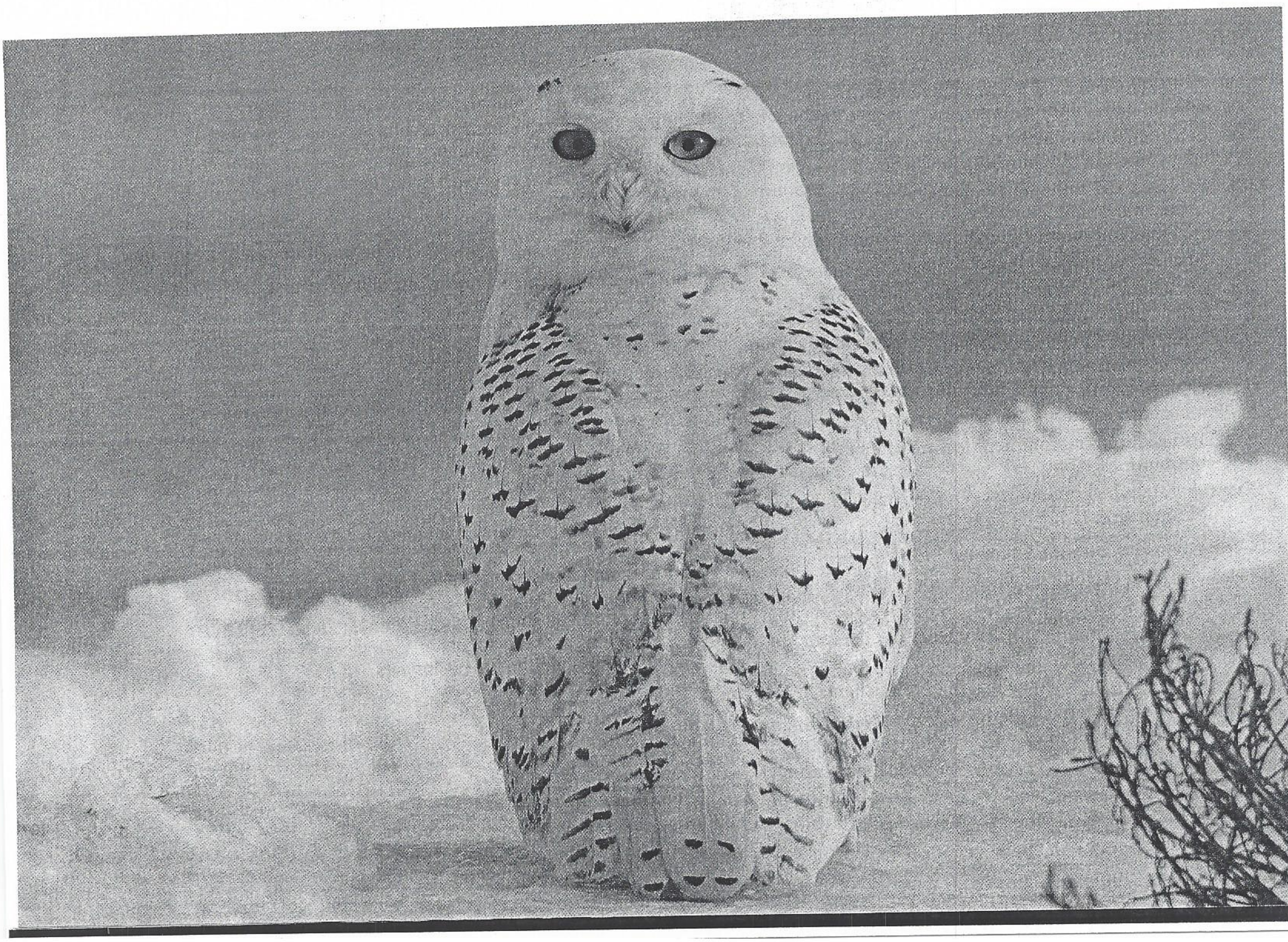
CHAPTER 1

Biology: *Exploring Life*

? *Why do so many animals match their surroundings?*

Snowy owls (*Bubo scandiacus*), such as the one on the cover of this textbook and pictured below, are strikingly beautiful owls with bright orange eyes and wingspans as wide as five feet. These swift and silent predators exhibit remarkable adaptations for life in their frozen, barren habitat. The layers of fine feathers on their face, body, legs, and even their feet provide insulation in subzero weather. They breed on the Arctic tundra, nesting on open ground. The female broods the eggs and young, while the male provides a steady supply of food. His keen vision and acute hearing help him locate small mammals such as voles and lemmings, which he then snatches in mid-flight with his sharp talons.

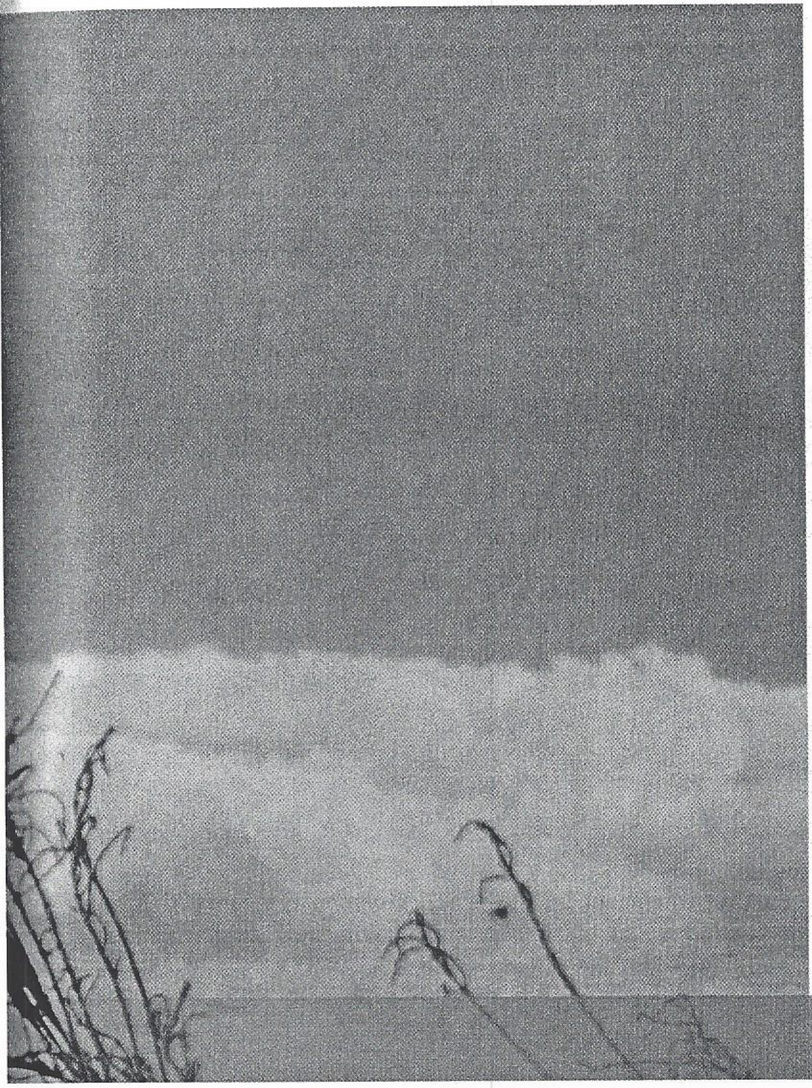
The majority of owl species are nocturnal. But during the endless days of arctic summers, snowy owls hunt in daylight. Projecting upper eyelids help shield their eyes from bright sun. As with all owls, the overlapping fields of vision of their forward-facing eyes provide superior depth perception. These large eyes cannot move, so an owl must turn its whole head to follow a moving object. This is not a problem for an owl, as you can see in the photo below, because adaptations of its neck



vertebrae enable it to rotate its head a full 270 degrees. Imagine being able to look over your left shoulder by turning your head to the right!

You may think of owls in general in shades of brown, nesting in tree cavities and blending in with their surroundings. And with snowy owls, you may think of Harry Potter's white-feathered companion. In real life, these owls also blend in with their wintry habitat. Later in this chapter, you will read about an experiment that tests the hypothesis that camouflage coloration protects animals from predators.

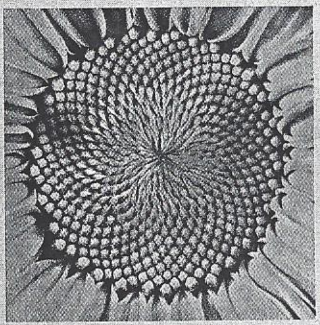
The amazing adaptations of snowy owls are the result of evolution, the process that has transformed life from its earliest beginnings to the astounding array of organisms living today. In this chapter, we begin our exploration of biology—the scientific study of life.



BIG IDEAS

Themes in the Study of Biology (1.1–1.4)

Common themes help to organize the study of life.

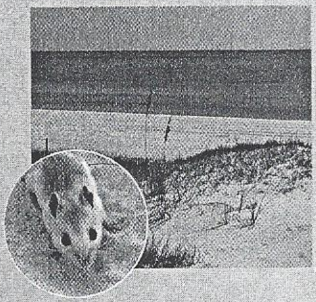


Evolution, the Core Theme of Biology (1.5–1.7)

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

The Process of Science (1.8–1.9)

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



Biology and Everyday Life (1.10–1.11)

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

▷ Themes in the Study of Biology

1.1 All forms of life share common properties

Defining **biology** as the scientific study of life raises the obvious question: What is *life*? Even a small child realizes that a bug or a flower is alive, whereas a rock or a car is not. But the phenomenon we call life defies a simple, one-sentence definition. We recognize life mainly by what living things do. **Figure 1.1** highlights seven of the properties and processes that we associate with life.

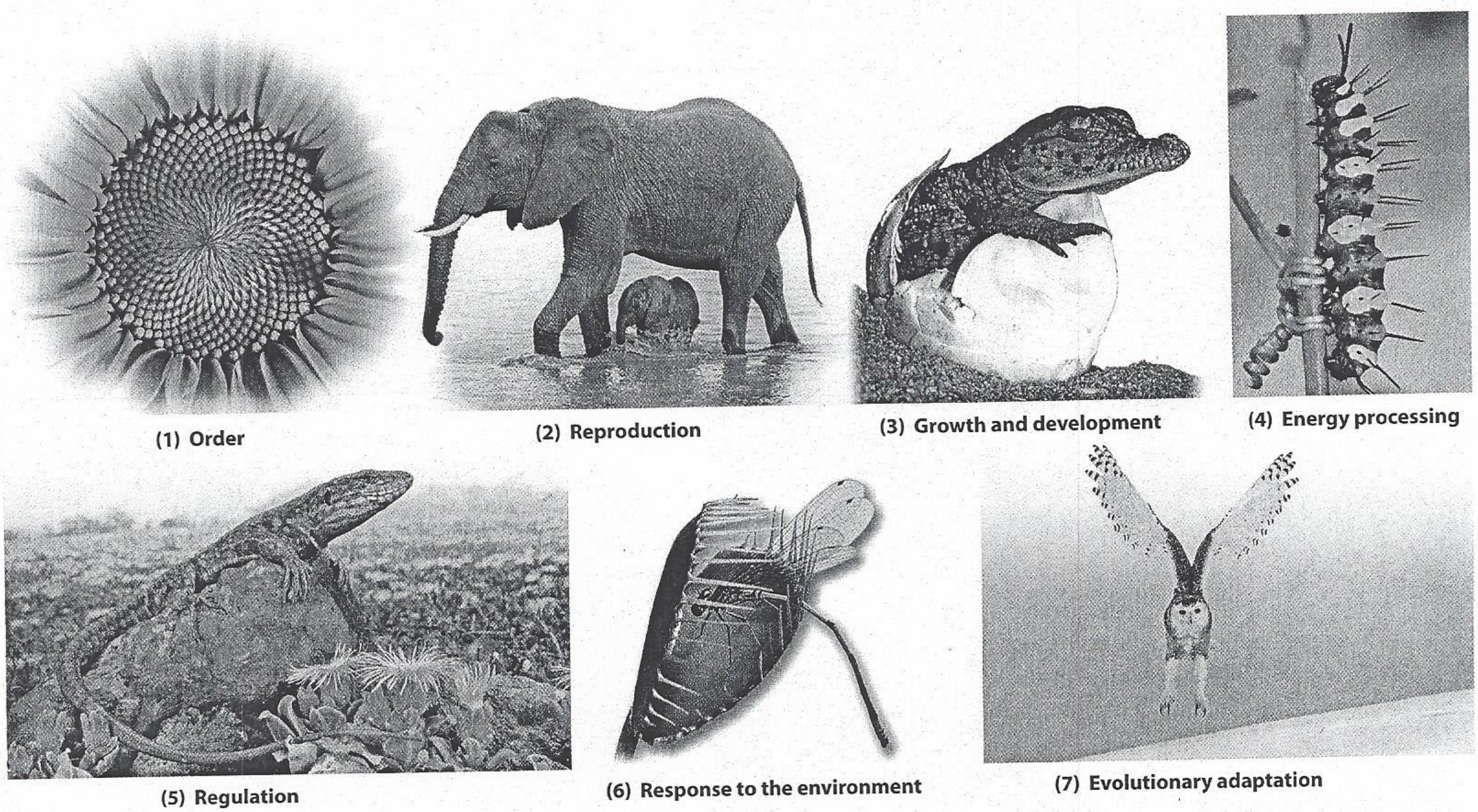
1. *Order.* This sunflower illustrates the ordered structure that typifies life. Living cells make up this complex organization.
2. *Reproduction.* Organisms reproduce their own kind. Here a baby African elephant walks beneath its mother.
3. *Growth and development.* Inherited information in the form of DNA controls the pattern of growth and development of all organisms, including this hatching crocodile.
4. *Energy processing.* This caterpillar will use the chemical energy stored in the plant it is eating to power its own activities and chemical reactions.
5. *Regulation.* Many types of mechanisms regulate an organism's internal environment, keeping it within limits that sustain life. Pictured here is a lizard "sunbathing"—which helps raise its body temperature on cool mornings.
6. *Response to the environment.* All organisms respond to environmental stimuli. This Venus flytrap closed its trap rapidly in response to the stimulus of a damselfly landing on it.
7. *Evolutionary adaptation.* A snowy owl's sharp talons facilitate prey capture and its feathered feet keep it warm in its cold habitat. Such adaptations evolve over many generations as individuals with traits best suited to their environment have greater reproductive success and pass their traits to offspring.

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

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

? **How would you define life?**

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



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

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

As **Figure 1.2** illustrates, the study of life extends from the global scale of the biosphere to the microscopic level of molecules. At the upper left we take a distant view of the **biosphere**, all of the environments on Earth that support life. These include most regions of land, bodies of water, and the lower atmosphere. A closer look at one of these environments brings us to the level of an **ecosystem**, which consists of all the organisms living in a particular area, as well as the physical components with which the organisms interact, such as air, soil, water, and sunlight.

The entire array of organisms in an ecosystem is called a **community**. In this community, we find alligators and snakes, herons and egrets, myriad insects, trees and other plants, fungi, and enormous numbers of microorganisms. Each unique form of life is called a species.

A **population** includes all the individuals of a particular species living in an area. Next in the hierarchy is the **organism**, an individual living thing, such as an alligator.

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

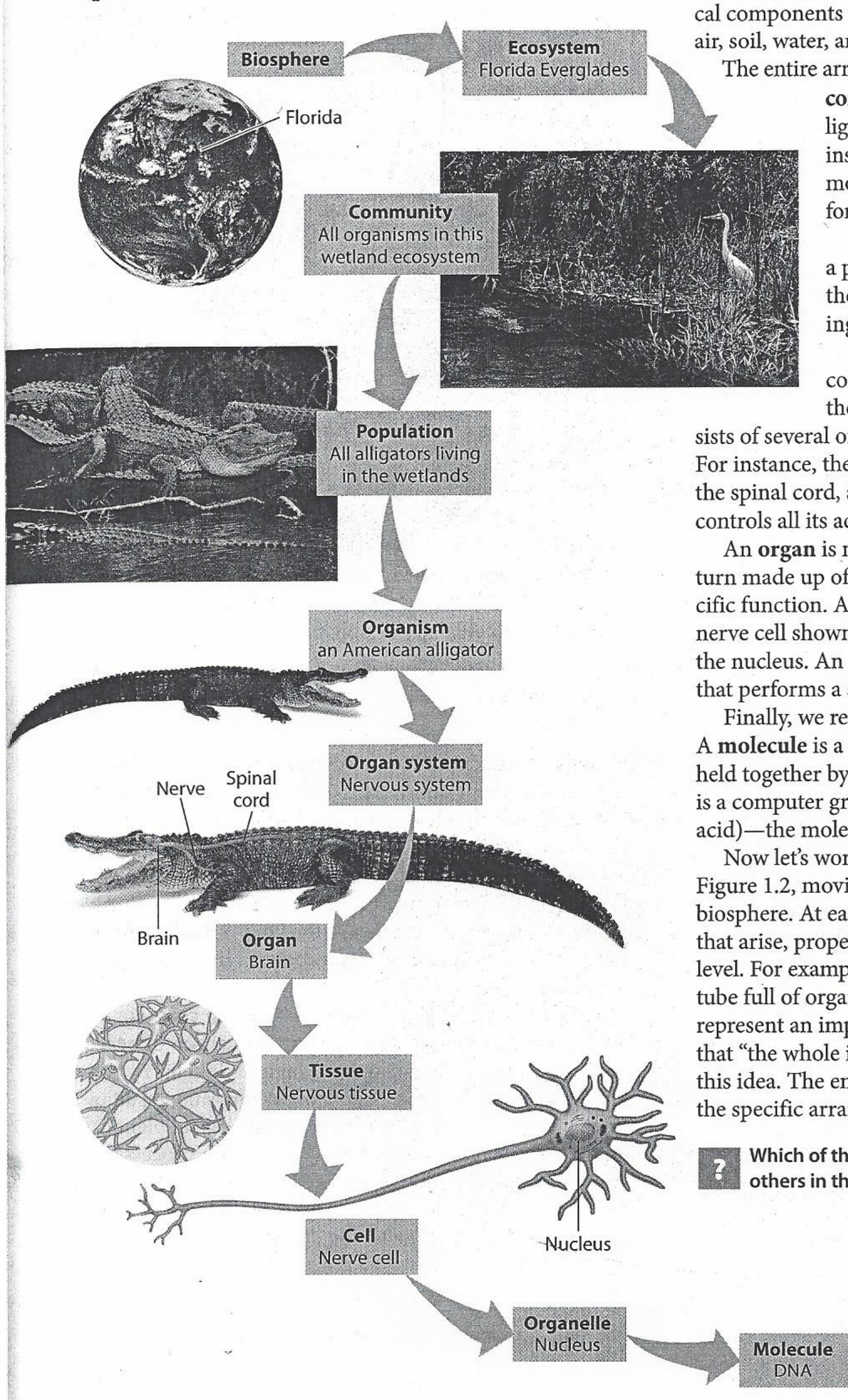
An **organ** is made up of several different **tissues**, each in turn made up of a group of similar cells that perform a specific function. A **cell** is the fundamental unit of life. In the nerve cell shown here, you can see several organelles, such as the nucleus. An **organelle** is a membrane-enclosed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

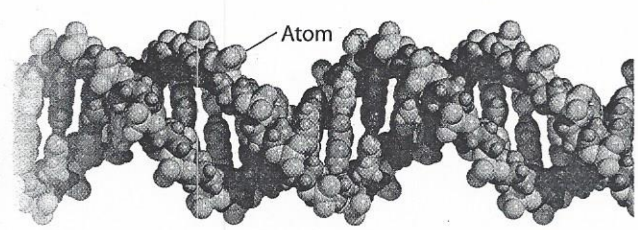
Finally, we reach the level of molecules in the hierarchy. A **molecule** is a cluster of small chemical units called atoms held together by chemical bonds. Our example in Figure 1.2 is a computer graphic of a section of DNA (deoxyribonucleic acid)—the molecule of inheritance.

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

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

● Organ





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

1.3 Cells are the structural and functional units of life

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

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

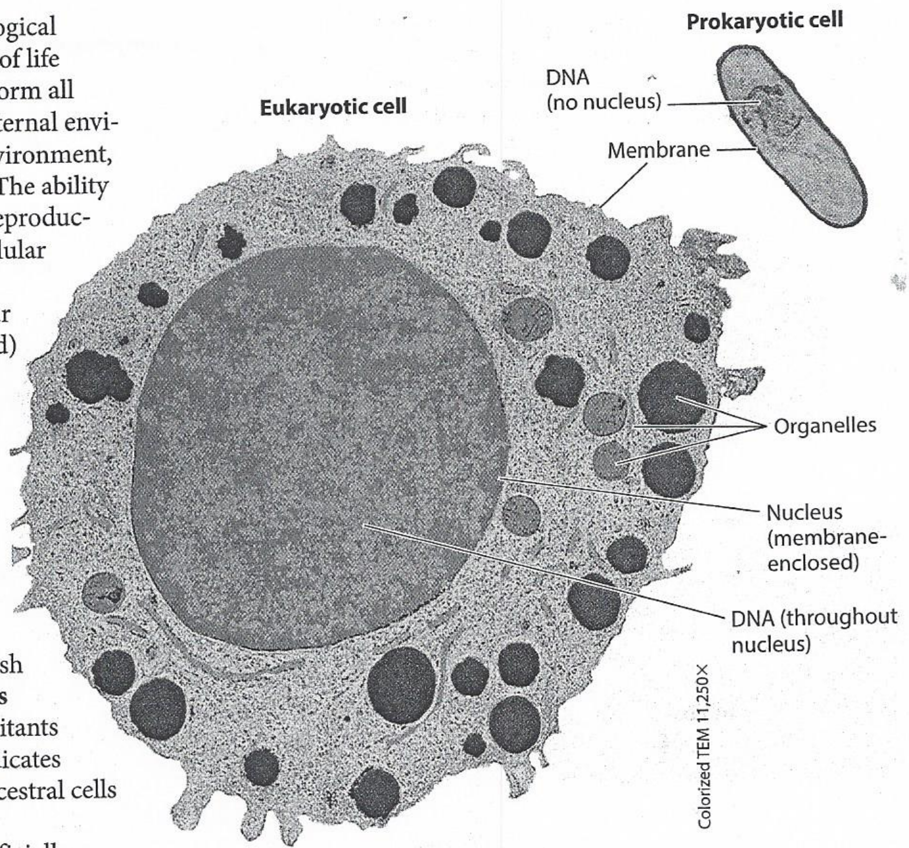
All cells share certain characteristics. For example, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. And every cell uses DNA as its genetic information. However, we can distinguish between two main forms of cells. **Prokaryotic cells** were the first to evolve and were Earth's sole inhabitants for more than 1.5 billion years. Fossil evidence indicates that **eukaryotic cells** evolved from prokaryotic ancestral cells about 1.8 billion years ago.

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

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

The emergent properties of life, however, are particularly challenging to study because of the unrivaled complexity of biological systems. Biologists today often use an approach called **systems biology**—the study of a biological system and the modeling of its dynamic behavior by analyzing the interactions among its parts. Biological systems can range from the functioning of the biosphere to the molecular machinery of an organelle.

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



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

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

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

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

1.4 Organisms interact with their environment, exchanging matter and energy

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

The consumers of a ecosystem eat plants and other animals. The moose in Figure 1.4 eats the grasses and tender shoots and leaves of trees in a forest ecosystem in Canada. To release the energy in food, animals (as well as plants and most other organisms) take in O_2 from the air and release CO_2. An animal's wastes return other chemicals to the environment.

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

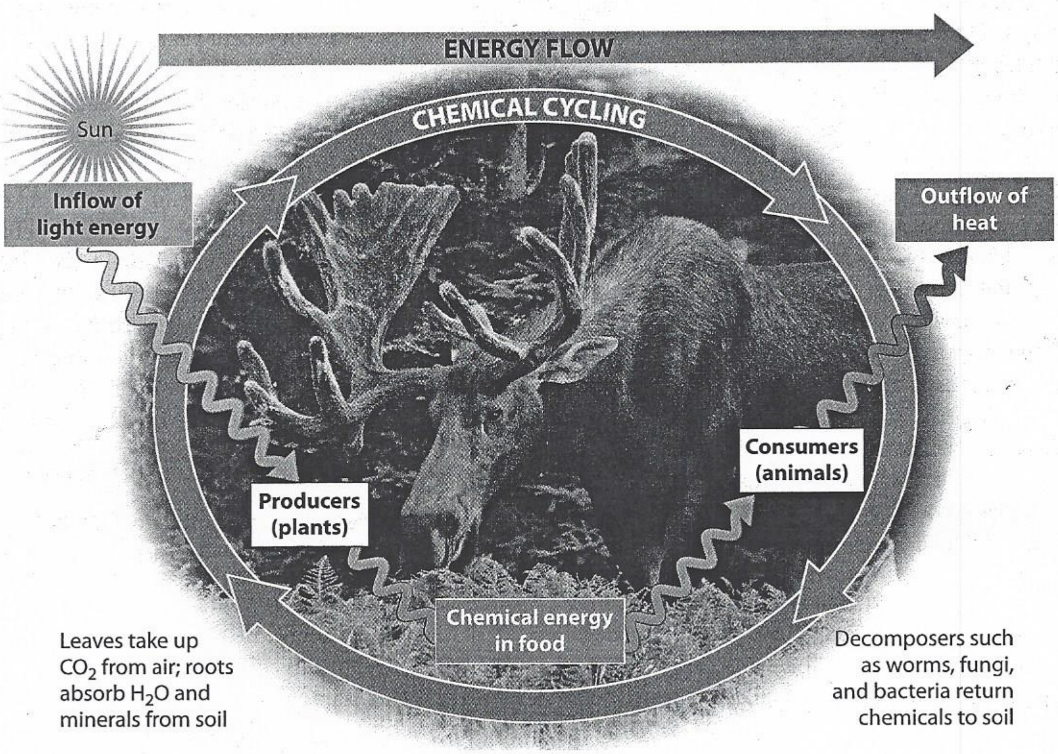
The dynamics of ecosystems include two major processes—the recycling of chemicals and the flow of energy. These processes are illustrated in Figure 1.4. The most basic chemicals necessary for life—carbon dioxide, oxygen, water, and various minerals—cycle within an ecosystem from the air and soil to plants,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

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

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

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

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



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

▷ Evolution, the Core Theme of Biology

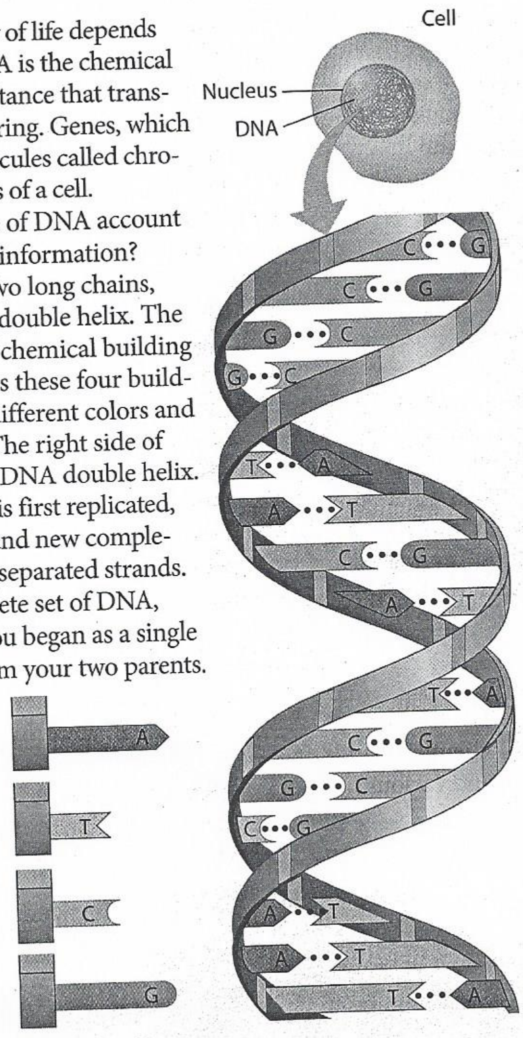
1.5 The unity of life is based on DNA and a common genetic code

All cells have DNA, and the continuity of life depends on this universal genetic material. DNA is the chemical substance of **genes**, the units of inheritance that transmit information from parents to offspring. Genes, which are grouped into very long DNA molecules called chromosomes, also control all the activities of a cell.

How does the molecular structure of DNA account for its ability to encode and transmit information? Each DNA molecule is made up of two long chains, called strands, coiled together into a double helix. The strands are made up of four kinds of chemical building blocks. **Figure 1.5** (left side) illustrates these four building blocks, called nucleotides, with different colors and letter abbreviations of their names. The right side of the figure shows a short section of a DNA double helix.

Each time a cell divides, its DNA is first replicated, or copied—the double helix unzips and new complementary strands assemble along the separated strands. Thus, each new cell inherits a complete set of DNA, identical to that of the parent cell. You began as a single cell stocked with DNA inherited from your two parents. The replication of that DNA during each round of cell division transmitted copies of the DNA to what eventually became the trillions of cells of your body.

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



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

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

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

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 contains about 3 billion nucleotide pairs. In recent years, scientists have determined the entire sequence of nucleotides in the human genome, as well as the genomes of thousands of other species. More species continue to be added to the list of species whose genomes have been sequenced as the rate at which sequencing can be done has accelerated rapidly in recent years. To deal with the resulting deluge of data, scientists are applying a systems biology approach at the molecular level. In an emerging field known as genomics, researchers now study whole sets of genes in a species and then compare genes across multiple species. The benefits from such an approach range from identifying genes that may be implicated in human cancers to revealing the evolutionary relationships among diverse organisms based on similarities in their genomes. Genomics affirms the unity of life based on the universal genetic material—DNA.

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

? **What are the two main functions of DNA?**

DNA is the genetic material that is passed from parents to offspring, and it codes for proteins that control the activity of cells.

1.6 The diversity of life can be arranged into three domains

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

Diversity is a hallmark of life. Biologists have so far identified and named about 1.8 million species. Estimates of the total number of species range from 10 million to more than 100 million.

There seems to be a human tendency to group things, such as owls or butterflies, although we recognize that each group includes many different species. And then we cluster groups into broader categories, such as birds and insects. Taxonomy, the branch of biology that names and classifies species, arranges species into a hierarchy of broader and broader groups: genus, family, order, class, phylum, and kingdom.

Historically, biologists divided all of life into five kingdoms. But new methods for assessing evolutionary relationships, such as comparisons of DNA sequences, have led to an ongoing reevaluation of the number and boundaries of kingdoms. Although the debate on such divisions continues, there is consensus among biologists that life can be organized into three higher levels called **domains**. **Figure 1.6** shows representatives of domains Bacteria, Archaea, and Eukarya.

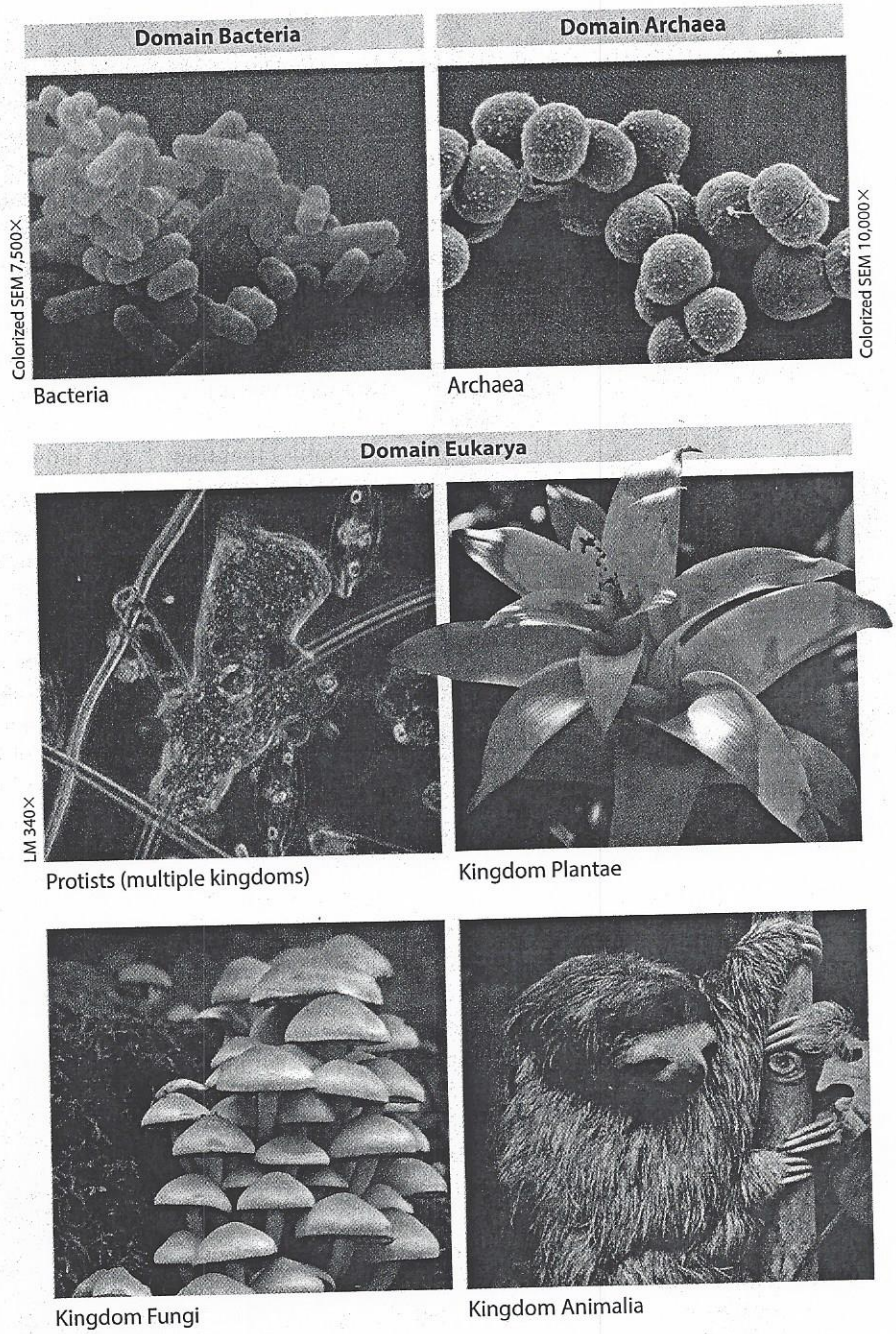
Domains **Bacteria** and **Archaea** both consist of prokaryotes, organisms with prokaryotic cells. Bacteria are the most diverse and widespread prokaryotes. Many of the prokaryotes known as archaea live in Earth's extreme environments, such as salty lakes and boiling hot springs. Each rod-shaped or round structure in the photos of the prokaryotes in Figure 1.6 is a single cell. These photos were made with an electron microscope, and the number along the side indicates the magnification of the image.

All the eukaryotes, organisms with eukaryotic cells, are grouped in domain **Eukarya.** Protists are a diverse collection of mostly single-celled organisms. Pictured in Figure 1.6 is an assortment of protists in a drop of pond water. Biologists are currently assessing how to group the protists to reflect their evolutionary relationships.

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

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

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



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

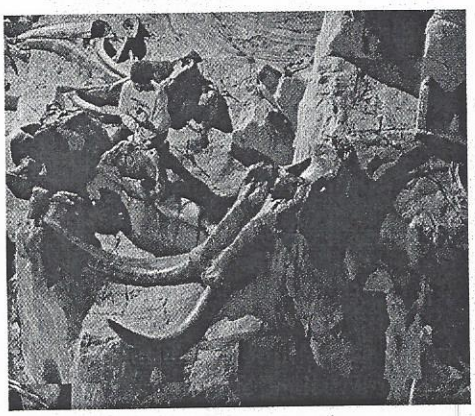
The diversity of life and its interconnectedness are evident almost everywhere. Earlier we looked at life's unity in its shared properties and common genetic code. In the next module, we explore how evolution explains both the unity and the diversity of life.

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

● Eukarya

1.7 Evolution explains the unity and diversity of life

Evolution can be defined as the process of change that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. The fossil record documents the fact that life has been evolving on Earth for billions of years, and patterns of ancestry can be traced through this record. For example, the mammoth being excavated in **Figure 1.7A** is clearly related to present-day elephants. We can explain the shared traits of mammoths and elephants with the premise that they descended from a common ancestor in the distant past. Their differences reflect the evolutionary changes that occurred within their separate lineages during the history of their existence on Earth. Thus, evolution accounts for life's dual nature of kinship and diversity.



▲ **Figure 1.7A** Excavation of 26,000-year-old fossilized mammoth bones from a site in South Dakota

This evolutionary view of life came into sharp focus in November 1859, when Charles Darwin (**Figure 1.7B**) published one of the most important and influential books ever written. Entitled *On the Origin of Species by Means of Natural Selection*, Darwin's book was an immediate bestseller and soon made his name synonymous with the concept of evolution.

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

As a young man, Darwin made key observations that greatly influenced his thinking. During a five-year, around-the-world voyage, he collected and documented plants and animals in widely varying locations—from the isolated Galápagos Islands off the coast of Ecuador to the heights of the Andes mountains to the jungles of Brazil. He was particularly struck by the adaptations of these varied organisms that fit them to their diverse habitats. After returning to England, Darwin spent more than two decades continuing his observations, performing experiments, corresponding with other scientists, and refining his thinking before he finally published his work.

The first of two main points that Darwin presented in *The Origin of Species* was that species living today arose from a successor of ancestors that differed from them. Darwin called this process "descent with modification." It was an insightful phrase, because it captured both the unity of life (descent from a common ancestor) and the diversity of life (modifications that evolved as species diverged from their ancestors). **Figure 1.7C** illustrates this unity and diversity among birds. These three birds all have a common "bird" body plan of wings, beak, feet, and feathers, but these features are highly specialized for each bird's unique lifestyle.

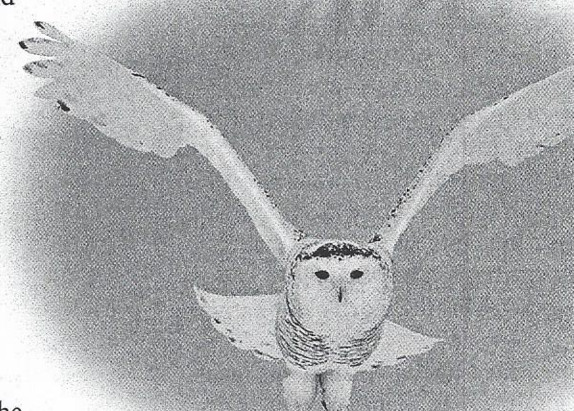
Darwin's second point was to propose a mechanism for evolution, which he called **natural selection**. Darwin started with two observations, from which he drew two inferences.

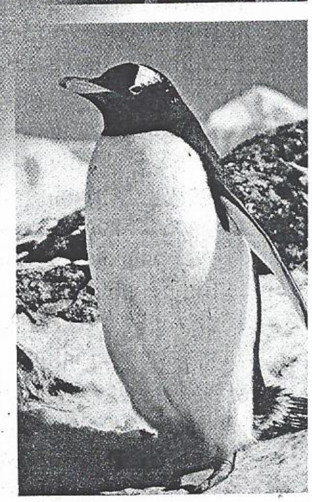
OBSERVATION #1: *Individual variation.* Individuals in a population vary in their traits, many of which are inherited from parents to offspring.

OBSERVATION #2: *Overproduction of offspring.* All species can produce far more offspring than the environment can support. Competition for resources is thus inevitable, and many of these offspring fail to survive and reproduce.

INFERENCE #1: *Unequal reproductive success.* Individuals with heritable traits best suited to the local environment are more likely to survive and reproduce than are less well-suited individuals.

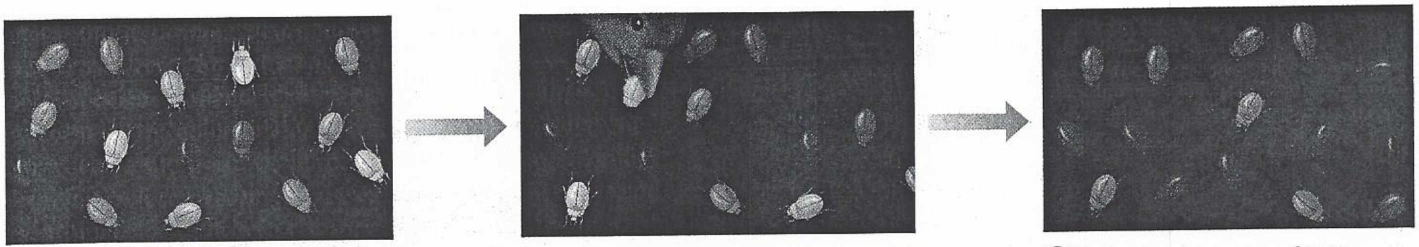
INFERENCE #2: *Accumulation of favorable traits over time.* As a result of this unequal reproductive success over many generations, a higher and higher proportion of individuals in the population will have the advantageous traits.





▲ **Figure 1.7C** Unity and diversity among birds

Try This For each bird, describe some adaptations that fit it to its environment and way of life.



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

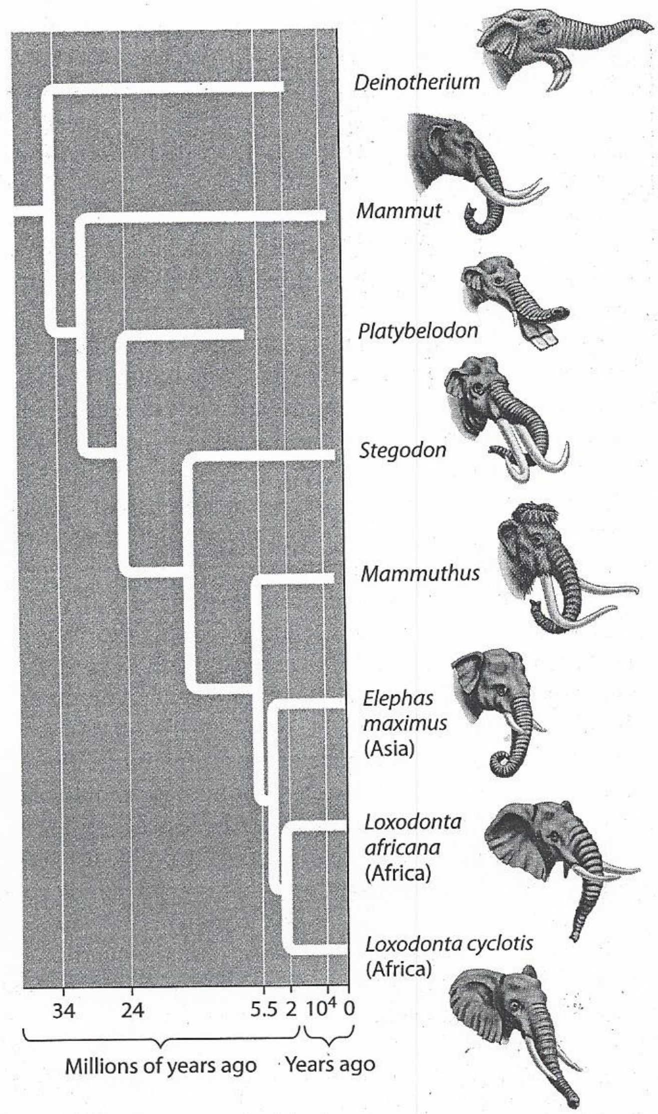
Try This Describe what might happen if some of these beetles colonized a sand dune habitat.

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

Darwin realized that numerous small changes in populations as a result of natural selection could eventually lead to major alterations of species. He proposed that new species could evolve as a result of the gradual accumulation of changes over long periods of time. This could occur, for example, if one population fragmented into subpopulations isolated in different environments. In these separate arenas of natural selection, one species could gradually divide into multiple species as isolated populations adapted over many generations to different sets of environmental factors.

The fossil record provides evidence of such diversification of species from ancestral species. **Figure 1.7E** traces an evolutionary tree of elephants and some of their relatives. (Biologists' diagrams of evolutionary relationships generally take the form of branching trees, usually turned sideways and read from left to right.) You can see that the three living species of elephants are very similar because they shared a recent common ancestor (dating to about 3 million years ago, which is relatively recent in an evolutionary timeframe). Notice that all the other close relatives of elephants are extinct—their branches do not extend to the present. (The mammoth being excavated in Figure 1.7A belonged to the genus *Mammuthus,* whose members became extinct less than 10,000 years ago.) If we were to trace this family tree back to about 60 million years ago, however, you would find a common ancestor that connects elephants to their closest living relatives—the manatees and hyraxes. The fossil record, along with other evidence such as comparisons of DNA, allows scientists to trace the evolutionary history of life back through time.

All of life is connected, and the basis for this kinship is evolution—the core theme that makes sense of everything we know and learn about life. In the next module, we introduce scientific inquiry, the process we use to study the natural world.



▲ **Figure 1.7E** An evolutionary tree of elephants

Try This Use this tree to determine when mastadons (in the genus *Mammut*) last shared a common ancestor with African elephants.

? Explain the cause and effect of unequal reproductive success.

● Those individuals with heritable traits best suited to the local environment produce the greatest number of offspring. Over many generations, the frequency of those adaptive traits increases in the population.

The Process of Science

1.8 In studying nature, scientists make observations and form and test hypotheses

Science is a way of knowing—an approach to understanding the natural world. It stems from our curiosity about ourselves and the world around us. At the heart of science is the process of inquiry, the search for information and explanations of natural phenomena. Scientific inquiry usually involves making observations, forming hypotheses, and testing them.

Observations may be made directly or indirectly, such as with the help of microscopes and other instruments that extend our senses. Recorded observations are the data of science. You may think of data as numbers, but a great deal of scientific data are in the form of detailed, carefully recorded observations. For example, much of our knowledge of snowy owl behavior is based on descriptive, or *qualitative*, data, documented in field notes, photographs, and videos. Other types of data are *quantitative*, such as numerical measurements that may be organized into tables and graphs.

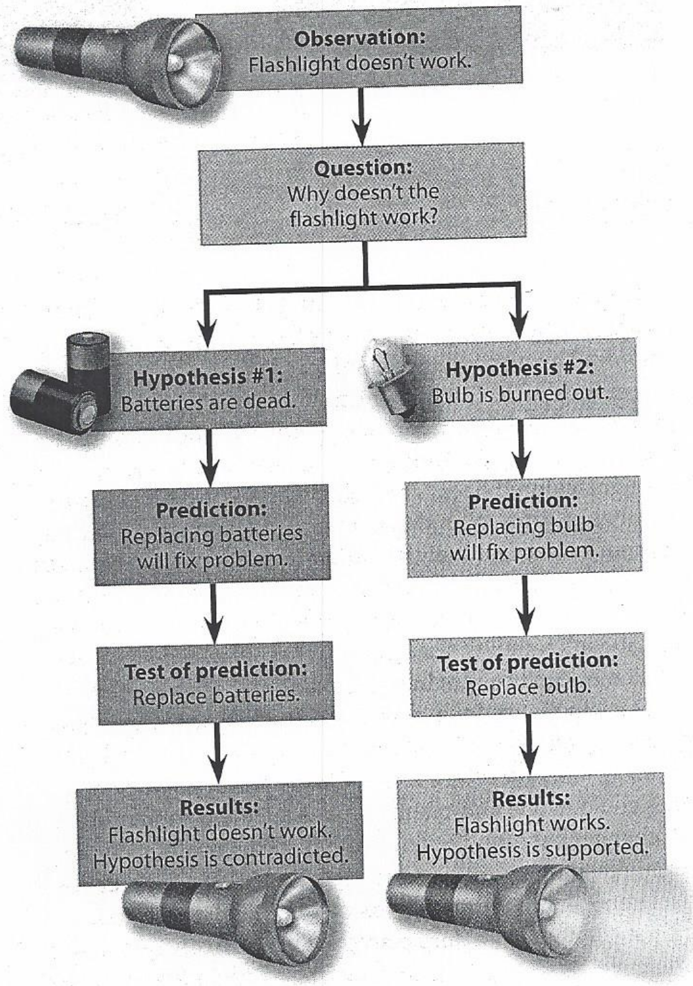
Collecting and analyzing a large number of specific observations can lead to generalizations based on inductive reasoning. For example, "All organisms are made of cells" is an inductive conclusion based on the discovery of cells in every biological specimen observed over two centuries of time.

Observations often prompt us to ask questions and seek answers through the forming and testing of hypotheses. A **hypothesis** is a proposed explanation for a set of observations. A good hypothesis leads to predictions that can be tested by making additional observations or by performing experiments.

Deductive reasoning is used to come up with ways to test hypotheses. Here, the logic flows from general premises to the specific results we should expect if the premises are correct. *If* all organisms are made of cells (premise 1), *and* humans are organisms (premise 2), *then* humans should be composed of cells (a prediction that can be tested).

We all use hypotheses in solving everyday problems. Let's say you are preparing for a big storm that is approaching your area and find that your flashlight isn't working. That your flashlight isn't working is an observation, and the question is obvious: Why doesn't it work? Reasonable hypotheses are that the batteries are dead or the bulb is burned out. Each of these hypotheses leads to predictions you can test with experiments. For example, the dead-battery hypothesis predicts that replacing the batteries with new ones will fix the problem. **Figure 1.8** diagrams the results of testing these hypotheses.

An important point about scientific inquiry is that we can never *prove* that a hypothesis is true. As shown in Figure 1.8, the burned-out bulb hypothesis is the more likely explanation in our hypothetical scenario. But perhaps the old bulb was simply loose and the new bulb was inserted correctly. We could test this hypothesis by trying another experiment—carefully reinstalling the original bulb. If the flashlight still doesn't work, the burned-out bulb hypothesis is supported by another line of evidence. Testing a hypothesis in various ways provides additional support for a hypothesis and increases our confidence in it.



▲ **Figure 1.8** An everyday example of forming and testing hypotheses

A scientific **theory** is much broader in scope than a hypothesis and is supported by a large and usually growing body of evidence. For example, the theory of evolution explains a great diversity of observations and is supported by multiple lines of evidence. In addition, the theory of evolution has not been contradicted by any scientific data.

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

Science is a social activity, with most scientists working in teams, which often include graduate and undergraduate students. Scientists share information through peer-reviewed publications, seminars, meetings, and personal communication. Scientists build on what has been learned from earlier research and often check each other's claims by attempting to confirm observations or repeat experiments.

To help you better understand what scientists do, we include a Scientific Thinking module in each chapter. These discussions will encompass several broad activities of science: the forming and testing of hypotheses using various research methods; the analysis and evaluation of data; the use of tools and technologies that have built and continue to expand scientific knowledge; and the communication of the results of scientific studies and the evaluation of their implications for society as a whole.

? **What is the main criterion for a scientific hypothesis?**

It must generate predictions that can be tested.

1.9 Hypotheses can be tested using controlled field studies

IENTIFIC HINKING

You have undoubtedly observed that many animals match their environment: white snowy owls in their arctic habitat, toads the color of dead leaves, flounders that blend in with the sandy sea floor. From these observations, you might hypothesize that such color patterns have evolved as adaptations that protect animals from predation. Can scientists test this camouflage hypothesis? Let's consider an experiment with two populations of mice that belong to the same species (*Peromyscus polionotus*) but live in different environments.

The beach mouse lives along the Florida seashore, a habitat of white sand dunes with sparse clumps of beach grass. The inland mouse lives on darker soil farther inland. As you can see in **Figure 1.9**, there is a striking match between mouse coloration and habitat. In 2010, biologist Hopi Hoekstra of Harvard University and a group of her students headed to Florida to test the camouflage hypothesis. They reasoned that *if* camouflage coloration protects mice from predators, *then* mice with coloration that did not match their habitat would be preyed on more heavily than the native mice that were well-matched to their environment.

The researchers built 250 plastic models of mice and painted them to resemble either beach or inland mice. Equal numbers of models were placed randomly in both habitats. The models resembling the native mice in each habitat were the control group, and the mice with the non-native coloration were the experimental group. Signs of predation were recorded for three days. Judging by the bite marks and surrounding tracks, the researchers determined the predators were likely foxes, coyotes, owls, herons, and hawks.

Why do so many animals match their surroundings?

As you can see by the results presented in **Table 1.9**, the noncamouflaged models had a much higher percentage of predation attacks in both the beach and inland habitats. The data thus fit the key prediction of the camouflage hypothesis.

This study is an example of a **controlled experiment**, one that is designed to compare an experimental group (the noncamouflaged mice models) with a control group (the camouflaged models that matched the mice native in each area). Ideally, in a controlled experiment the two groups differ only in the one factor the experiment is designed to test—in this case, coat color and its effect on the success of predators. The experimental design left coloration as the only factor that could account for the higher predation rate on the noncamouflaged mice in both the beach and the inland habitats. This study is also an example of a field study, one not done in a laboratory but out in nature. Researchers tested their hypothesis using the natural habitat of the mice and their predators.

TABLE 1.9 | RESULTS FROM CAMOUFLAGE EXPERIMENT

	Number of Attacks		
Habitat	On Camouflaged Models	On Non-camouflaged Models	% Attacks on Non-camouflaged Models
Beach (light habitat)	2	5	71%
Inland (dark habitat)	5	16	76%

Data from S. N. Vignieri et al., The selective advantage of crypsis in mice, *Evolution* 64: 2153–2158 (2010).

each population Beach mice living n sparsely vegetated sand dunes along e coast have light tan, dappled coats.

Inland population Members of the same species living about 30 km inland are darker in color.

▲ **Figure 1.9** Beach mouse and inland mouse with their native habitat

? **These two populations of mice belong to the same species, yet they have very different coloration. How does natural selection explain these differences?**

Camouflaged mice are more likely to survive and reproduce, passing their protective coloration to their offspring.

Biology and Everyday Life

1.10 Evolution is connected to our everyday lives

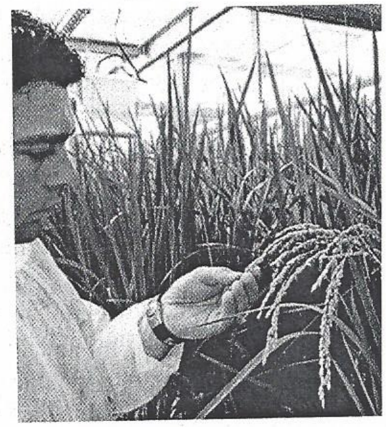
EVOLUTION CONNECTION

To emphasize evolution as the core theme of biology, we include an Evolution Connection module in each chapter in this text. But how is evolution connected to your everyday life?

You just learned that natural selection is the primary mechanism of evolution, in which the environment "selects" for adaptive traits when organisms with such traits are better able to survive and reproduce. Through the selective breeding of plants and animals, humans are also an agent of evolution. As a result of **artificial selection**, our crops, livestock, and pets bear little resemblance to their wild ancestors. Humans have been modifying species for millennia, and recent advances in biotechnology have increased our capabilities. Plant biologists using genomics can identify beneficial genes in relatives of our crop plants, enabling the breeding or genetic engineering of enhanced crops. Genes from totally unrelated species have also been inserted into plants. For example, genes for such traits as drought or flood tolerance, improved growth, and increased nutrition have been engineered into rice plants (**Figure 1.10**).

But humans also affect evolution unintentionally. The impact of habitat loss and global climate change can be seen in the loss of species. Indeed, scientists estimate that the current rate of extinction is 100 to 1,000 times the typical rate seen in the fossil record. Our actions are also driving evolutionary changes in species. For example, our widespread use of antibiotics and pesticides has led to the evolution of antibiotic resistance in bacteria and pesticide resistance in insects.

How can evolutionary theory help address such worldwide problems? Understanding evolution can help us develop strategies for conservation efforts and prompt us to be more judicious in our use of antibiotics and pesticides. It can also help us create flu vaccines and HIV drugs by tracking the rapid evolution of these viruses. Identifying shared genes and studying their actions in closely related organisms may produce new knowledge about cancer or other diseases and lead to new medical treatments. New sources of drugs may be found by tracing the evolutionary history of medicinal plants and identifying beneficial compounds in their relatives. Our understanding of evolution can yield many beneficial results.



▲ **Figure 1.10** Researcher working w transgenic rice

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

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

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

CONNECTION

Many of the current issues facing society are related to biology, and they often involve our expanding technology. What are the differences between science and technology? The goal of science is to understand natural phenomena. In contrast, the goal of **technology** is to apply scientific knowledge for some specific purpose. Scientists usually speak of "discoveries," whereas engineers more often speak of "inventions." These two fields, however, are interdependent. Scientists use new technology in their research, and scientific discoveries often lead to the development of new technologies.

The potent combination of science and technology can have dramatic effects on society. For example, the discovery of the structure of DNA by Watson and Crick 60 years ago and subsequent advances in DNA science led to the technologies of DNA manipulation that today are transforming applied fields such as medicine, agriculture, and forensics.

Technology has improved our standard of living in many ways, but not without consequences. Technology has helped Earth's population to grow tenfold in the past three centuries and more than double to 7 billion in just the past 40 years. Global climate change, toxic wastes, deforestation, and nuclear accidents are just some of the repercussions of more and more people wielding more and more technology. Science can help identify problems and provide insight into how to slow down or prevent further damage. But solutions to these problems have as much to do with politics, economics, and cultural values as with science and technology. Every citizen has a responsibility to develop a reasonable amount of scientific literacy to be able to participate in the debates regarding science and technology. The crucial science-technology-society relationship is a theme we will return to throughout this text.

We hope this book will help you develop an appreciation for biology and help you apply your new knowledge to evaluating issues ranging from your personal health to the well-being of the whole world.

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

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

CHAPTER 1 REVIEW

For practice quizzes, BioFlix animations, MP3 tutorials, video tutors, and more study tools designed for this textbook, go to MasteringBiology®

Reviewing the Concepts

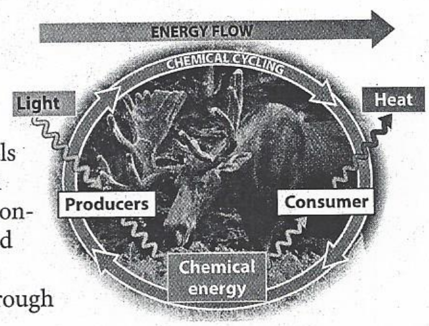
Themes in the Study of Biology (1.1–1.4)

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

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

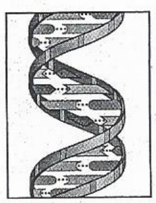
1.3 Cells are the structural and functional units of life. Eukaryotic cells contain membrane-enclosed organelles, including a nucleus. Prokaryotic cells lack such organelles. Structure is related to function at all levels of organization. Systems biology models the complex behavior of biological systems.

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



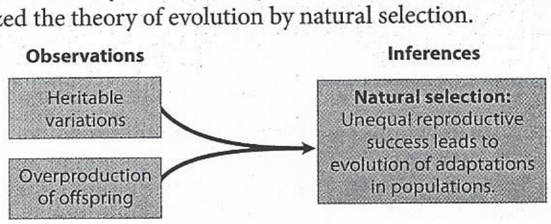
Evolution, the Core Theme of Biology (1.5–1.7)

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



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

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



The Process of Science (1.8–1.9)

1.8 In studying nature, scientists make observations and form and test hypotheses. Scientists use inductive reasoning to draw general conclusions from many observations. They form hypotheses and use deductive reasoning to make predictions, which can be tested with experiments or additional observations. Data may be qualitative or quantitative. A scientific theory is broad in scope and is supported by a large body of evidence.

1.9 Hypotheses can be tested using controlled field studies. Researchers found that mice models that did not match their habitat had higher predation rates than camouflaged models. In a controlled experiment, the use of control and experimental groups can demonstrate the effect of a single variable.

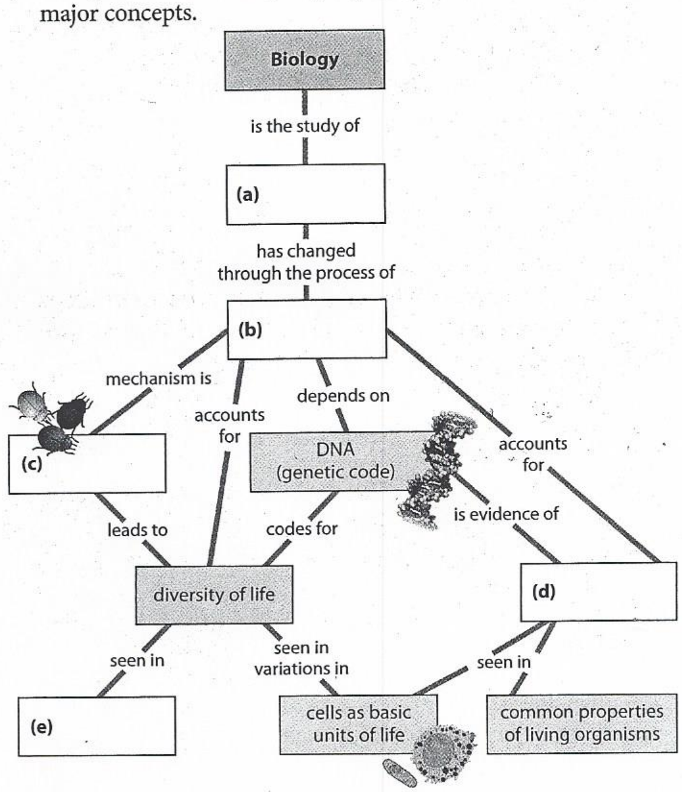
Biology and Everyday Life (1.10–1.11)

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

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

Connecting the Concepts

1. Complete the following map organizing some of biology's major concepts.



Your Knowledge

wledge/Comprehension

e organisms on your campus make up
an ecosystem.
b. a community.
c. a population.
d. the domain Eukarya.

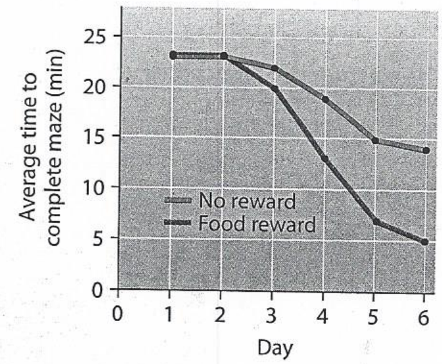
3. Single-celled amoebas and bacteria are grouped into different domains because
   a. amoebas eat bacteria.
   b. bacteria are not made of cells.
   c. bacterial cells lack a membrane-enclosed nucleus.
   d. amoebas are motile; bacteria are not.
4. Which of the following statements best distinguishes hypotheses from theories in science?
   a. Theories are hypotheses that have been proved.
   b. Hypotheses usually are narrow in scope; theories have broad explanatory power.
   c. Hypotheses are tentative guesses; theories are correct answers to questions about nature.
   d. Hypotheses and theories are different terms for essentially the same thing in science.
5. Which of the following best demonstrates the unity among all living organisms?
   a. descent with modification
   b. DNA and a common genetic code
   c. emergent properties
   d. natural selection
6. A controlled experiment is one that
   a. proceeds slowly enough that a scientist can make careful records of the results.
   b. keeps all variables constant.
   c. is repeated many times to make sure the results are accurate.
   d. tests experimental and control groups in parallel.
7. The core idea that makes sense of all of biology is
   a. evolution.
   b. the correlation of function with structure.
   c. systems biology.
   d. the process of science.

Level 2: Application/Analysis

8. A biologist studying interactions among the protists in an ecosystem could *not* be working at which level in life's hierarchy? (*Choose carefully and explain your answer.*)
   a. the population level
   b. the molecular level
   c. the organism level
   d. the organ level
9. Which of the following best describes the logic of scientific inquiry?
   a. If I generate a testable hypothesis, tests and observations will support it.
   b. If my prediction is correct, it will lead to a testable hypothesis.
   c. If my observations are accurate, they will support my hypothesis.
   d. If my hypothesis is correct, I can expect certain test results.
10. In an ecosystem, how is the movement of energy similar to that of chemicals, and how is it different?
11. Explain the role of heritable variations in Darwin's theory of natural selection.
12. Describe the process of scientific inquiry and explain why it is not a rigid method.
13. Contrast technology with science. Give an example of each to illustrate the difference.
14. Biology can be described as having both a vertical scale and a horizontal scale. Explain what that means.

Level 3: Synthesis/Evaluation

15. Explain what is meant by this statement: Natural selection is an editing mechanism rather than a creative process.
16. The graph below shows the results of an experiment in which mice learned to run through a maze.



    a. State the hypothesis and prediction that you think this experiment tested.
    b. Which was the control group and which the experimental? Why was a control group needed?
    c. List some variables that must have been controlled so as not to affect the results.
    d. Do the data support the hypothesis? Explain.
17. **SCIENTIFIC THINKING** Suppose that in an experiment similar to the camouflage experiment described in Module 1.9, a researcher observed and recorded more total predator attacks on dark-model mice in the inland habitat than on dark models in the beach habitat. From comparing these two pieces of data, the researcher concluded that the camouflage hypothesis is false. Do you think this conclusion is justified? Why or why not?
18. The fruits of wild species of tomato are tiny compared to the giant beefsteak tomatoes available today. This difference in fruit size is almost entirely due to the larger number of cells in the domesticated fruits. Plant biologists have recently discovered genes that are responsible for controlling cell division in tomatoes. Why would such a discovery be important to producers of other kinds of fruits and vegetables? To the study of human development and disease? To our basic understanding of biology?
19. The news media and popular magazines frequently report stories that are connected to biology. In the next 24 hours, record the ones you hear or read about in three different sources and briefly describe the biological connections in each story.

Answers to all questions can be found in Appendix 4.