Selection

An evolutionary view of life came into sharp focus in 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 1.14)**. *The Origin of Species* articulated two main points. The first was that species accumulate differences from their ancestors as they adapt to

▼ **Figure 1.13 Studying the history of life.** 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.





▲ **Figure 1.14 Charles Darwin.** The portrait shows Darwin in about 1840, before the 1859 publication of his revolutionary book, commonly referred to as *The Origin of Species*.

different environments over time. 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 1.15)**. Darwin's second main point was his proposal that "natural selection" is a primary cause of descent with modification.

Darwin developed his theory of natural selection from observations that by themselves were neither new nor profound.

▼ **Red-tailed hawk (*Buteo borealis*)**

▲ **Gentoo penguin (*Pygoscelis papua*)**

▼ **American flamingo (*Phoenicopterus ruber*)**

▲ **Figure 1.15 Unity and diversity among birds.** These three birds are variations on a common body plan. For example, each has feathers, a beak, and wings, although these features are highly specialized for the birds' diverse lifestyles.

However, although others had described the pieces of the puzzle, it was Darwin who saw how they fit together. His three essential observations were the following: 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 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 are less well-suited individuals. Over many generations, a higher and higher proportion of individuals in a population will have the advantageous traits. 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 **(Figure 1.16)**.

The Tree of Life

For another example of unity and diversity, consider the human arm. The bones, joints, nerves, and blood vessels in your forelimb are very similar to those in 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.

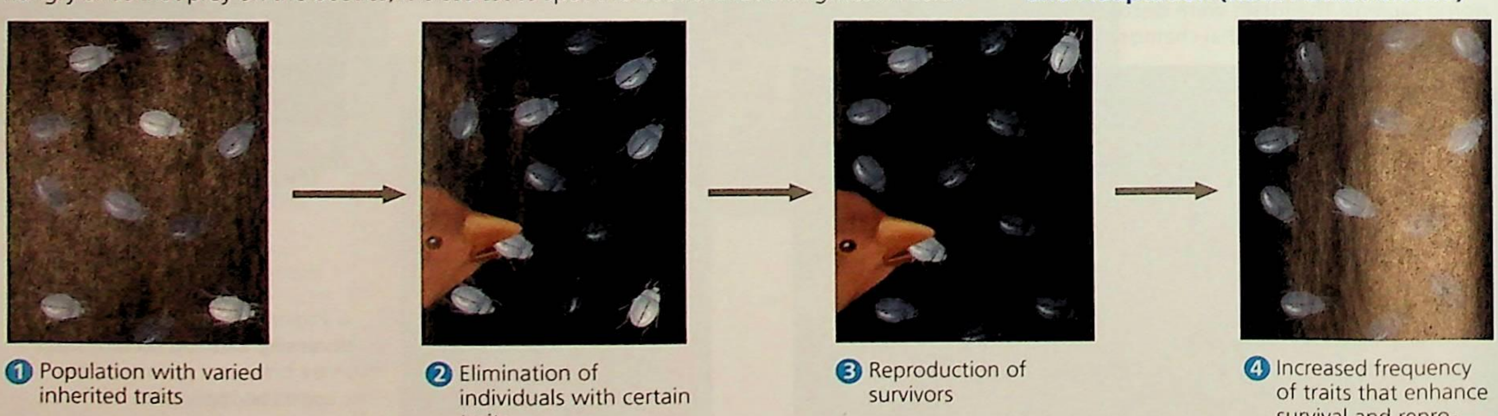
Darwin proposed that natural selection, by its cumulative effects over long periods of time, could cause an ancestral species to give rise to two or more descendant species. This could occur, for example, if one population of organisms fragmented into several subpopulations isolated in different environments. 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 "family tree" of six finch species shown in **Figure 1.17** illustrates a famous example of the process of radiation. Darwin collected specimens of finches during his 1835 visit to the remote Galápagos Islands, 900 kilometers (km) west of South America. 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 using DNA sequence comparisons.

Biologists' diagrams of such evolutionary relationships generally take treelike forms, though the trees are often turned sideways, as in Figure 1.17. 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 farther back in time, finches are related to

▼ **Figure 1.16 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 hungry birds that prey on the beetles, it is easiest to spot the beetles that are lightest in color.

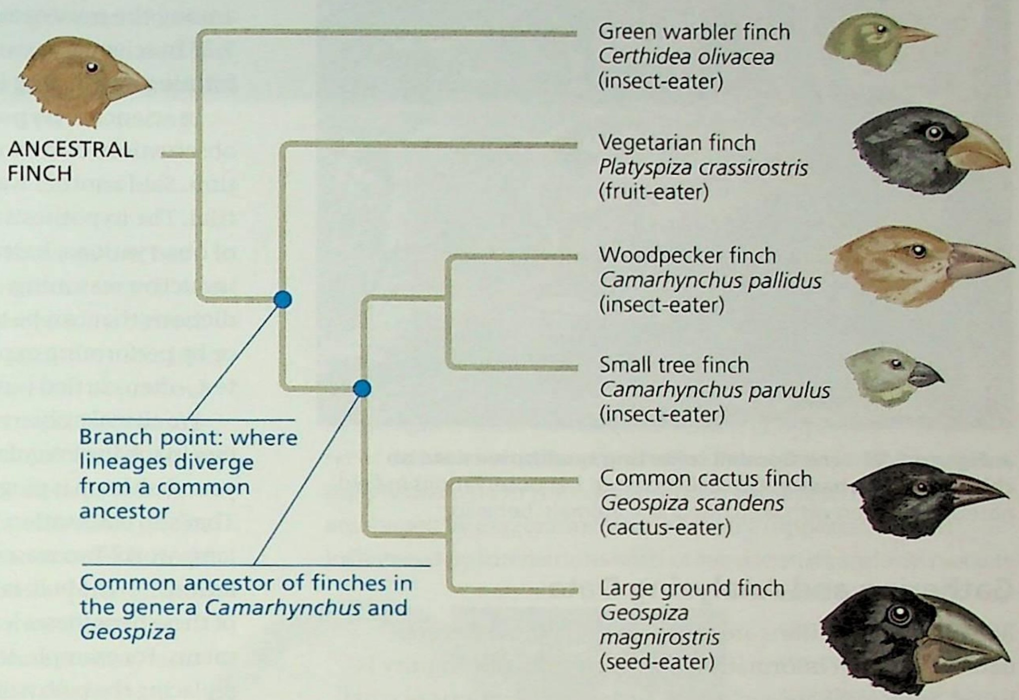
Mastering Biology
HHMI Video: The Making of the Fittest: Natural Selection and Adaptation (Rock Pocket Mouse)



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. Then explain how the population would change over time as the soil becomes lighter.*

▶ Figure 1.17 Descent with modification: finches on the Galápagos Islands. This "tree" diagram illustrates a current hypothesis for the evolutionary relationships of finches on the Galápagos. Note the various beaks, which are adapted to particular food sources. For example, heavier, thicker beaks are better at cracking seeds, while more slender beaks are better at grasping insects.

Mastering Biology
HHMI Video: The Origin of Species: The Beak of the Finch



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 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. **DRAW IT** 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

In studying nature, scientists form and test hypotheses

Science is a way of knowing—an approach to understanding the natural world. It developed out of our curiosity about ourselves, other life-forms, our planet, and the universe.

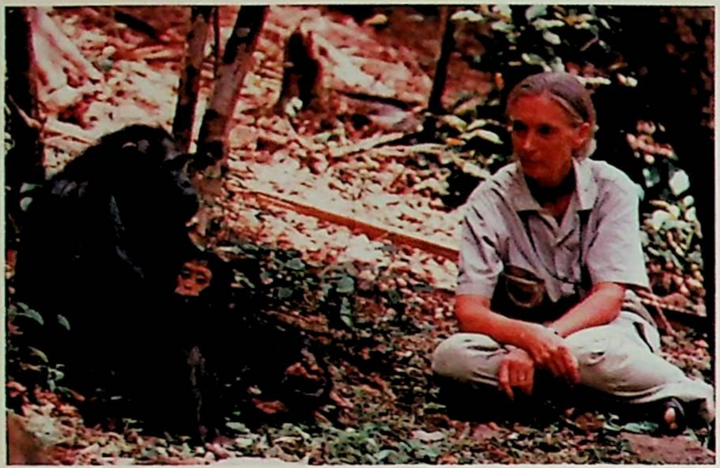
At the heart of science is **inquiry**, the search for information and explanations of natural phenomena. There is no formula for successful scientific inquiry, no single scientific method that researchers must rigidly follow. As in all quests, science includes elements of challenge, adventure, and luck, along with careful planning, reasoning, creativity, patience, and the persistence to overcome setbacks. Such diverse elements of inquiry make science less structured than most people realize. That said, it is possible to highlight 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 explanations (*hypotheses*), and testing them. The process is necessarily repetitive: In testing a hypothesis, our observations may 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.

Exploration and Discovery

Biology, like other sciences, begins with careful observation. In gathering information, biologists often use tools, such as microscopes, precision thermometers, or high-speed cameras, that extend their senses or facilitate careful measurement. Observations can reveal valuable information about the natural world. For example, a series of detailed observations have shaped our understanding of cell structure. Another set of observations is currently expanding our databases of genome sequences from diverse species and of genes whose expression is altered in diseases.

In exploring nature, biologists also rely heavily on the scientific literature, the published contributions of fellow scientists. By reading about and understanding past studies, scientists can build on the foundation of existing knowledge, focusing their investigations on observations that are original and on hypotheses that are consistent with previous findings. Identifying publications relevant to a new line of research is now easier than at any point in the past, thanks to indexed and searchable electronic databases.



▲ **Figure 1.18 Jane Goodall collecting qualitative data on chimpanzee behavior.** Goodall recorded her observations in field notebooks, often with sketches of the animals' behavior.

Gathering and Analyzing Data

Recorded observations are called **data**. Put another way, data are items of information on which scientific inquiry is based. Some data are *qualitative*, such as descriptions of what is observed. For example, British researcher Jane Goodall spent decades recording her observations of chimpanzee behavior during field research in a Tanzanian jungle **(Figure 1.18)**. She also documented her observations with photographs and movies.

In her studies, Goodall also gathered and recorded volumes of *quantitative* data, such as the frequency and duration of specific behaviors for different members of a group of chimpanzees in a variety of situations. Quantitative data are generally expressed as numerical measurements and often organized into tables or graphs. Scientists analyze their data using a type of mathematics called *statistics* to test whether their results are significant or merely due to random fluctuations. All results presented in this text have been shown to be statistically significant.

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 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.

Mastering Biology
Interview with Jane Goodall: Living with chimpanzees

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 different chimpanzee behaviors observed in the wild? What *explains* the variation in coat color among the mice of a single species, shown in Figures 1.1 and 1.2? In science, answering such questions usually involves forming and testing logical explanations—that is, hypotheses.

In science, a **hypothesis** is an explanation, based on observations and assumptions, that leads to a testable prediction. Said another way, a hypothesis 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 must lead to predictions that can be tested by making additional observations or by performing experiments. An **experiment** is a scientific test, often carried out under controlled conditions.

We all make observations and develop questions and hypotheses in solving everyday problems. Let's say, for example, that your desk lamp is plugged in and turned on but the bulb isn't lit. That's an observation. The question is obvious: Why doesn't the lamp work? Two reasonable hypotheses based on your experience are that (1) the bulb is burnt out or (2) the lamp is broken. Each of these hypotheses leads to predictions you can test with experiments. For example, the burnt-out bulb hypothesis predicts that replacing the bulb will fix the problem. Figuring things out in this way by performing a series of tests 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 desk lamp example: *If* the burnt-out bulb hypothesis is correct, *then* the lamp should work when you replace the bulb with a new one.

We can use the desk lamp example to illustrate two other key points about the use of hypotheses in science. First, one can always devise additional hypotheses to explain a set of observations. For instance, another of the many possible alternative hypotheses to explain our dead desk lamp is that the wall outlet is faulty. Although you could design an experiment to test this hypothesis, we can never test all possible explanations. Second, we can never *prove* that a hypothesis is true. Suppose that replacing the bulb fixed the lamp. The burnt-out bulb hypothesis would be the most likely explanation, but testing supports that hypothesis *not* by proving that it is correct, but rather by not finding that it is false. For example, if replacing the bulb fixed the desk lamp, it might have been because the bulb we replaced was good but not screwed in properly.

Although a hypothesis can never be proved beyond all doubt, testing it in various ways can significantly increase our confidence in its validity. Often, rounds of hypothesis formulation and testing lead to a scientific consensus—the shared conclusion of many scientists that a particular hypothesis explains the known data well and stands up to experimental testing.

Questions That Can and Cannot Be Addressed by Science

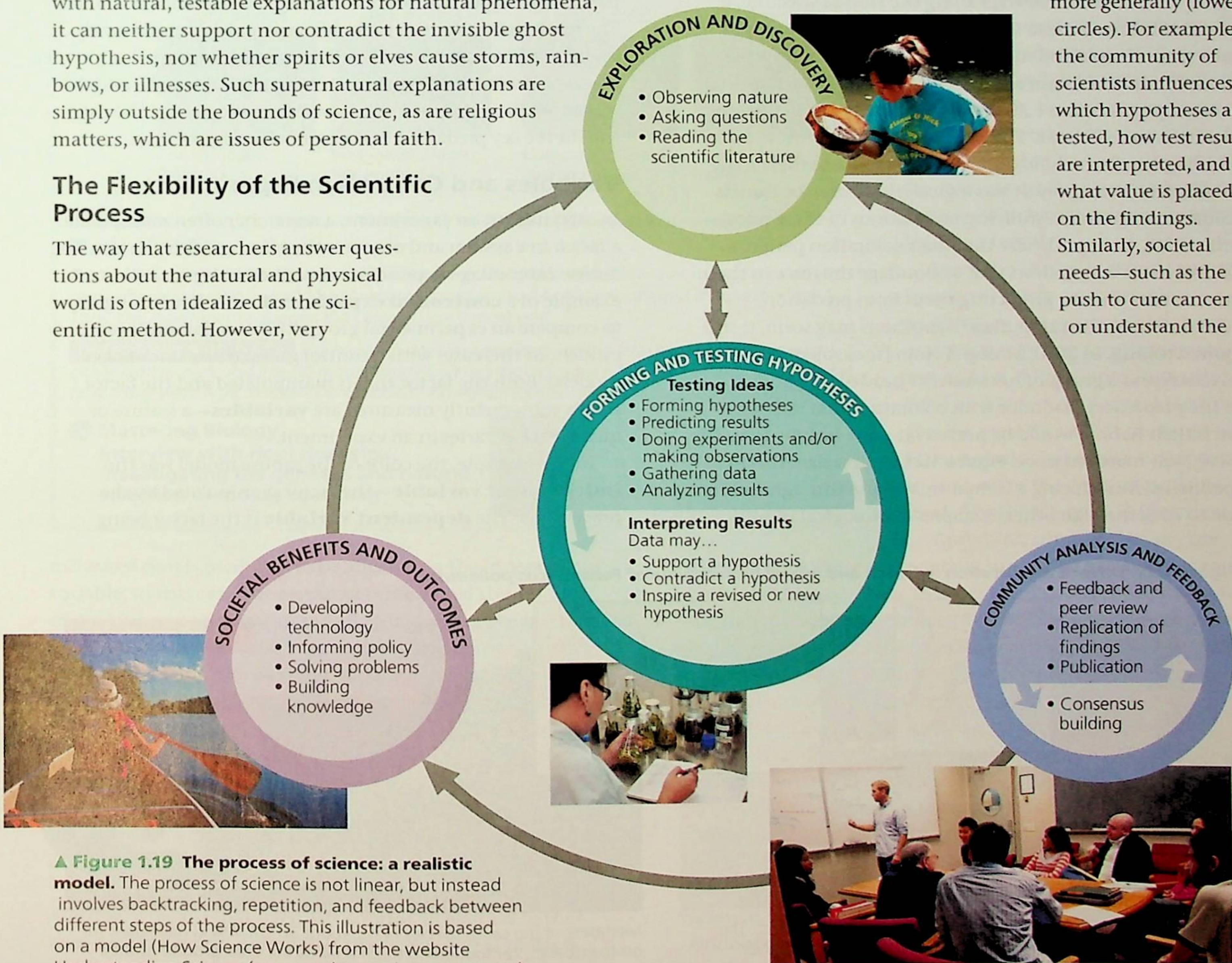
Scientific inquiry is a powerful way to learn about nature, but there are limitations to the kinds of questions it can answer. A scientific hypothesis must be *testable*; there must be some observation or experiment that could reveal if such an idea is more likely to be true or false. For example, the hypothesis that a burnt-out bulb is the sole reason the lamp doesn't work would not be supported if replacing the bulb with a new one didn't fix the lamp.

Not all hypotheses meet the criteria of science: You wouldn't be able to test the hypothesis that invisible ghosts are fooling with your desk lamp! Because science only deals with natural, testable explanations for natural phenomena, it can neither support nor contradict the invisible ghost hypothesis, nor whether spirits or elves cause storms, rainbows, or illnesses. Such supernatural explanations are simply outside the bounds of science, as are religious matters, which are issues of personal faith.

The Flexibility of the Scientific Process

The way that researchers answer questions about the natural and physical world is often idealized as the scientific method. However, very few scientific studies adhere rigidly to the sequence of steps that are typically used to describe this approach. For example, a scientist may start to design an experiment, but then backtrack after realizing that more preliminary observations are necessary. In other cases, observations remain too puzzling to prompt well-defined questions until further study provides a new context in which to view those observations. For example, scientists could not unravel the details of how genes encode proteins until *after* the discovery of the structure of DNA (an event that took place in 1953).

A more realistic model of the scientific process is shown in **Figure 1.19**. The focus of this model, shown in the central circle in the figure, is the forming and testing of hypotheses. This core set of activities is the reason that science does so well in explaining phenomena in the natural world. These activities, however, are shaped by exploration and discovery (upper circle) and influenced by interactions with other scientists and with society more generally (lower circles). For example, the community of scientists influences which hypotheses are tested, how test results are interpreted, and what value is placed on the findings. Similarly, societal needs—such as the push to cure cancer or understand the



▲ **Figure 1.19 The process of science: a realistic model.** The process of science is not linear, but instead involves backtracking, repetition, and feedback between different steps of the process. This illustration is based on a model (How Science Works) from the website Understanding Science (www.understandingscience.org).

process of climate change—may help shape what research projects are funded and how extensively the results are discussed.

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.

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

Our case study begins with a set of observations and inductive generalizations. Color patterns of animals vary widely in nature, sometimes even among 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 have different coat (fur) color patterns and reside in different environments. The beach mouse lives along the Florida seashore, a habitat of brilliant white sand dunes with sparse clumps of beach grass. The inland mouse lives on darker, more fertile soil farther inland **(Figure 1.20)**. Even a brief glance at the photographs in Figure 1.20 reveals a striking match of mouse coloration to its habitat. The natural predators of these mice, including hawks, owls, foxes, and coyotes, all use their sense of sight to hunt for prey. It was logical, therefore, for Francis B. Sumner, a naturalist studying populations of these mice in the 1920s, to hypothesize that their coloration 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 1.21** 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 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 mice in the habitat were the *control* group (for instance, light-colored mouse models in the beach habitat), while the models with the non-native coloration were the *experimental* group (for example, darker models in the beach habitat). The following morning, the team counted and recorded signs of predation events, which ranged from bites and gouge marks on some models to the outright disappearance of other models. Judging by the shape of the predators' bites and the tracks surrounding the experimental sites, the predators appeared to be split fairly evenly between mammals (such as foxes and coyotes) and birds (such as owls, herons, and hawks).

For each environment, the researchers then calculated the percentage of predator attacks that targeted camouflaged models. The results were clear-cut: Camouflaged models showed much lower predation rates than those lacking camouflage in both the dune habitat (where light mice were less vulnerable) and the inland habitat (where dark mice were less vulnerable). The data thus fit the key prediction of the camouflage hypothesis.

Variables and Controls in Experiments

In carrying out an experiment, a researcher often manipulates a factor in a system and observes the effects of this change. The mouse camouflage experiment described in Figure 1.21 is an example of a **controlled experiment**, one that is designed to compare an experimental group (the non-camouflaged models, in this case) with a control group (the camouflaged models). Both the factor that is manipulated and the factor that is subsequently measured are **variables**—a feature or quantity that varies in an experiment.

In our example, the color of the mouse model was the **independent variable**—the factor manipulated by the researchers. The **dependent variable** is the factor being

▼ **Figure 1.20 Different coloration in beach and inland populations of *Peromyscus polionotus*.**

Beach mice live on sparsely vegetated sand dunes along the coast. The light tan, dappled fur on their backs causes them to blend into their surroundings, providing camouflage.

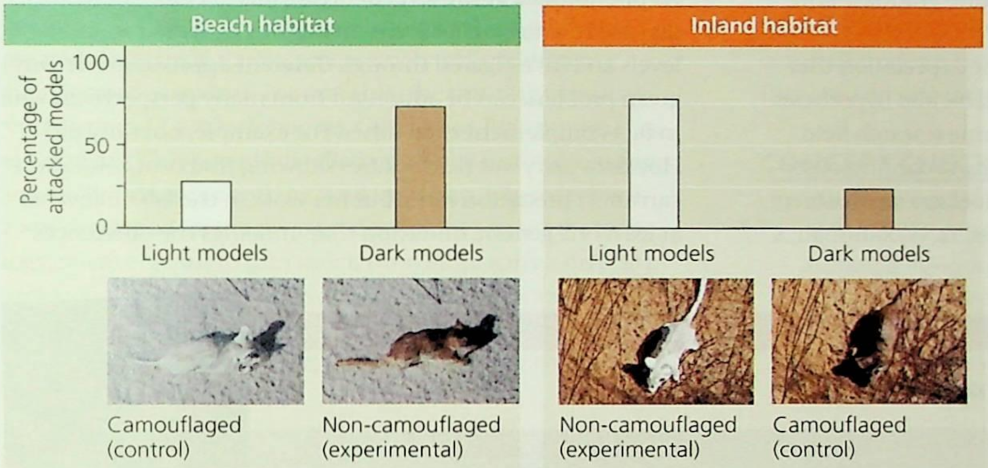
Members of the same species living about 30 km inland have dark fur on their backs, camouflaging them against the dark ground of their habitat.

▼ Figure 1.21 Inquiry

Does camouflage affect predation rates on two populations of mice?

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

Results For each habitat, the researchers calculated the percentage of attacked models that were camouflaged or non-camouflaged. In both cases, the models whose pattern did not match their surroundings suffered much higher "predation" than did the camouflaged models.



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

Conclusion The results are consistent with the researchers' prediction that mouse models with camouflage coloration would be attacked less often than non-camouflaged mouse models. Thus, the experiment supports the camouflage hypothesis.

INTERPRET THE DATA *The bars indicate the percentage of the attacked models that were either light or dark. Assume 50 mouse models were attacked in each habitat. For the beach habitat, how many were light models? Dark models? Answer the same questions for the inland habitat.*

Mastering Biology
Interview with Hopi Hoekstra: Investigating the genetics and natural selection of mouse coat color

measured that is predicted to be affected by the independent variable; in this case, the researchers measured the amount of predation in response to variation in color of the mouse model. Note also that the experimental and control groups differ in only one independent variable: color. As a result, the researchers could rule out other factors as causes of the more frequent attacks on the non-camouflaged models—such as different numbers of predators or different temperatures in the various test areas. The experimental design left coloration as the only factor that could account for the low predation rate on models camouflaged with respect to the surrounding environment.

A common misconception is that the term *controlled experiment* means that scientists control all features of the experimental environment. But that's impossible in field research and can be very difficult even in a highly regulated laboratory setting. Researchers usually "control" unwanted variables not by *eliminating* them but by *canceling out* their effects using control groups.

Theories in Science

"It's just a theory!" Our everyday use of the word *theory* often implies an untested speculation. But this term has a different meaning in science. What is a scientific theory, and how is it different from a hypothesis or from mere speculation?

First, a scientific **theory** is much broader in scope than a hypothesis. This is a *hypothesis*: "Coat coloration that is well matched to habitat is an adaptation that protects mice from predators." But *this* is a *theory*: "Evolutionary adaptations arise by natural selection." This theory proposes that natural selection accounts for an enormous variety of adaptations, of which coat color in mice is but 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. (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 or the theory of gravity) explain a great diversity of observations and are supported by a vast accumulation of evidence.

Finally, scientists will modify or even reject a previously supported theory if new research consistently produces 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

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. Furthermore, 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.

Science is continuously vetted through the expectation that observations and experiments must be repeatable and hypotheses must be testable. 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, four decades earlier. You can study the design of Kaufman's experiment and interpret the results in the **Scientific Skills Exercise**.

If scientific colleagues cannot repeat experimental findings, this failure may reflect an underlying weakness in the original claim, which will then have to be revised. In this sense, science polices itself. Adherence to high professional standards in reporting results is central to the scientific endeavor, since the validity of experimental data is key to designing further 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 observed at different levels and investigated through different approaches. Yet any given problem can be addressed from many perspectives, which in fact complement each other. For example, not only did Hoekstra carry out field studies showing that coat coloration can affect predation rates, but her work in the lab uncovered at least one genetic mutation that underlies the differences

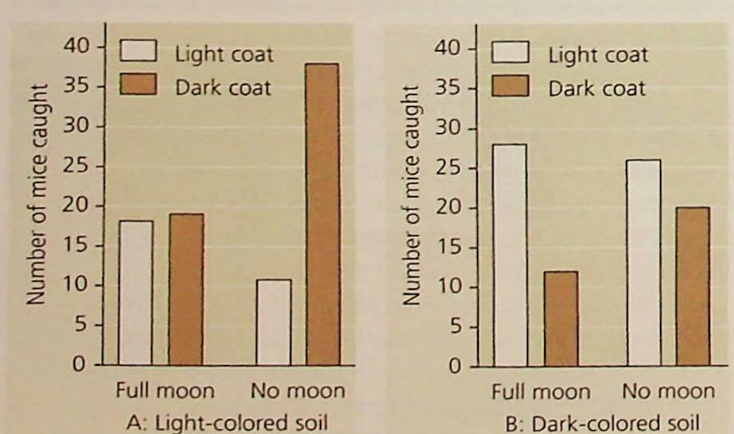
Scientific Skills Exercise

Interpreting a Pair of Bar Graphs

How Much Does Camouflage Affect Predation on Mice by Owls with and without Moonlight? D. W. Kaufman hypothesized that the extent to which the coat color of a mouse contrasted with the color of its surroundings would affect the rate of nighttime predation by owls. He also hypothesized that contrast would be affected by the amount of moonlight. In this exercise, you will analyze data from his studies of owl-mouse predation that tested these hypotheses.

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



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

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? (For additional information about graphs, see the Scientific Skills Review in Appendix F.)
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)** What about 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?
6. Thinking about your answers to question 5, provide a simple statement describing conditions that are especially deadly for either color of mouse.
7. Combining the data from both graphs, estimate the number of mice caught in moonlight versus no-moonlight conditions. Which condition is optimal for predation by the owl? Explain.

Instructors: A version of this Scientific Skills Exercise can be assigned in **Mastering Biology**.

between beach and inland mouse coloration. Because the biologists in her lab have different specialties, her research group has been able not only to characterize evolutionary adaptations, but also to define the molecular basis for particular adaptations in the DNA sequence of the mouse genome.

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 around 1440 by Johannes Gutenberg, living in what is now Germany. This invention relied on several innovations from China, 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 racial and ethnic groups 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 women now constitute roughly half of undergraduate majors and Ph.D. students in the field. The pace of change 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 qualitative observation led to the quantitative study outlined in Figure 1.21?
3. Why is natural selection called a theory?
4. How does science differ from technology?

For suggested answers, see Appendix A.

1 Chapter Review

Go to **Mastering Biology** for Assignments, the eText, the Study Area, and Dynamic Study Modules.

SUMMARY OF KEY CONCEPTS

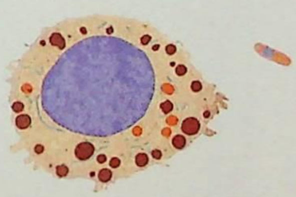
To review key terms, go to the **Vocab Self-Quiz** in the **Mastering Biology** eText or Study Area, or go to goo.gl/ywgNry.

CONCEPT 1.1

The study of life reveals unifying themes (pp. 3–9)

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 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.

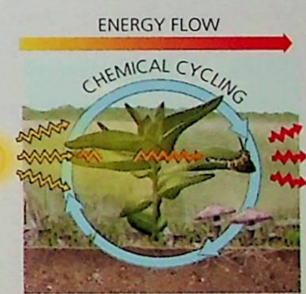


Theme: Information

- 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 mRNA and then translated into specific proteins, a process called **gene expression**. Gene expression also produces RNAs that are not translated into proteins but serve other important functions.

Theme: Energy and Matter

- Energy flows through an ecosystem. Producers convert energy from sunlight to chemical energy, which is used by organisms to do work and is eventually lost from the ecosystem as heat. Chemicals cycle between organisms and the environment.



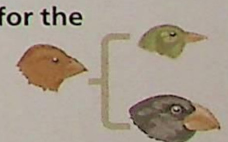
Theme: Interactions

- 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.

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

CONCEPT 1.2

The Core Theme: Evolution accounts for the unity and diversity of life (pp. 9–13)



- **Evolution**, the process of change that has transformed life on Earth, accounts for the unity and diversity of life. It also explains evolutionary adaptation—the match of organisms to their environments.

- 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.
- Darwin proposed **natural selection** as the mechanism for evolutionary adaptation of populations to their environments. Natural selection is the evolutionary process that occurs when a population is exposed to environmental factors that consistently cause individuals with certain heritable traits to have greater reproductive success than do individuals with other heritable traits.
- Each species is one twig of a branching tree of life extending back in time through more and more remote ancestral species. 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

In studying nature, scientists form and test hypotheses (pp. 13–19)

- 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.
- **Controlled experiments** are designed to demonstrate the effect of one **variable** by testing control groups and experimental groups differing in only that one variable.
- A scientific **theory** is broad in scope, generates new hypotheses, and is supported by a large body of evidence.
- Observations and experiments must be repeatable, and hypotheses must be testable. **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 gathering and interpreting data in scientific inquiry?*

TEST YOUR UNDERSTANDING

For more multiple-choice questions, go to the **Practice Test** in the **Mastering Biology** eText or Study Area, or go to goo.gl/BghzNr.

LEVELS 1-2: Remembering/Understanding

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

2. Which of the following best demonstrates the unity among all organisms?
(A) emergent properties
(B) descent with modification
(C) DNA structure and function
(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) Theories are proved true; hypotheses are often contradicted by experimental results.

LEVELS 3-4: Applying/Analyzing

5. 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 prediction is correct, my hypothesis is supported.

6. **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.

LEVELS 5-6: Evaluating/Creating

7. **SCIENTIFIC INQUIRY**
Based on the results of the mouse coloration case study, propose a hypothesis researchers might use to further study the role of predators in the natural selection process.

8. **SCIENTIFIC INQUIRY**
Scientists search the scientific literature by means of electronic databases such as PubMed, a free online database maintained by the National Center for Biotechnology Information. Use PubMed to find the abstract of a scientific article that Hopi Hoekstra published in 2016 or later.

9. **FOCUS ON A THEME: EVOLUTION**
In a short essay (100–150 words), describe Darwin's view of how natural selection resulted in both unity and diversity of life on Earth. Include in your discussion some of his evidence. (For help in writing good essays, see "Writing Tips and Rubrics" in the Study Area of **Mastering Biology** under "Additional Resources.")

10. **FOCUS ON A THEME: INFORMATION**
A typical prokaryotic cell has about 3,000 genes in its DNA, while a human cell has almost 21,000 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 1,000 genes. (b) What functions might these shared genes have? Justify your choices.

11. **SYNTHESIZE YOUR KNOWLEDGE**

Can you pick out the mossy leaf-tailed gecko lying against the tree trunk in this photo? How is the appearance of the gecko a benefit in terms of survival? Given what you learned about evolution, natural selection, and genetic information in this chapter, describe how the gecko's coloration might have evolved.

For selected answers, see Appendix A.

Unit 1 Chemistry and Cells

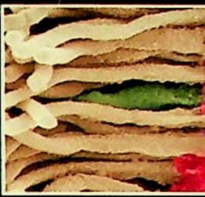
2 The Chemical Context of Life

The structures and functions of living organisms are based on the **chemistry** of atoms and molecules.

3 Carbon and the Molecular Diversity of Life

The carbon atom is the foundation of all organic molecules, and its versatility gives rise to the **molecular diversity of life.**

4 A Tour of the C



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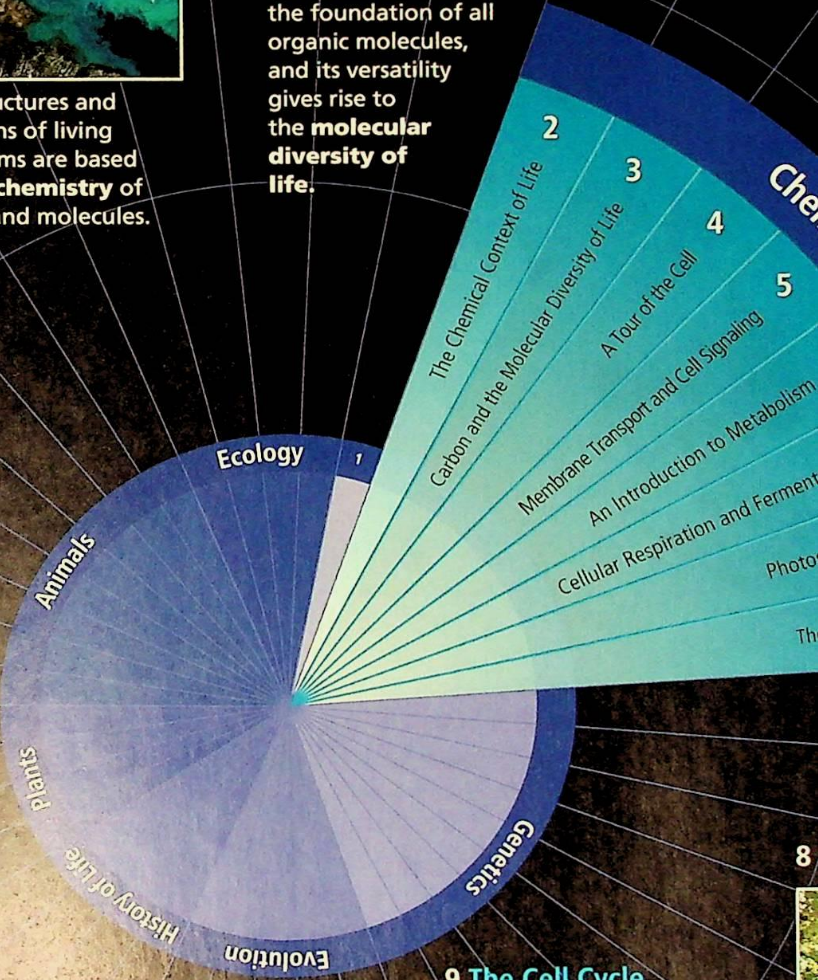

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9 The Cell Cycle

A eukaryotic cell grows and then divides in two, passing along identical genetic information to its daughter cells via **mitosis.** The **cell cycle** describes this progression.