tenth edition

Biology

Sylvia S. Mader

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BRIEF CONTENTS

PREFACE

The mission of my text, *Biology*, has always been to give students an understanding of biological concepts and a working knowledge of the scientific process. If one understands the concepts of biology and the methodology of science, they can be used to understand the particulars of new ideas or a system on any scale from the cell to the biosphere. By now, we are well into the twenty-first century, and the field of biology has been flooded with exciting new discoveries and insights way beyond our predictions even a few short years ago. It is our task, as instructors, to make these findings available to our students so they will have the background to keep up with the many discoveries still to come. At the same time, we must provide students with a firm foundation in those core principles on which biology is founded. This means that the tenth edition of *Biology* is both new and old at the same time. With this edition, instructors will be confident that they are "up to date," while still teaching the fundamental concepts of biology in a way that allows students to apply them in new and different ways. In this edition you will find:

- *Increased Evolutionary Coverage*
- *Currency of Coverage*
- *Media Integration*

Birth of *Biology*

I am an instructor of biology as are the contributors that have lent their several talents to this edition of *Biology*. Collectively, we have taught students for many years from the community college to the university level. We are all dedicated to the desire that students develop a particular view of the world—a biological view. When I wrote the first edition of *Biology,* it seemed to me that a thorough grounding in biological principles would lead to an appreciation of the structure and function of individual organisms, how they evolved, and how they interact in the biosphere. This caused me to use the levels of biological organization as my guide—thus, this edition, like the previous editions, begins with chemistry and ends with the biosphere.

Students need to be aware that our knowledge of biology is built on theories that have survived the rigors of scientific testing. The first chapter explains the process of science and thoroughly reviews examples of how scientists come to conclusions. Throughout the text, biologists are introduced, and their experiments are explained. An appreciation of how science progresses should lead to the perception that, without the scientific process, biology could not exist.

Evolution of *Biology*

While I have always guided the development of each new edition of *Biology*, many instructors have lent their talents to ensuring its increasing success. I give my utmost thanks to all the reviewers and contributors that have been so generous with their time and expertise. This edition, I want to particularly thank Andrew Baldwin, of Mesa Community College, who revised the ecology chapters; Rebecca Roush, of Sandhills Community College, for her work on Part VI; Michael Thompson, of Middle Tennessee State University, who did the first chapter and the genetics chapters; and Stephanie Songer, of North Georgia College and State University, who revised Part IV and many chapters in Part V. My involvement ensured that each of these chapters, along with the chapters I revised, are written and illustrated in the familiar Mader style.

The brilliance of the illustrations and the eye-catching paging of *Biology* are due to the talented staff of EPS (Electronic Publishing Services Inc.), who took my first attempts and altered them to produce the most detailed, refined, and pedagogically sound presentations ever developed for an introductory biology book.

The Learning System

Mader books excel in pedagogy, and *Biology* is consistent with the usual high standard. Pages xii–xv of this preface review "The Learning System" of *Biology*. As explained, each part opening page introduces that part in a new engaging way that explains the rationale of that part. The chapter opening page lists the key concepts under the major sections for that chapter. In this way, students are given an overview of the chapter and its concepts. The opening vignette captures student interest and encourages them to begin their study of the chapter. New to this edition, major sections end with "Check Your Progress" questions designed to foster confidence as they proceed through the chapter. "Connecting the Concepts" at the end of the chapter ties the concepts of this chapter to those in other chapters. The end matter gives students an opportunity to review the chapter and test themselves on how well they understand the concepts.

The Mader writing style is well known for its clarity and a simplicity of style that appeals to students because it meets them where they are and assists them in achieving mastery of the concept. Concepts are only grasped if a student comes away with "take-home messages." Once students have internalized the fundamental concepts of biology, they will have developed a biological view of the world that is essential in the twenty-first century.

Changes in *Biology*, Tenth Edition

The tenth edition builds on the visual appeal of the previous edition. New illustrations have been developed that are just as stunning as those prepared for the ninth edition, and many new photographs and micrographs have been added.

Biology has a new table of contents that consolidates chapters so that the book is shorter by some forty pages compared to the last edition. No individual chapter is overly long, however. In Part II, certain material from Chapter 12 was moved into Chapter 10, *Meiosis and Sexual Reproduction* and Chapter 11, *Mendelian Patterns of Inheritance*. In Part III, *Speciation and Macroevolution* is a much needed new chapter. In Part VI, the two invertebrate evolution chapters from the previous edition have become Chapter 28, *Invertebrates*. In Part VIII, Chapter 45, *Community and Ecosystem Ecology* is a consolidation of two chapters from the previous edition.

I believe you will be interested in knowing about these chapters that demonstrate the quality of *Biology*, Tenth Edition:

- Chapter 1, *A View of Life*, was revised to have a new section: "Evolution, the Unifying Concept of *Biology*." This section presents basic evolutionary principles and contains a depiction of the Tree of Life, which introduces the three domains of life and the various types of eukaryotes. Prokaryotes and eukaryotes are also pictorially displayed.

Part I The Cell

- Chapter 5, *Membrane Structure and Function*, introduces the concept of cell signaling. New to this edition, the plasma membrane art now depicts the extracellular matrix (see Fig. 5.1), which has a role in cell signaling—a topic that is further explored in the Science Focus, "How Cells Talk to One Another."
- Chapter 8, *Cellular Respiration*, begins with a new section that now emphasizes that cellular respiration is the reason we eat and breathe (see Figure 8.1). The fermentation section in this edition precedes the events that occur in mitochondria and is enhanced by a new Science Focus box, "Fermentation Helps Produce Numerous Food Products." The chapter now ends with a comparison of photosynthesis to cellular respiration (see Fig. 8.12).

Overview of Changes to *Biology*, Tenth Edition

VISUALS

The brilliant visuals program of the previous edition is enhanced even more by the addition of many new micrographs and innovative page layouts.

CELLULAR BIOLOGY

Cell signaling receives expanded coverage as a mechanism of cellular metabolism and cell division control.

GENETICS

Reorganization of the genetics chapters results in increased genome coverage, including the role of small RNA molecules in regulation.

SYSTEMATICS

Cladistics is better explained, and new evolutionary trees are presented for protists, plants, and animals.

EVOLUTION

A new chapter, *Speciation and Macroevolution*, points to the possible role of Hox genes in punctuated evolution.

PLANT EVOLUTION

A reorganization of Chapter 23 better describes the evolution of plants from an aquatic green algal ancestor.

ANIMAL EVOLUTION

Reorganization of Part VI results in two new animal diversity chapters: the invertebrates and the vertebrates.

Part II Genetic Basis of Life

- Chapter 9, *The Cell Cycle and Cellular Reproduction*, builds on the topic of cell signaling that was introduced in Chapter 5. Cell signaling is the means by which the cell cycle, and, therefore, cell division is regulated. A new Science Focus box shows how the G_1 checkpoint is highly regulated by cell signaling, and Figure 9.8 dramatically illustrates how a breakdown in cell cycle regulation may contribute to cancer.
- Chapter 13, *Regulation of Gene Activity*, is an excellent chapter that instructors will not want to overlook because it explains how humans can make do with far fewer protein-coding genes than have been discovered by DNA sequencing of our genome. The chapter is updated by continued emphasis on chromatin structure, many references to the regulatory role of RNA molecules including a new Science Focus box, "Alternative mRNA Splicing in Disease."
- Chapter 14, *Biotechnology and Genomics*, has an expanded section on genomics. Much of chromatin consists of introns and intergenic sequences which may have important functions still to be discovered (see Fig. 14.8). Molecular geneticists are seeking a new definition of a gene that can apply to both protein-coding and non-protein-coding sequences. The chapter also discusses genomic diversity. The new Science Focus box, "DNA Microarray Technology," explains how this technique is now being applied to identify genes involved in health and disease. Another new Science Focus box, "Copy Number Variations," gives another example of genetic diversity within the population and its relationship to health and disease.

Part III Evolution

- Chapter 16, *How Populations Evolve*, is an exciting new chapter that begins with an introduction based on community acquired MRSA. This chapter is also enhanced by new figures: an example of genetic diversity (see Fig. 16.1), the gene pool (see Fig. 16.2), microevolution (see Fig. 16.3), and a natural selection experiment (see Fig. 16.10) are included. Also, sexual selection is now included in this chapter.
- Chapter 17, *Speciation and Macroevolution*, is new to this edition. This chapter begins by describing species concepts, and examples of both allopatric and sympatric speciation are given. The concepts of gradualistic and punctuated equilibrium are discussed with reference to the Burgess Shale as an example of rapid evolution to produce many species, and Hox genes are offered as a possible mechanism to bring it about.

Part IV Microbiology and Evolution

- Chapter 21, *Protist Evolution and Diversity*, has been revised because protist classification has undergone dramatic changes in recent years. This chapter is reorganized accordingly, but the biological and ecological relevance of each type of protist is still discussed.

Part V Plant Evolution and Biology

- Chapter 23, *Plant Evolution and Diversity*, employs a new evolutionary tree based in part on molecular data. Land plants and stoneworts, which are charophytes, share a common green algal ancestor. All land plants protect the embryo, and thereafter each of five innovations can be associated with a particular group of land plants.

Part VI Animal Evolution and Diversity

- Chapter 28, *Invertebrates*, has been thoroughly updated and revised in this edition. The chapter better defines an animal and explains the colonial flagellate hypothesis on the origin of animals. The organization of this chapter follows a new evolutionary tree based on molecular and developmental data; the biology of each group is discussed as before.
- Chapter 29, *Vertebrates*, has been reorganized, and each vertebrate group is now a major section. In keeping with modern findings, birds are considered reptiles. Each section begins with a listing of characteristics for that group and is followed by a discussion of the evolution and then the diversity of that group.

Part VII Comparative Animal Biology

- Chapter 33, *Lymph Transport and Immunity*, has been reorganized and revised so that both nonspecific defense (innate immunity) and specific defense (acquired immunity) have their own major section. All concepts regarding antibodies have been brought together in the specific defense section. Immunity side effects has new illustrations; Cytokines and Cancer Therapy is a new subsection.
- Chapter 35, *Respiratory Systems*, is much improved in this edition from an increased emphasis on diversity to a better description of the human respiratory tract and transport of gases (see Figs. 35.3, 35.6, and 35.12). This chapter now ends with a dramatic photo of emphysema and lung cancer (see Fig. 35.15). "Connecting the Concepts" emphasizes the contribution of the respiratory system to homeostasis by description and art.
- Chapter 41, *Reproductive Systems*, now begins with a revised comparative section that includes more photos. An illustration depicting contraceptives replaces a table, and there is a new Health Focus, "Preimplantation Genetic Diagnosis." Sexually transmitted diseases have been updated to reflect current statistics. A new bioethical issue concerns the use of fertility drugs.

Part VIII Behavior and Ecology

- Chapter 43, *Behavioral Ecology*, has an evolutionary emphasis culminating in a new section entitled "Behaviors that Increase Fitness" in which several types of societal interactions are explored as a means to increase representation of genes in the next generation. Orientation and migratory behavior and cognitive learning are ways of learning not discussed previously.
- Chapter 45, *Community and Ecosystem Ecology*, is a combined chapter that allows instructors to cover the basics of ecology in one chapter. A discussion of symbiotic relationships and ecological succession precede the concepts of chemical cycling and energy flow in ecosystems.

About the Author

Dr. Sylvia S. Mader has authored several nationally recognized biology texts published by McGraw-Hill. Educated at Bryn Mawr College, Harvard University, Tufts University, and Nova Southeastern University, she holds degrees in both Biology and Education. Over the years, she has taught at the University of Massachusetts–Lowell, Massachusetts Bay Community College, Suffolk University, and Nathan Matthew Seminars. Her ability to reach out to science-shy students led to the writing of her first text, *Inquiry into Life*, which is now in its twelfth edition. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

Although her writing schedule is always quite demanding, Dr. Mader enjoys taking time to visit and explore the various ecosystems of the biosphere. Her several trips to the Florida Everglades and Caribbean coral reefs resulted in talks she has given to various groups around the country. She has visited the tundra in Alaska, the taiga in the Canadian Rockies, the Sonoran Desert in Arizona, and tropical rain forests in South America and Australia. A photo safari to the Serengeti in Kenya resulted in a number of photographs for her texts. She was thrilled to think of walking in Darwin's steps when she journeyed to the Galápagos Islands with a group of biology educators. Dr. Mader was also a member of a group of biology educators who traveled to China to meet with their Chinese counterparts and exchange ideas about the teaching of modern-day biology.

For My Children
Sylvia Mader

Guided Tour

Increased Evolutionary Coverage

NEW CHAPTERS

16 (*How Populations Evolve*) and 17 (*Speciation and Macroevolution*) highlight new evolutionary coverage.

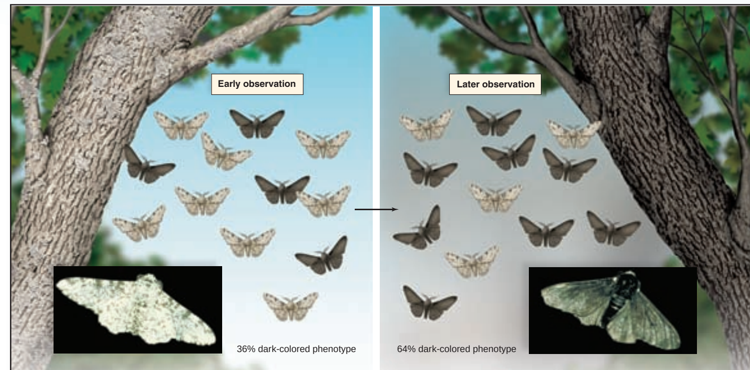


FIGURE 16.3 **Microevolution.**

Microevolution has occurred when there is a change in gene pool frequencies—in this case, due to natural selection. On the left, birds cannot see light-colored peppered moths, *Biston betularia*, against light-colored vegetation—and, therefore, light-colored moths are more frequent in the population. On the right, after vegetation has been darkened due to pollution, birds are less likely to see dark-colored moths against dark vegetation, and dark moths are more frequent in the population.

The **Hardy-Weinberg principle** states that an equilibrium of gene pool frequencies, calculated by using the bi- ression, will remain in effect in each succeeding of a sexually reproducing population, as long as ons are met:

utations: Allele changes do not occur, or changes direction are balanced by changes in the ite direction.
ne flow: Migration of alleles into or out of the ation does not occur.
om mating: Individuals pair by chance, not ling to their genotypes or phenotypes.
netic drift: The population is very large, and es in allele frequencies due to chance alone are ificant.
ection: Selective forces do not favor one ype over another.

l life, these conditions are rarely, if ever, met, frequencies in the gene pool of a population from one generation to the next. Therefore, has occurred. The significance of the Hardy- principle is that it tells us what factors cause -those that violate the conditions listed. Micro- an be detected by noting any deviation from a nberg equilibrium of allele frequencies in the of a population. nge in allele frequencies may result in a change pe frequencies. Our calculation of gene pool frequencies in Figure 16.3 assumes that industrial melanism may have started but was not fully in force yet. **Industrial melanism** refers to a darkening of moths once industrialization has begun in a country. Prior to the Industrial Revolution in Great Britain, light-colored peppered moths living on the light-colored, unpolluted vegetation, were more common than dark-colored peppered moths. When dark-colored moths landed on light vegetation, they were seen and eaten by predators. In Figure 16.3, *left*, we suppose that only 36% of the population were dark-colored, while 64% were light-colored. With the advent of industry and an increase in pollution, the vegetation was stained darker. Now, light-colored moths were easy prey for predators. Figure 16.3, *right*, assumes that the gene pool frequencies switched, and now the dark-colored moths are 64% of the population. Can you calculate the change in gene pool frequencies using Figure 16.2 as a guide?

Just before the Clean Air legislation in the mid-1950s, the numbers of dark-colored moths exceeded a frequency of 80% in some populations. After the legislation, a dramatic reversal in the ratio of light-colored moths to dark-colored moths occurred once again as light-colored moths became more and more frequent. Aside from showing that natural selection can occur within a short period of time, our example shows that a change in gene pool frequencies does occur as microevolution occurs. Recall that microevolution occurs below the species level.

Causes of Microevolution

The list of conditions for a Hardy-Weinberg equilibrium implies that the opposite conditions can cause evolutionary

16 How Populations Evolve

When your grandparents were young, infectious diseases, such as tuberculosis, pneumonia, and syphilis, killed thousands of people every year. Then in the 1940s, penicillin and other antibiotics were developed, and public health officials thought infectious diseases were a thing of the past. Today, however, many infections are back with a vengeance. Why? Because natural selection occurred. As with Staphylococcus aureus, *a few bacteria were resistant to penicillin. Therefore, they were selected over and over again to reproduce, until the entire population of bacteria became resistant to penicillin. A new antibiotic called methicillin became available in 1959 to treat penicillin-resistant bacterial strains, but by 1997, 40% of hospital staph infections were caused by methicillin-resistant* Staphylococcus aureus, *or MRSA. Now, community-acquired MRSA (CA-MRSA) can spread freely through the general populace, particularly when people are in close contact.*

This chapter gives the principles of evolution a genetic basis and shows how it is possible to genetically recognize when a population has undergone evolutionary changes. Evolutionary changes observed at the population level are termed microevolution.

MRSA can spread between members of a human social group.

concepts

16.1 POPULATION GENETICS

- Genetic diversity is a necessity for microevolution to occur, and today investigators are interested in DNA sequence differences between individuals. It might be possible to associate particular variations with illnesses. 284
- The Hardy-Weinberg principle provides a way to know if a population has evolved. Allele frequency changes in the next generation signify that microevolution has occurred. 285–86
- Microevolution will occur unless five conditions are met: no mutations, no gene flow, mating is random, no genetic drift, and no selection of a particular trait. 286–88

16.2 NATURAL SELECTION

- A change in phenotype frequencies occurs if a population has undergone stabilizing selection, directional selection, or disruptive selection. 289–90
- Sexual selection fostered by male competition and female choice is also a type of natural selection because it influences reproductive success. 291–92

16.3 MAINTENANCE OF DIVERSITY

- Genetic diversity is maintained within a population; for example, by the diploid genotype and also when the heterozygote is the most adaptive genotype. 294–95

17 Speciation and Macroevolution

The immense liger featured here is an offspring of a lion and a tiger, two normally reproductively isolated animal species. Ligers are the largest of all known cats, measuring up to 12 feet tall when standing on their hind legs and weighing as much as 1,000 lbs. Their coat color is usually tan with tiger stripes on the back and hindquarters and lion cub spots on the abdomen. A liger can produce both the "chuff" sound of a tiger and the roar of a lion. Male ligers may have a modest lion mane or no mane at all. Most ligers like to be near water and love to swim. Generally, ligers have a gentle disposition; however, considering their size and heritage, handlers should be extremely careful. By what criteria could a liger be considered a new species? Only if they, in turn, were reproductively isolated and only mated with ligers. In this chapter, we will explore the definition of a species and how species arise. In so doing, we will begin our discussion of macroevolution, which we continue in the next chapter.

This liger is a hybrid because it has a lion father and a tiger mother.

concepts

17.1 SEPARATION OF THE SPECIES

- Species can be recognized by their traits, by reproductive isolation, and by DNA differences. 300–301
- Mechanisms that prevent reproduction between species are divided into those that prevent attempts at reproduction and those that prevent development of an offspring or cause the offspring to be infertile. 302–3

17.2 MODES OF SPECIATION

- Allopatric speciation occurs when a new species evolves in geographic isolation from an ancestral species. 304–5
- Adaptive radiation, during which a single species gives rise to a number of different species, is an example of allopatric speciation. 306
- Sympatric speciation occurs when a new species evolves without geographic isolation. 307
- The Burgess Shale gives us a glimpse of marine life some 540 million years ago. 308–9

17.3 PRINCIPLES OF MACROEVOLUTION

- Macroevolution is phenotypic changes at the species and higher levels of taxonomy up to a domain. 310
- The tempo of speciation can be rapid or slow. Developmental genes provide a mechanism for rapid speciation. 311–12
- Macroevolution involves speciation, diversification, and extinction, as observed in the evolution of the horse. Macroevolution is not goal directed and, instead, represents adaptation to varied environments through time. 313–14

1.2 Evolution, the Unifiying Concept of Biology

Despite diversity in form, function, and lifestyle, organisms share the same basic characteristics. As mentioned, they are all composed of cells organized in a similar manner. Their genes are composed of DNA, and they carry out the same metabolic reactions to acquire energy and maintain their organization. The unity of living things suggests that they are descended from a common ancestor—the first cell or cells.

An evolutionary tree is like a family tree (Fig. 1.5). Just as a family tree shows how a group of people have descended from one couple, an evolutionary tree traces the ancestry of life on Earth to a common ancestor. One couple can have diverse children, and likewise a population can be a common ancestor to several other groups, each adapted to a particular set of environmental conditions. In this way, over time, diverse life-forms have arisen. Evolution may be considered the unifying concept of biology because it explains so many aspects of biology, including how living organisms arose from a single ancestor.

Organizing Diversity

Because life is so diverse, it is helpful to group organisms into categories. **Taxonomy** [Gk. *tasso*, arrange, and *nomos*, usage] is the discipline of identifying and grouping organisms according to certain rules. Taxonomy makes sense out of the bewildering variety of life on Earth and is meant to provide valuable insight into evolution. As more is learned about living things, including the evolutionary relationships between species, taxonomy changes. DNA technology is now being used to revise current information and to discover previously unknown relationships between organisms.

Several of the basic classification categories, or *taxa*, going from least inclusive to most inclusive, are **species, genus, family, order, class, phylum, kingdom,** and **domain** (Table 1.1). The least inclusive category, species [L. *species*, model, kind], is defined as a group of interbreeding individuals. Each successive classification category above species contains more types of organisms than the preceding one. Species placed within one genus share many specific characteristics and are the most closely related, while species placed in the same kingdom share only general characteristics with one another. For example, all species in the genus *Pisum* look pretty much the same—that is, like pea plants—but species in the plant kingdom can be quite varied, as is evident when we compare grasses to trees. Species placed in different domains are the most distantly related.

TABLE 1.1

Levels of Classification

Category	*Human*	*Corn*
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Anthophyta
Class	Mammalia	Monocotyledones
Order	Primates	Commelinales
Family	Hominidae	Poaceae
Genus	*Homo*	*Zea*
Species*	*H. sapiens*	*Z. mays*

*To specify an organism, you must use the full binomial name, such as *Homo sapiens*.

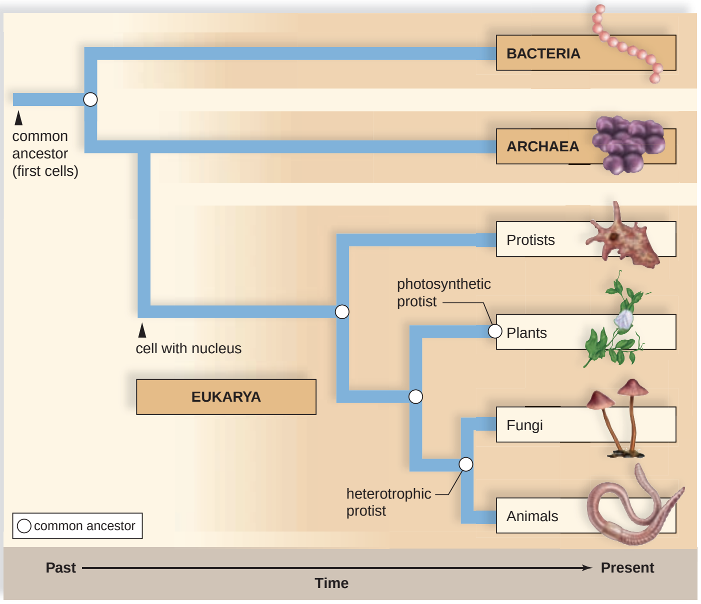


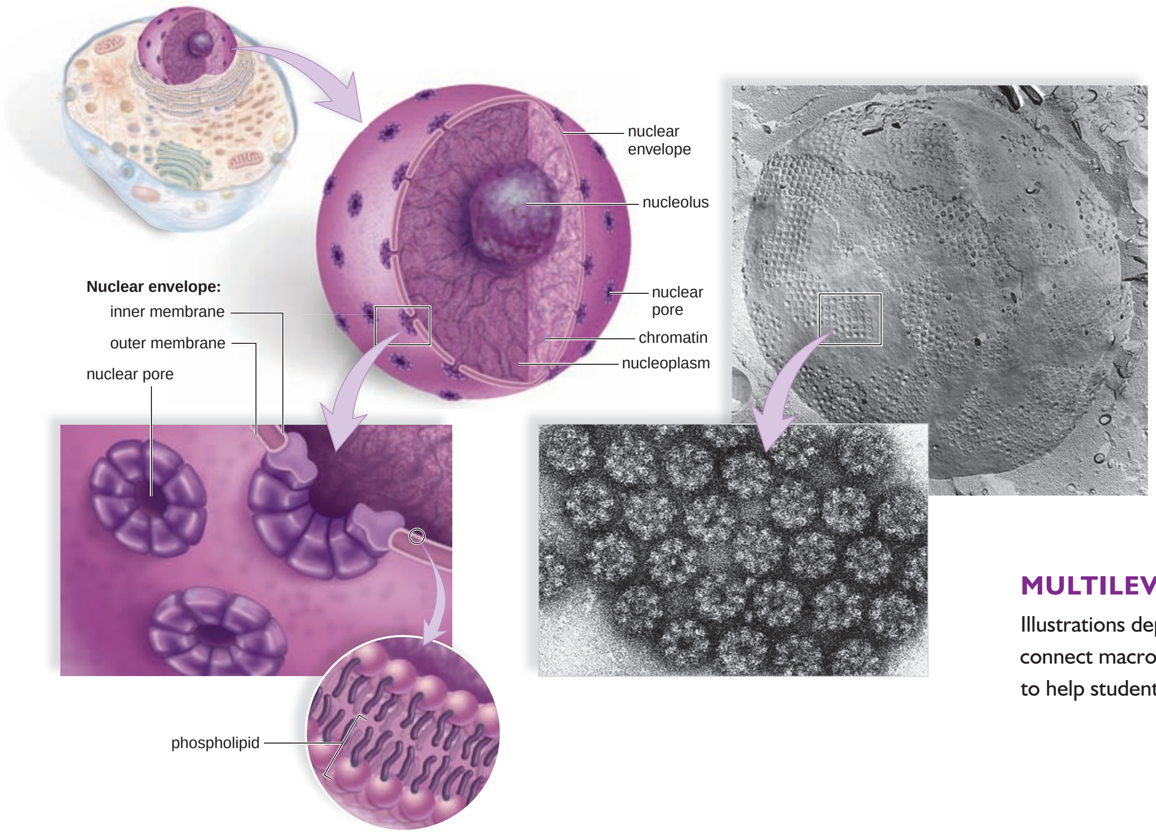
FIGURE 1.5 **Evolutionary tree of life.**

As existing organisms change over time, they give rise to new species. Evolutionary studies show that all living organisms arose from a common ancestor about 4 billion years ago. Domain Archaea includes prokaryotes capable of surviving in extreme environments, such as those with high salinity and temperature and low pH. Domain Bacteria includes metabolically diverse prokaryotes widely distributed in various environments. The domain Eukarya includes both unicellular and multicellular organisms that possess a membrane-bounded nucleus.

NEW SECTION

Chapter 1 includes a new section that covers basic evolutionary principles and a new depiction of the Tree of Life which introduces the three domains of life.

A Stunning Visuals Program

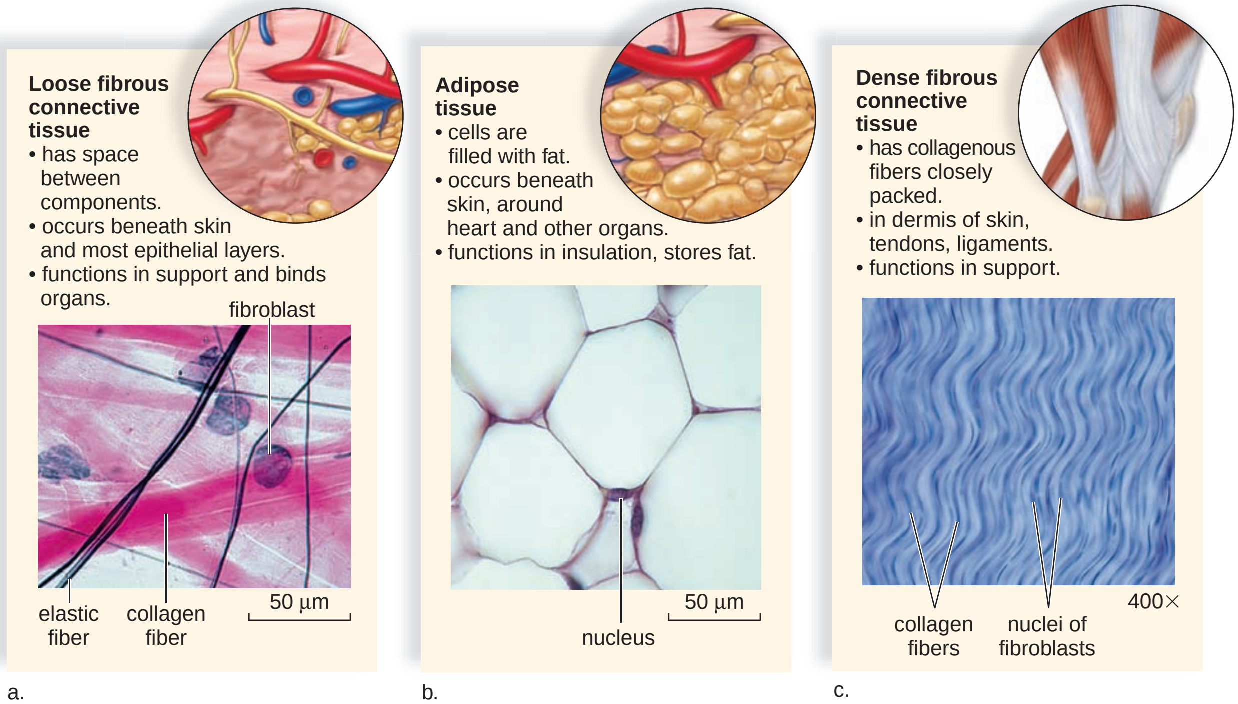


MULTILEVEL PERSPECTIVE

Illustrations depicting complex structures connect macroscopic and microscopic views to help students connect the two levels.

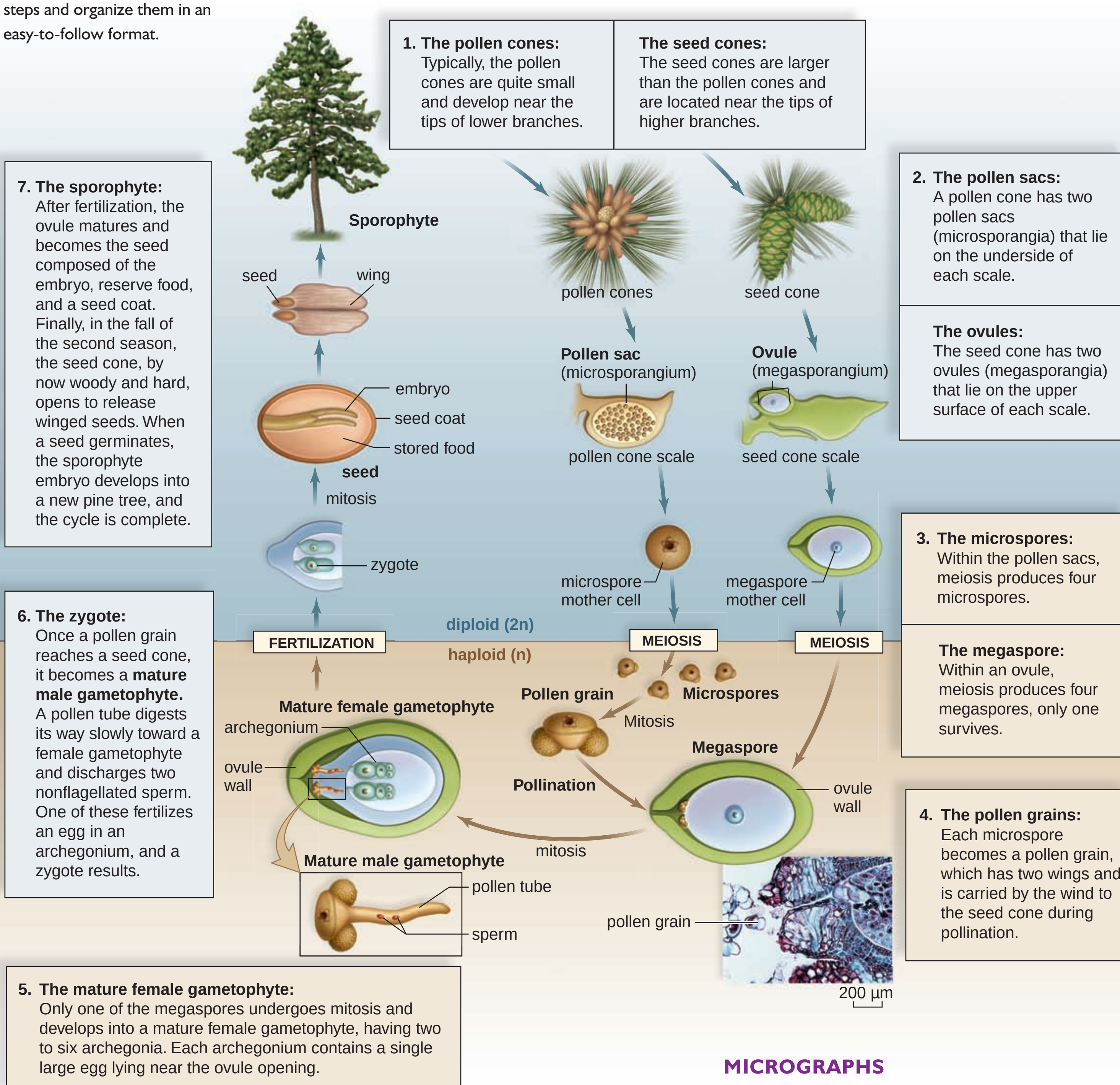
COMBINATION ART

Drawings of structures are often paired with micrographs to enhance visualization.



PROCESS FIGURES

These figures break down processes into a series of smaller steps and organize them in an easy-to-follow format.



MICROGRAPHS

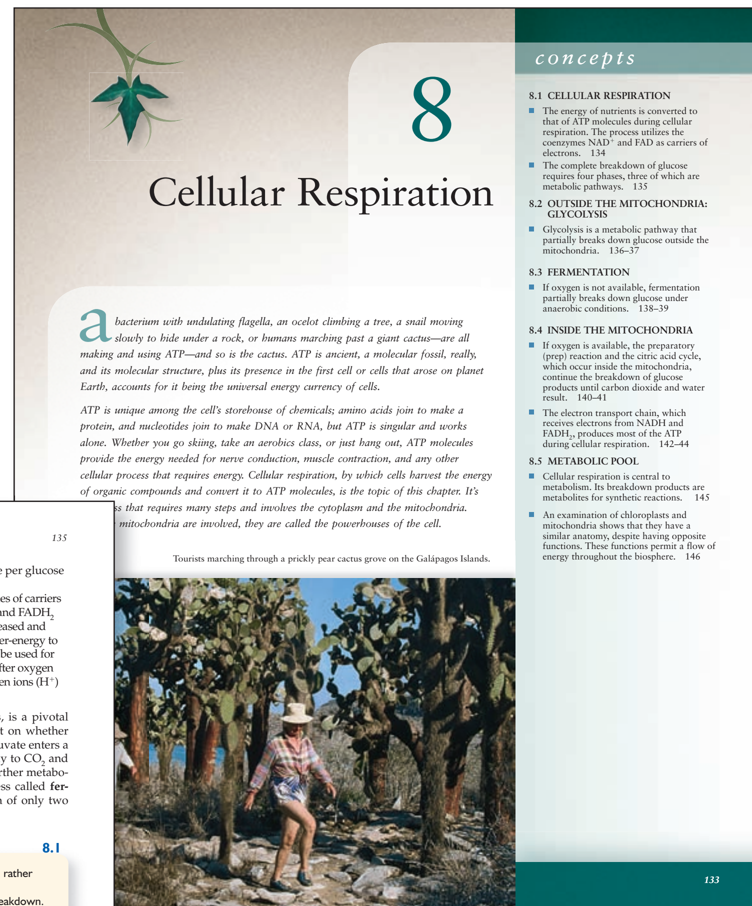
The brilliant visuals program has been enhanced by many new micrographs.

The Learning System

Proven Pedagogical Features That Will Facilitate Your Understanding of Biology

CHAPTER CONCEPTS

The chapter begins with an integrated outline that numbers the major topics of the chapter and lists the concepts for each topic.



8

Cellular Respiration

a bacterium with undulating flagella, an ocelot climbing a tree, a snail moving slowly to hide under a rock, or humans marching past a giant cactus—are all making and using ATP—and so is the cactus. ATP is ancient, a molecular fossil, really, and its molecular structure, plus its presence in the first cell or cells that arose on planet Earth, accounts for it being the universal energy currency of cells.

ATP is unique among the cell's storehouse of chemicals; amino acids join to make a protein, and nucleotides join to make DNA or RNA, but ATP is singular and works alone. Whether you go skiing, take an aerobics class, or just hang out, ATP molecules provide the energy needed for nerve conduction, muscle contraction, and any other cellular process that requires energy. Cellular respiration, by which cells harvest the energy of organic compounds and convert it to ATP molecules, is the topic of this chapter. It's ...s that requires many steps and involves the cytoplasm and the mitochondria. ... mitochondria are involved, they are called the powerhouses of the cell.

Tourists marching through a prickly pear cactus grove on the Galápagos Islands.

concepts

8.1 CELLULAR RESPIRATION

- The energy of nutrients is converted to that of ATP molecules during cellular respiration. The process utilizes the coenzymes NAD^+ and FAD as carriers of electrons. 134
- The complete breakdown of glucose requires four phases, three of which are metabolic pathways. 135

8.2 OUTSIDE THE MITOCHONDRIA: GLYCOLYSIS

- Glycolysis is a metabolic pathway that partially breaks down glucose outside the mitochondria. 136–37

8.3 FERMENTATION

- If oxygen is not available, fermentation partially breaks down glucose under anaerobic conditions. 138–39

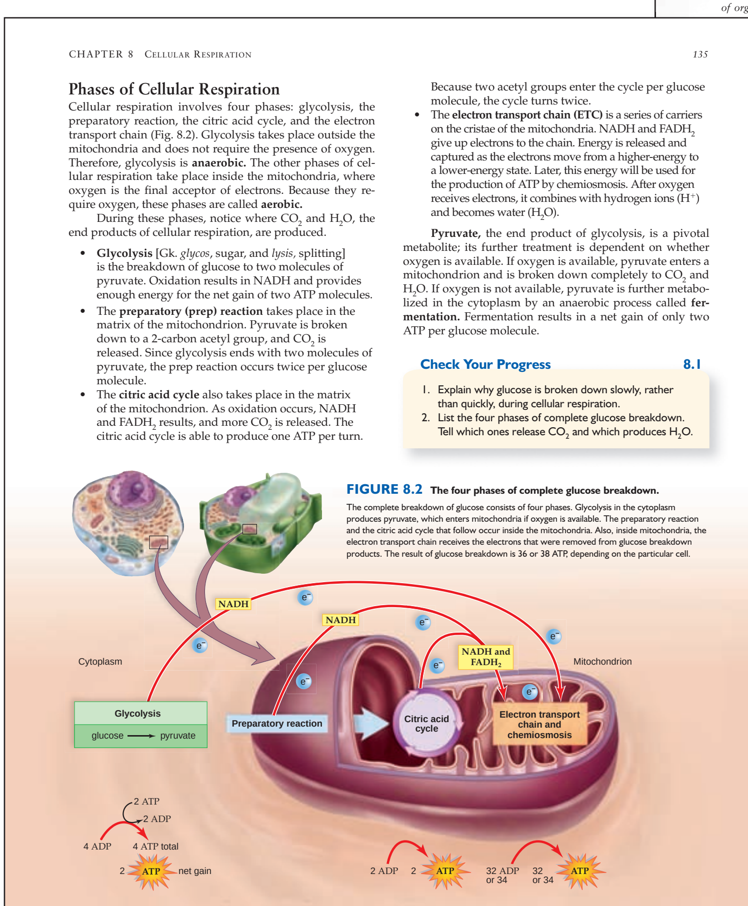
8.4 INSIDE THE MITOCHONDRIA

- If oxygen is available, the preparatory (prep) reaction and the citric acid cycle, which occur inside the mitochondria, continue the breakdown of glucose products until carbon dioxide and water result. 140–41
- The electron transport chain, which receives electrons from NADH and $FADH_2$, produces most of the ATP during cellular respiration. 142–44

8.5 METABOLIC POOL

- Cellular respiration is central to metabolism. Its breakdown products are metabolites for synthetic reactions. 145
- An examination of chloroplasts and mitochondria shows that they have a similar anatomy, despite having opposite functions. These functions permit a flow of energy throughout the biosphere. 146

133



CHAPTER 8 Cellular Respiration 135

Phases of Cellular Respiration

Cellular respiration involves four phases: glycolysis, the preparatory reaction, the citric acid cycle, and the electron transport chain (Fig. 8.2). Glycolysis takes place outside the mitochondria and does not require the presence of oxygen. Therefore, glycolysis is **anaerobic.** The other phases of cellular respiration take place inside the mitochondria, where oxygen is the final acceptor of electrons. Because they require oxygen, these phases are called **aerobic.**

During these phases, notice where CO_2 and H_2O, the end products of cellular respiration, are produced.

- **Glycolysis** [Gk. *glycos*, sugar, and *lysis*, splitting] is the breakdown of glucose to two molecules of pyruvate. Oxidation results in NADH and provides enough energy for the net gain of two ATP molecules.
- The **preparatory (prep) reaction** takes place in the matrix of the mitochondrion. Pyruvate is broken down to a 2-carbon acetyl group, and CO_2 is released. Since glycolysis ends with two molecules of pyruvate, the prep reaction occurs twice per glucose molecule.
- The **citric acid cycle** also takes place in the matrix of the mitochondrion. As oxidation occurs, NADH and $FADH_2$ results, and more CO_2 is released. The citric acid cycle is able to produce one ATP per turn. Because two acetyl groups enter the cycle per glucose molecule, the cycle turns twice.
- The **electron transport chain (ETC)** is a series of carriers on the cristae of the mitochondria. NADH and $FADH_2$ give up electrons to the chain. Energy is released and captured as the electrons move from a higher-energy to a lower-energy state. Later, this energy will be used for the production of ATP by chemiosmosis. After oxygen receives electrons, it combines with hydrogen ions (H^+) and becomes water (H_2O).

Pyruvate, the end product of glycolysis, is a pivotal metabolite; its further treatment is dependent on whether oxygen is available. If oxygen is available, pyruvate enters a mitochondrion and is broken down completely to CO_2 and H_2O. If oxygen is not available, pyruvate is further metabolized in the cytoplasm by an anaerobic process called **fermentation.** Fermentation results in a net gain of only two ATP per glucose molecule.

Check Your Progress 8.1

1. Explain why glucose is broken down slowly, rather than quickly, during cellular respiration.
2. List the four phases of complete glucose breakdown. Tell which ones release CO_2 and which produces H_2O.

FIGURE 8.2 **The four phases of complete glucose breakdown.**

The complete breakdown of glucose consists of four phases. Glycolysis in the cytoplasm produces pyruvate, which enters mitochondria if oxygen is available. The preparatory reaction and the citric acid cycle that follow occur inside the mitochondria. Also, inside mitochondria, the electron transport chain receives the electrons that were removed from glucose breakdown products. The result of glucose breakdown is 36 or 38 ATP, depending on the particular cell.

CHECK YOUR PROGRESS

Check Your Progress questions appear at the end of each major section of the chapter to help students focus on the key concepts.

Three Types of Boxed Readings

Science Focus readings describe how experimentation and observations have contributed to our knowledge about the living world.


CHAPTER 8 Cellular Respiration 139

science focus

Fermentation Helps Produce Numerous Food Products

At the grocery store, you will find such items as bread, yogurt, soy sauce, pickles, and maybe even wine (Fig. 8A). These are just a few of the many foods that are produced when microorganisms ferment (break down sugar in the absence of oxygen). Foods produced by fermentation last longer because the fermenting organisms have removed many of the nutrients that would attract other organisms. The products of fermentation can even be dangerous to the very organisms that produced them, as when yeasts are killed by the alcohol they produce.

Yeast Fermentation

Baker's yeast, *Saccharomyces cerevisiae*, is added to bread for the purpose of leavening—the dough rises when the yeasts give off CO_2. The ethyl alcohol produced by the fermenting yeast evaporates during baking. The many different varieties of sourdough breads obtain their leavening from a starter composed of fermenting yeasts along with bacteria from the environment. Depending on the community of microorganisms in the starter, the flavor of the bread may range from sour and tangy, as in San Francisco–style sourdough, to a milder taste, such as that produced by most Amish friendship bread recipes.

Ethyl alcohol is desired when yeasts are used to produce wine and beer. When yeasts ferment the carbohydrates of fruits, the end result is wine. If they ferment grain, beer results. A few specialized varieties of beer, such as traditional wheat beers, have a distinctive sour taste because they are produced with the assistance of lactic acid–producing bacteria, such as those of the genus *Lactobacillus*. Stronger alcoholic drinks (e.g., whiskey and vodka) require distillation to concentrate the alcohol content.

The acetic acid bacteria, including *Acetobacter aceti*, spoil wine. These bacteria convert the alcohol in wine or cider to acetic acid (vinegar). Until the renowned nineteenth-century scientist Louis Pasteur invented the process of pasteurization, acetic acid bacteria commonly caused wine to spoil. Although today we generally associate the process of pasteurization with making milk safe to drink, it was originally developed to reduce bacterial contamination in wine so that limited acetic acid would be produced.

Bacterial Fermentation

Yogurt, sour cream, and cheese are produced through the action of various lactic acid bacteria that cause milk to sour. Milk contains lactose, which these bacteria use as a substrate for fermentation. Yogurt, for example, is made by adding lactic acid bacteria, such as *Streptococcus thermophilus* and *Lactobacillus bulgaricus*, to milk and then incubating it to encourage the bacteria to act on lactose. During the production of cheese, an enzyme called rennin must also be added to the milk to cause it to coagulate and become solid.

Old-fashioned brine cucumber pickles, sauerkraut, and kimchi are pickled vegetables produced by the action of acid-producing, fermenting bacteria that can survive in high-salt environments. Salt is used to draw liquid out of the vegetables and aid in their preservation. The bacteria need not be added to the vegetables, because they are already present on the surfaces of the plants.

Soy Sauce Production

Soy sauce is traditionally made by adding a mold, *Aspergillus*, and a combination of yeasts and fermenting bacteria to soybeans and wheat. The mold breaks down starch, supplying the fermenting microorganisms with sugar they can use to produce alcohol and organic acids.

FIGURE 8A Products from fermentation.
Fermentation helps make the products shown on this page.


CHAPTER 23 Plant Evolution and Diversity 423

ecology focus

Carboniferous Forests

Our industrial society runs on fossil fuels such as coal. The term *fossil fuel* might seem odd at first until one realizes that it refers to the remains of organic material from ancient times. During the Carboniferous period more than 300 million years ago, a great swamp forest (Fig. 23A) encompassed what is now northern Europe, the Ukraine, and the Appalachian Mountains in the United States. The weather was warm and humid, and the trees grew very tall. These are not the trees we know today; instead, they are related to today's seedless vascular plants: the lycophytes, horsetails, and ferns! Lycophytes today may stand as high as 30 cm, but their ancient relatives were 35 m tall and 1 m wide. The stroboli were up to 30 cm long, and some had leaves more than 1 m long. Horsetails too—at 18 m tall—were giants compared to today's specimens. Tree ferns were also taller than tree ferns found in the tropics today. The progymnosperms, including "seed ferns," were significant plants of a Carboniferous swamp. Seed ferns are misnamed because they are actually progymnosperms.

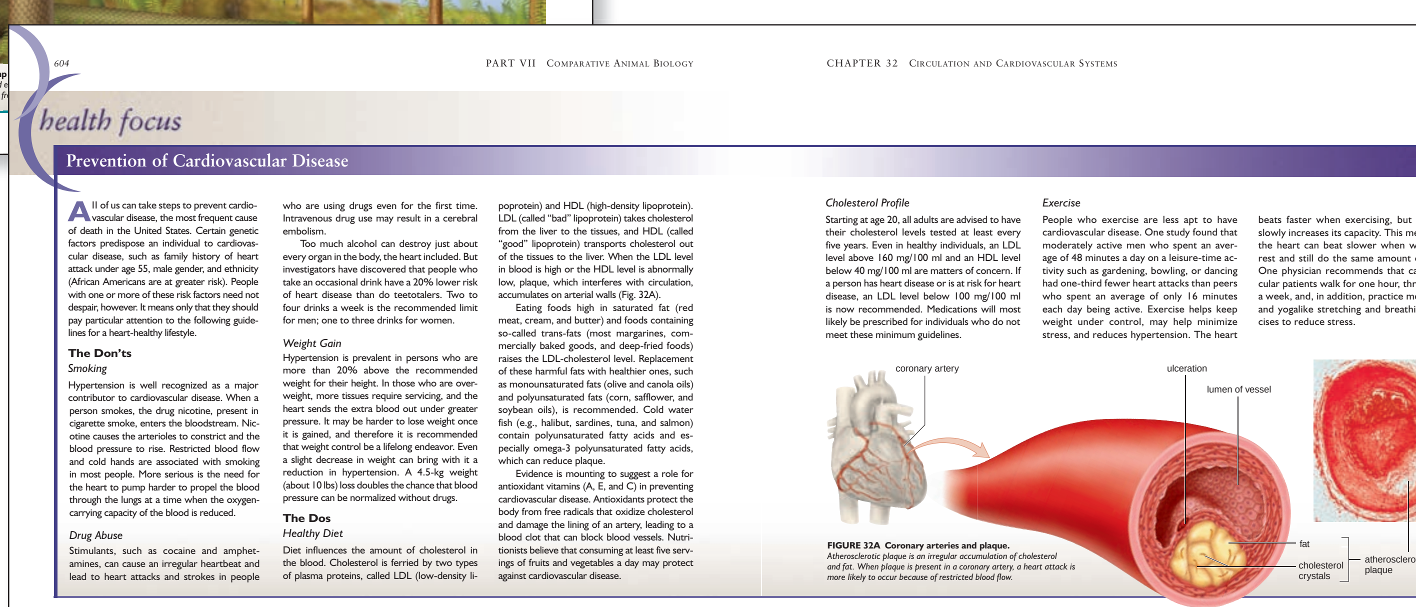
The amount of biomass in a Carboniferous swamp forest was enormous, and occasionally the swampy water rose and the trees fell. Trees under water do not decompose well, and their partially decayed remains became covered by sediment that sometimes changed to sedimentary rock. Exposed to pressure from sedimentary rock, the organic material then became coal, a fossil fuel. This process continued for millions of years, resulting in immense deposits of coal. Geological upheavals raised the deposits to the level where they can be mined today.

With a change of climate, the trees of the Carboniferous period became extinct, and only their herbaceous relatives survived to our time. Without these ancient forests, our life today would be far different because they helped bring about our industrialized society.

FIGURE 23A Swamp
Nonvascular plants and e... their leaves looked like fr...

Ecology Focus readings show how the concepts of the chapter can be applied to ecological concerns.

Health Focus readings review procedures and technology that can contribute to our well-being.


604 PART VII Comparative Animal Biology   CHAPTER 32 Circulation and Cardiovascular Systems

health focus

Prevention of Cardiovascular Disease

All of us can take steps to prevent cardiovascular disease, the most frequent cause of death in the United States. Certain genetic factors predispose an individual to cardiovascular disease, such as family history of heart attack under age 55, male gender, and ethnicity (African Americans are at greater risk). People with one or more of these risk factors need not despair, however. It means only that they should pay particular attention to the following guidelines for a heart-healthy lifestyle.

The Don'ts

Smoking

Hypertension is well recognized as a major contributor to cardiovascular disease. When a person smokes, the drug nicotine, present in cigarette smoke, enters the bloodstream. Nicotine causes the arterioles to constrict and the blood pressure to rise. Restricted blood flow and cold hands are associated with smoking in most people. More serious is the need for the heart to pump harder to propel the blood through the lungs at a time when the oxygen-carrying capacity of the blood is reduced.

Drug Abuse

Stimulants, such as cocaine and amphetamines, can cause an irregular heartbeat and lead to heart attacks and strokes in people who are using drugs even for the first time. Intravenous drug use may result in a cerebral embolism.

Too much alcohol can destroy just about every organ in the body, the heart included. But investigators have discovered that people who take an occasional drink have a 20% lower risk of heart disease than do teetotalers. Two to four drinks a week is the recommended limit for men; one to three drinks for women.

Weight Gain

Hypertension is prevalent in persons who are more than 20% above the recommended weight for their height. In those who are overweight, more tissues require servicing, and the heart sends the extra blood out under greater pressure. It may be harder to lose weight once it is gained, and therefore it is recommended that weight control be a lifelong endeavor. Even a slight decrease in weight can bring with it a reduction in hypertension. A 4.5-kg weight (about 10 lbs) loss doubles the chance that blood pressure can be normalized without drugs.

The Dos

Healthy Diet

Diet influences the amount of cholesterol in the blood. Cholesterol is ferried by two types of plasma proteins, called LDL (low-density lipoprotein) and HDL (high-density lipoprotein). LDL (called "bad" lipoprotein) takes cholesterol from the liver to the tissues, and HDL (called "good" lipoprotein) transports cholesterol out of the tissues to the liver. When the LDL level in blood is high or the HDL level is abnormally low, plaque, which interferes with circulation, accumulates on arterial walls (Fig. 32A).

Eating foods high in saturated fat (red meat, cream, and butter) and foods containing so-called trans-fats (most margarines, commercially baked goods, and deep-fried foods) raises the LDL-cholesterol level. Replacement of these harmful fats with healthier ones, such as monounsaturated fats (olive and canola oils) and polyunsaturated fats (corn, safflower, and soybean oils), is recommended. Cold water fish (e.g., halibut, sardines, tuna, and salmon) contain polyunsaturated fatty acids and especially omega-3 polyunsaturated fatty acids, which can reduce plaque.

Evidence is mounting to suggest a role for antioxidant vitamins (A, E, and C) in preventing cardiovascular disease. Antioxidants protect the body from free radicals that oxidize cholesterol and damage the lining of an artery, leading to a blood clot that can block blood vessels. Nutritionists believe that consuming at least five servings of fruits and vegetables a day may protect against cardiovascular disease.

Cholesterol Profile

Starting at age 20, all adults are advised to have their cholesterol levels tested at least every five years. Even in healthy individuals, an LDL level above 160 mg/100 ml and an HDL level below 40 mg/100 ml are matters of concern. If a person has heart disease or is at risk for heart disease, an LDL level below 100 mg/100 ml is now recommended. Medications will most likely be prescribed for individuals who do not meet these minimum guidelines.

Exercise

People who exercise are less apt to have cardiovascular disease. One study found that moderately active men who spent an average of 48 minutes a day on a leisure-time activity such as gardening, bowling, or dancing had one-third fewer heart attacks than peers who spent an average of only 16 minutes each day being active. Exercise helps keep weight under control, may help minimize stress, and reduces hypertension. The heart beats faster when exercising, but slowly increases its capacity. This me... the heart can beat slower when w... rest and still do the same amount ... One physician recommends that ca... cular patients walk for one hour, thr... a week, and, in addition, practice me... and yogalike stretching and breathi... cises to reduce stress.

FIGURE 32A Coronary arteries and plaque.
Atherosclerotic plaque is an irregular accumulation of cholesterol and fat. When plaque is present in a coronary artery, a heart attack is more likely to occur because of restricted blood flow.

End of Chapter Study Tools

CONNECTING THE CONCEPTS

These appear at the close of the text portion of the chapter, and they stimulate critical thinking by showing how the concepts of the chapter are related to other concepts in the text.

CHAPTER SUMMARY

The summary is organized according to the major sections in the chapter and helps students review the important topics and concepts.

UNDERSTANDING THE TERMS

The boldface terms in the chapter are page referenced, and a matching exercise allows you to test your knowledge of the terms.

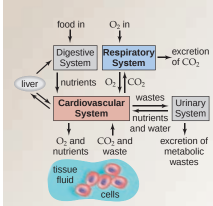
REVIEWING THIS CHAPTER

These page-referenced study questions follow the sequence of the chapter.

TESTING YOURSELF

These objective questions allow you to test your ability to answer recall-based questions. Answers to Testing Yourself questions are provided in Appendix A.

Connecting the Concepts



In mammals, the respiratory system consists of the respiratory tract with the nasal passages (or mouth) at one end and the lungs at the other end. Inspired air is 20% O_2 and 0.04% CO_2, while expired air is about 14% O_2 and 6% CO_2. Gas exchange in the lungs accounts for the difference in composition of inspired and expired air.

In the lungs, oxygen is absorbed into the bloodstream and from there it is transported by red blood cells to the capillaries, where it exits and enters tissue fluid. On the other hand, carbon dioxide enters capillaries at the tissues and is transported largely as the bicarbonate ion to the lungs, where it is converted to carbon dioxide and exits the body. Diffusion alone accounts for gas exchange in the lungs, called external respiration, and gas exchange in the tissues, called internal respiration. Energy is not needed, as gases follow their concentration gradients according to their partial pressures.

Internal gas exchange is extremely critical because cells use oxygen and release carbon dioxide as a result of cellular respiration, the process that generates ATP in cells. External gas exchange has the benefit of helping to keep the pH of the blood constant as required for homeostasis. When carbon dioxide exits, the blood pH returns to normal. In Chapter 36, we consider the contribution of the kidneys to homeostasis.

summary

35.1 Gas Exchange Surfaces
Some aquatic animals, such as hydras and planarians, use their entire body surface for gas exchange. Most animals have a specialized gas-exchange area. Large aquatic animals usually pass water through gills. In bony fishes, blood in the capillaries flows in the direction opposite that of the water. Blood takes up almost all of the oxygen in the water as a result of this countercurrent flow. On land, insects use tracheal systems, and vertebrates have lungs. In insects, air enters the tracheae at openings called spiracles. From there, the air moves to ever smaller tracheoles until gas exchange takes place at the cells themselves. Lungs are found inside the body, where water loss is reduced. To ventilate the lungs, some vertebrates use positive pressure, but most inhale, using muscular contraction to produce a negative pressure that causes air to rush into the lungs. When the breathing muscles relax, air is exhaled.

Birds have a series of air sacs attached to the lungs. When a bird inhales, air enters the posterior air sacs, and when a bird exhales, air moves through the lungs to the anterior air sacs before exiting the respiratory tract. The one-way flow of air through the lungs allows more fresh air to be present in the lungs with each breath, and this leads to greater uptake of oxygen from one breath of air.

35.2 Breathing and Transport of Gases
During inspiration, air enters the body at nasal cavities and then passes from the pharynx through the glottis, larynx, trachea, bronchi, and bronchioles to the alveoli of the lungs, where exchange occurs, and during expiration air passes in the opposite direction. Humans breathe by negative pressure, as do other mammals. During inspiration, the rib cage goes up and out, and the diaphragm lowers. The lungs expand ushing in. During expiration, the rib cage goes down diaphragm rises. Therefore, air rushes out. f breathing increases when the amount of H^+ and in the blood rises, as detected by chemoreceptors tic and carotid bodies. ge in the lungs and tissues is brought about by diffusion. nsports oxygen in the blood; carbon dioxide is mainly lasma as the bicarbonate ion. Excess hydrogen ions are transported by hemoglobin. The enzyme carbonic anhydrase found in red blood cells speeds the formation of the bicarbonate ion.

35.3 Respiration and Health
The respiratory tract is subject to infections such as pneumonia and pulmonary tuberculosis. New strains of tuberculosis are resistant to the usual antibiotic therapy.

Major lung disorders are usually due to cigarette smoking. In chronic bronchitis the air passages are inflamed, mucus is common, and the cilia that line the respiratory tract are gone. Emphysema and lung cancer are two of the most serious consequences of smoking cigarettes. When the lungs of these patients are removed upon death, they are blackened by smoke.

understanding the terms

alveolus (pl., alveoli) 654
aortic body 657
bicarbonate ion 659
bronchiole 655
bronchus (pl., bronchi) 655
carbaminohemoglobin 659
carbonic anhydrase 659
carotid body 657
countercurrent exchange 652
diaphragm 656
epiglottis 654
expiration 656
external respiration 650
gills 651
glottis 654
heme 659
hemoglobin (Hb) 659
inspiration 656
internal respiration 650
larynx 654
lungs 651
oxyhemoglobin 659
partial pressure 658
pharynx 654
respiration 650
respiratory center 657
trachea (pl., tracheae) 653, 654
ventilation 650
vocal cord 654

Match the terms to these definitions:

a. ______________ In terrestrial vertebrates, the mechanical act of moving air in and out of the lungs; breathing.
b. ______________ Dome-shaped muscularized sheet separating the thoracic cavity from the abdominal cavity in mammals.
c. ______________ Fold of tissue within the larynx; creates vocal sounds when it vibrates.

d. ______________ Respiratory organ in most aquatic animals; in fish, an outward extension of the pharynx.
e. ______________ Stage during breathing when air is pushed out of the lungs.

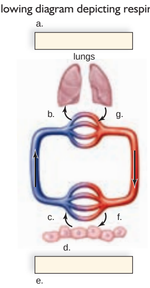
reviewing this chapter

1. Compare the respiratory organs of aquatic animals to those of terrestrial animals. 650–54
2. How does the countercurrent flow of blood within gill capillaries and water passing across the gills assist respiration in fishes? 652
3. Why is it beneficial for the body wall of earthworms to be moist? Why don't insects require circulatory system involvement in air transport? 653
4. Name the parts of the human respiratory system, and list a function for each part. How is the air reaching the lungs cleansed? 654
5. Explain the phrase "breathing by using negative pressure." 656
6. Contrast the tidal ventilation mechanism in humans with the one-way ventilation mechanism in birds, and explain the benefits of the ventilation mechanism in birds. 656–57
7. The concentration of what substances in blood controls the breathing rate in humans? Explain. 658
8. How are oxygen and carbon dioxide transported in blood? What does carbonic anhydrase do? 659
9. Which conditions depicted in Figure 35.14 are due to infection? Which are due to behavioral or environmental factors? Explain. 660–61

testing yourself

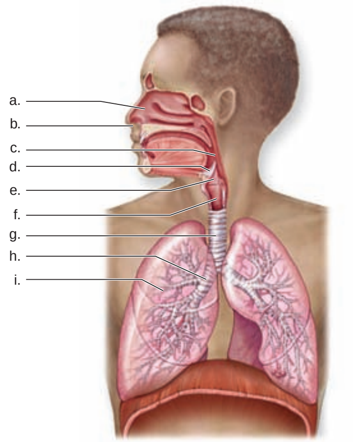
Choose the best answer for each question.

1. Label the following diagram depicting respiration.



2. One problem faced by terrestrial animals with lungs, but not by aquatic animals with gills, is that
   a. gas exchange involves water loss.
   b. breathing requires considerable energy.
   c. oxygen diffuses very slowly in air.
   d. the concentration of oxygen in water is greater than that in air.
   e. All of these are correct.
3. In which animal is the circulatory system not involved in gas transport?
   a. mouse
   b. dragonfly
   c. trout
   d. sparrow
   e. human
4. Birds have more efficient lungs than humans because the flow of air
   a. is the same during both inspiration and expiration.
   b. travels in only one direction through the lungs.
   c. never backs up as it does in human lungs.
   d. is not hindered by a larynx.
   e. enters their bones.
5. Which animal breathes by positive pressure?
   a. fish
   b. human
   c. bird
   d. frog
   e. planarian
6. Which of these is a true statement?
   a. In lung capillaries, carbon dioxide combines with water to produce carbonic acid.
   b. In tissue capillaries, carbonic acid breaks down to carbon dioxide and water.
   c. In lung capillaries, carbonic acid breaks down to carbon dioxide and water.
   d. In tissue capillaries, carbonic acid combines with hydrogen ions to form the carbonate ion.
   e. All of these statements are true.
7. Air enters the human lungs because
   a. atmospheric pressure is less than the pressure inside the lungs.
   b. atmospheric pressure is greater than the pressure inside the lungs.
   c. although the pressures are the same inside and outside, the partial pressure of oxygen is lower within the lungs.
   d. the residual air in the lungs causes the partial pressure of oxygen to be less than it is outside.
   e. the process of breathing pushes air into the lungs.
8. If the digestive and respiratory tracts were completely separate in humans, there would be no need for
   a. swallowing.
   b. a nose.
   c. an epiglottis.
   d. a diaphragm.
   e. All of these are correct.
9. In tracing the path of air in humans, you would list the trachea
   a. directly after the nose.
   b. directly before the bronchi.
   c. before the pharynx.
   d. directly before the lungs.
   e. Both a and c are correct.
10. In humans, the respiratory control center
    a. is stimulated by carbon dioxide.
    b. is located in the medulla oblongata.
    c. controls the rate of breathing.
    d. is stimulated by hydrogen ion concentration.
    e. All of these are correct.
11. Carbon dioxide is carried in the plasma
    a. in combination with hemoglobin.
    b. as the bicarbonate ion.
    c. combined with carbonic anhydrase.
    d. only as a part of tissue fluid.
    e. All of these are correct.
12. Which of these is anatomically incorrect?
    a. The nose has two nasal cavities.
    b. The pharynx connects the nasal and oral cavities to the larynx.
    c. The larynx contains the vocal cords.
    d. The trachea enters the lungs.
    e. The lungs contain many alveoli.

13. How is inhaled air modified before it reaches the lungs?
    a. It must be humidified.
    b. It must be warmed.
    c. It must be filtered and cleansed.
    d. All of these are correct.
14. Internal respiration refers to
    a. the exchange of gases between the air and the blood in the lungs.
    b. the movement of air into the lungs.
    c. the exchange of gases between the blood and tissue fluid.
    d. cellular respiration, resulting in the production of ATP.
15. The chemical reaction that converts carbon dioxide to a bicarbonate ion takes place in
    a. the blood plasma.
    b. red blood cells.
    c. the alveolus.
    d. the hemoglobin molecule.
16. Which of these would affect hemoglobin's O_2-binding capacity?
    a. pH
    b. partial pressure of oxygen
    c. blood pressure
    d. temperature
    e. All of these except c are correct.
17. The enzyme carbonic anhydrase
    a. causes the blood to be more basic in the tissues.
    b. speeds the conversion of carbonic acid to carbon dioxide and water.
    c. actively transports carbon dioxide out of capillaries.
    d. is active only at high altitudes.
    e. All of these are correct.
18. Which of these is incorrect concerning inspiration?
    a. Rib cage moves up and out.
    b. Diaphragm contracts and moves down.
    c. Pressure in lungs decreases, and air comes rushing in.
    d. The lungs expand because air comes rushing in.
19. Label this diagram of the human respiratory system.



thinking scientifically

1. You are a physician who witnessed Christopher Reeve's riding accident. Why might you immediately use mouth to mouth resuscitation until mechanical ventilation becomes available?
2. Fetal hemoglobin picks up oxygen from the maternal blood. If the oxygen-binding characteristics of hemoglobin in the fetus were identical to the hemoglobin of the mother, oxygen could never be transferred at the placenta to fetal circulation. What hypothesis about the oxygen-binding characteristics of fetal hemoglobin would explain how fetuses get the oxygen they need?

bioethical issue

Antibiotic Therapy

Antibiotics cure respiratory infections, but there are problems associated with antibiotic therapy. Aside from a possible allergic reaction, antibiotics not only kill off disease-causing bacteria, but they also reduce the number of beneficial bacteria in the intestinal tract and other locations. These beneficial bacteria hold in check the growth of other pathogens that now begin to flourish. Diarrhea can result, as can a vaginal yeast infection. The use of antibiotics can also prevent natural immunity from occurring, leading to the need for recurring antibiotic therapy. Especially alarming at this time is the occurrence of resistance. Resistance takes place when vulnerable bacteria are killed off by an antibiotic, and this allows resistant bacteria to become prevalent. The bacteria that cause ear, nose, and throat infections as well as scarlet fever and pneumonia are becoming widely resistant because we have not been using antibiotics properly. Tuberculosis is on the rise, and the new strains are resistant to the usual combined antibiotic therapy.

Every citizen needs to be aware of our present crisis situation. Stuart Levy, a Tufts University School of Medicine microbiologist, says that we should do what is ethical for society and ourselves. What is needed? Antibiotics kill bacteria, not viruses—therefore, we shouldn't take antibiotics unless we know for sure we have a bacterial infection. And we shouldn't take them prophylactically—that is, just in case we might need one. If antibiotics are taken in low dosages and intermittently, resistant strains are bound to take over. Animal and agricultural use should be pared down, and household disinfectants should no longer be spiked with antibacterial agents. Perhaps then, Levy says, vulnerable bacteria will begin to supplant the resistant ones in the population. Are you doing all you can to prevent bacteria from becoming resistant?

Biology website

The companion website for *Biology* provides a wealth of information organized and integrated by chapter. You will find practice tests, animations, videos, and much more that will complement your learning and understanding of general biology.

http://www.mhhe.com/maderbiology10

THINKING SCIENTIFICALLY

Critical thinking questions give you an opportunity to reason as a scientist. Detailed answers to these questions are found on ARIS, the Biology, Tenth Edition website. Answers to these questions are found in Appendix A.

BIOETHICAL ISSUE

A Bioethical Issue is found at the end of most chapters. These short readings discuss a variety of controversial topics that confront our society. Each reading ends with appropriate questions to help you fully consider the issue and arrive at an opinion.

WEBSITE REMINDER

Located at the end of the chapter is this reminder that additional study questions and other learning activities are on the *Biology,* Tenth Edition website.

ACKNOWLEDGMENTS

The hard work of many dedicated and talented individuals helped to vastly improve this edition of *Biology*. Let me begin by thanking the people who guided this revision at McGraw-Hill. I am very grateful for the help of so many professionals who were involved in bringing this book to fruition. In particular, let me thank Janice Roerig-Blong, who guided us as we shaped the content and pedagogy of the book. Lisa Bruflodt, the developmental editor, who kept everyone on target as the book was developed. The biology editor was Michael Hackett, who became a member of the team this past year. The project manager, Jayne Klein, faithfully and carefully steered the book through the publication process. Tamara Maury, the marketing manager, tirelessly promoted the text and educated the sales reps on its message.

The design of the book is the result of the creative talents of David Hash and many others who assisted in deciding the appearance of each element in the text. EPS followed their guidelines as they created and reworked each illustration, emphasizing pedagogy and beauty to arrive at the best presentation on the page. Lori Hancock and Jo Johnson did a superb job of finding just the right photographs and micrographs.

My assistant, Beth Butler, worked faithfully to do a preliminary paging of the book, helped proof the chapters, and made sure all was well before the book went to press. As always, my family was extremely patient with me as I remained determined to make every deadline on the road to publication. My husband, Arthur Cohen, is also a teacher of biology. The many discussions we have about the minutest detail to the gravest concept are invaluable to me.

As stated previously, the content of the tenth edition of *Biology* is not due to my efforts alone. I want to thank the many specialists who were willing to share their knowledge to improve *Biology*. Also, this edition was enriched by four contributors: Michael Thompson revised the genetics chapters, Stephanie Songer reworked the microbiology chapters and several animal biology chapters, Rebecca Roush contributed to the animal diversity chapters, and Andy Baldwin oversaw the ecology chapters. The tenth edition of *Biology* would not have the same excellent quality without the input of these contributors and those of the many reviewers who are listed on page xvii.

360 Development

McGraw-Hill's 360° Development Process is an ongoing, never-ending, market-oriented approach to building accurate and innovative print and digital products. It is dedicated to continual large-scale and incremental improvement driven by multiple customer feedback loops and checkpoints. This is initiated during the early planning stages of our new products, and intensifies during the development and production stages, then begins again upon publication in anticipation of the next edition.

This process is designed to provide a broad, comprehensive spectrum of feedback for refinement and innovation of our learning tools, for both student and instructor. The 360° Development Process includes market research, content reviews, course- and product-specific symposia, accuracy checks, and art reviews. We appreciate the expertise of the many individuals involved in this process.

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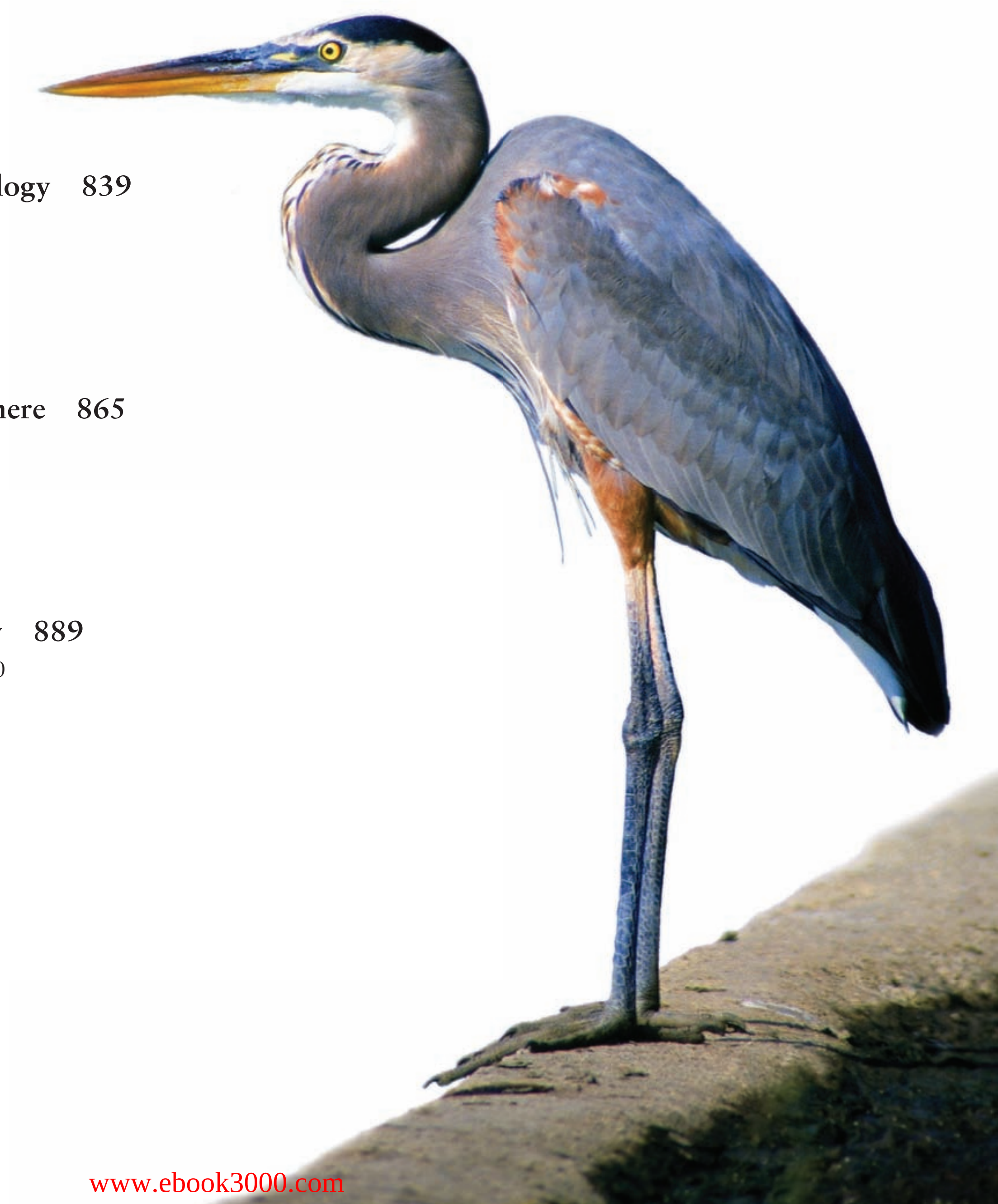

READINGS

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Science Focus

1

A View of Life

At a height of nearly 3 m (10 ft), the titan arum slowly unfurls its enormous flower, which heats up, turns red, and emits an overpowering stench reminiscent of rotting meat. Its home is the forests of Sumatra, and the smell attracts the beetles and flies that ordinarily pollinate the flower. Now the plant is cultivated in botanical gardens around the world to the delight of curious onlookers.

The Earth hosts a wide variety of ecosystems, from which spring a mind-boggling diversity of life, including the titan arum. Even so, all Earth's organisms, regardless of form, are united by a number of common characteristics, such as the need to acquire nutrients, the ability to respond to a changing environment, and to reproduce their own kind. Incredibly, even organisms as diverse as the titan arum and a human being share similar characteristics, including a common chemistry and genetic code. As you read this chapter, reflect on the staggering diversity of life on Earth and on the many ties that bind even the most diverse organisms, from bacteria to the titan arum to humans. It is through these ties that our fates are linked together in the web of life.

The titan arum (*Amorphophallus titanum*).

concepts

1.1 How to Define Life

Life on Earth takes on a staggering variety of forms, often functioning and behaving in ways strange to humans. For example, gastric-brooding frogs swallow their embryos and give birth to them later by throwing them up! Some species of puffballs, a type of fungus, are capable of producing trillions of spores when they reproduce. Fetal sand sharks kill and eat their siblings while still inside their mother. Some *Ophrys* orchids look so much like female bees that male bees try to mate with them. Octopuses and squid have remarkable problem-solving abilities despite a small brain. Some bacteria live their entire life in 15 minutes, while bristlecone pine trees outlive ten generations of humans. Simply put, from the deepest oceanic trenches to the upper reaches of the atmosphere, life is plentiful and diverse.

Figure 1.1 illustrates the major groups of living things, also called **organisms.** From left to right, bacteria are widely distributed, tiny, microscopic organisms with a very simple structure. A *Paramecium* is an example of a microscopic protist. Protists are larger in size and more complex than bacteria. The other organisms in Figure 1.1 are easily seen with the naked eye. They can be distinguished by how they get their food. A morel is a fungus that digests its food externally. A sunflower is a photosynthetic plant that makes its own food, and a snow goose is an animal that ingests its food.

Because life is so diverse, it seems reasonable that it cannot be defined in a straightforward manner. Instead, life is best defined by several basic characteristics shared by all organisms. Like nonliving things, organisms are composed of chemical elements. Also, organisms obey the same laws of chemistry and physics that govern everything within the universe. The characteristics of life, however, will provide great insight into the unique nature of organisms and will help us distinguish living things from nonliving things.

Living Things Are Organized

The levels of organization depicted in Figure 1.2 begin with atoms, which are the basic units of matter. Atoms combine with other atoms of the same or different elements to form molecules. The **cell,** which is composed of a variety of molecules working together, is the basic unit of structure and function of all living things. Some cells, such as **unicellular** paramecia, live independently. Other cells, for example, the colonial alga *Volvox,* cluster together in microscopic colonies.

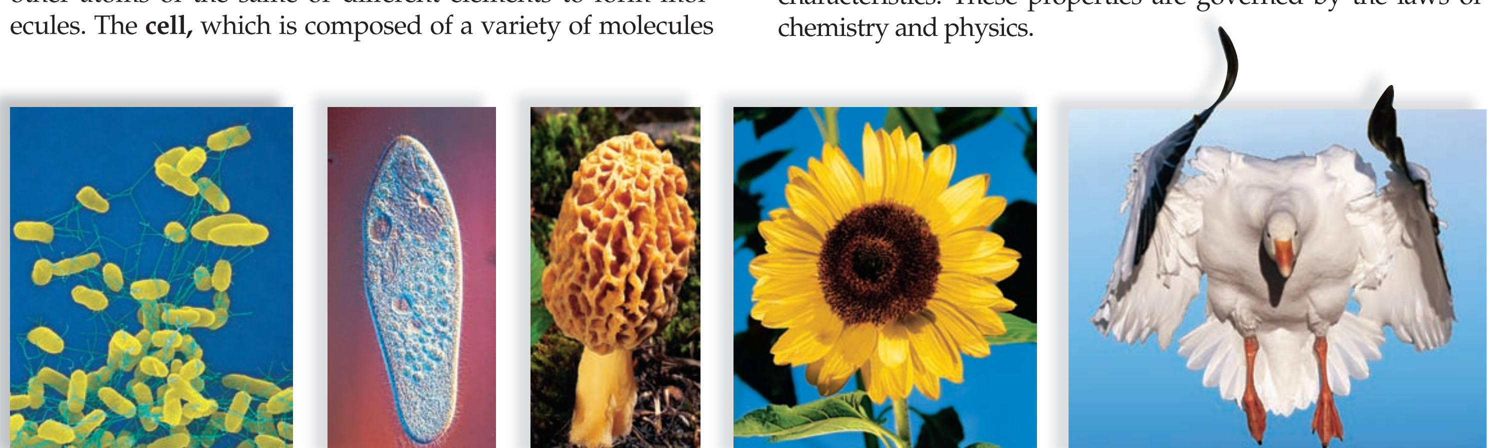
Many living things are **multicellular,** meaning they contain more than one cell. In multicellular organisms, similar cells combine to form a tissue; nerve tissue is a common tissue in animals. Tissues make up organs, as when various tissues combine to form the brain. Organs work together in systems; for example, the brain works with the spinal cord and a network of nerves to form the nervous system. Organ systems are joined together to form a complete living thing, or organism, such as an elephant.

The levels of biological organization extend beyond the individual organism. All the members of one species in a particular area belong to a population. A nearby forest may have a population of gray squirrels and a population of white oaks, for example. The populations of various animals and plants in the forest make up a community. The community of populations interacts with the physical environment and forms an ecosystem. Finally, all the Earth's ecosystems make up the biosphere.

Emergent Properties

Each level of biological organization builds upon the previous level, and is more complex. Moving up the hierarchy, each level acquires new **emergent properties** that are determined by the interactions between the individual parts. When cells are broken down into bits of membrane and liquids, these parts themselves cannot carry out the business of living. For example, you can take apart a lump of coal, rearrange the pieces in any order, and still have a lump of coal with the same function as the original one. But, if you slice apart a living plant and rearrange the pieces, the plant is no longer functional as a complete plant, because it depends on the exact order of those pieces.

In the living world, the whole is indeed more than the sum of its parts. The emergent properties created by the interactions between levels of biological organization are new, unique characteristics. These properties are governed by the laws of chemistry and physics.



Bacteria *Paramecium* Morel Sunflower Snow goose

FIGURE 1.1 Diversity of life.

Biology is the scientific study of life. Many diverse forms of life are found on planet Earth.

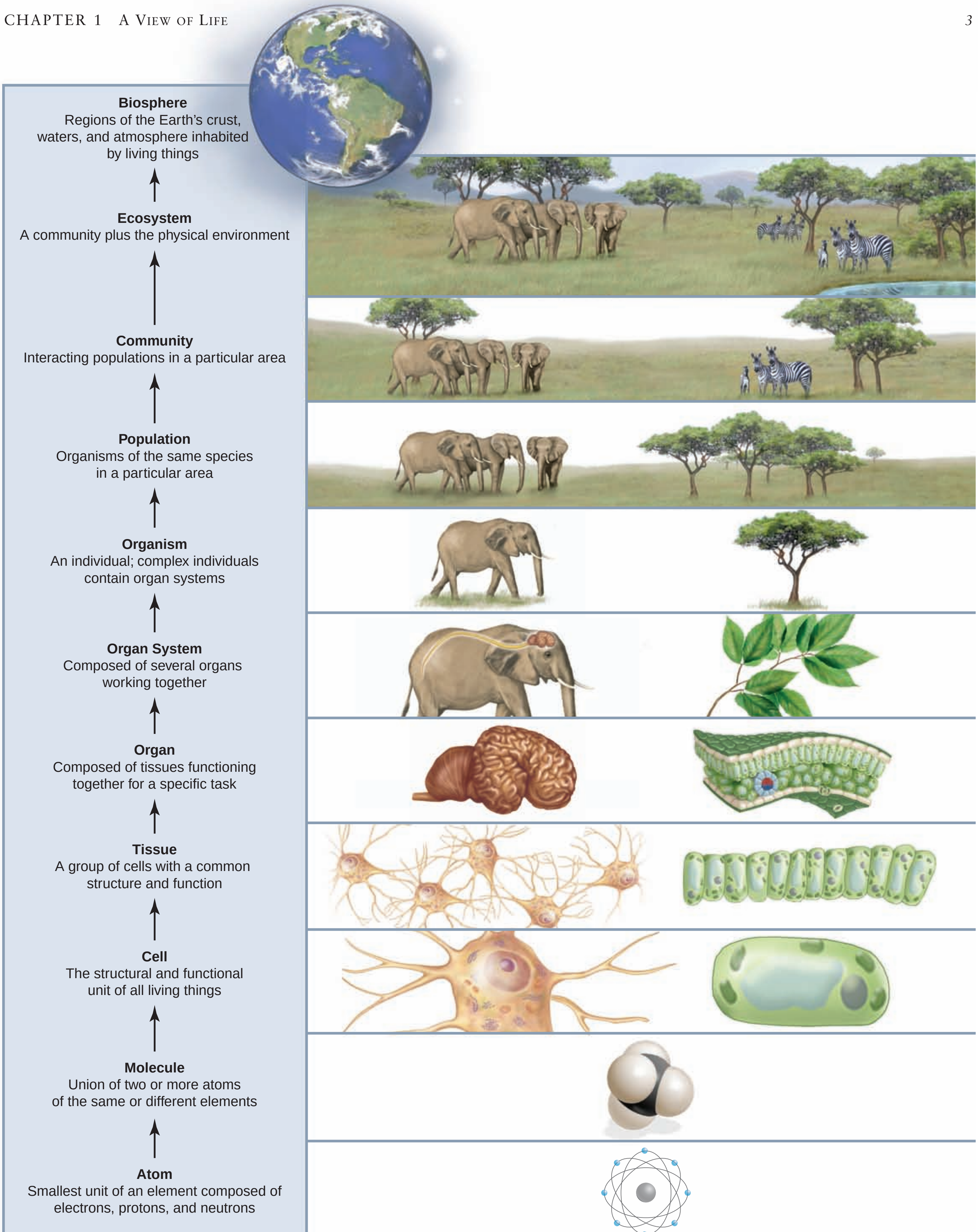


FIGURE 1.2 **Levels of biological organization.**

Living Things Acquire Materials and Energy

Living things cannot maintain their organization or carry on life's activities without an outside source of nutrients and energy (Fig. 1.3). Food provides nutrients, which are used as building blocks or for energy. **Energy** is the capacity to do work, and it takes work to maintain the organization of the cell and the organism. When cells use nutrient molecules to make their parts and products, they carry out a sequence of chemical reactions. The term **metabolism** [Gk. *meta*, change] encompasses all the chemical reactions that occur in a cell.

The ultimate source of energy for nearly all life on Earth is the sun. Plants and certain other organisms are able to capture solar energy and carry on **photosynthesis,** a process that transforms solar energy into the chemical energy of organic nutrient molecules. All life on Earth acquires energy by metabolizing nutrient molecules made by photosynthesizers. This applies even to plants.

Remaining Homeostatic

To survive, it is imperative that an organism maintain a state of biological balance or **homeostasis** [Gk. *homoios*, like, and *stasis*, the same]. For life to continue, temperature, moisture level, acidity, and other physiological factors must remain within the tolerance range of the organism. Homeostasis is maintained by systems that monitor internal conditions and make routine and necessary adjustments.

Organisms have intricate feedback and control mechanisms that do not require any conscious activity. These mechanisms may be controlled by one or more tissues themselves, or by the nervous system. When a student is so engrossed in her textbook that she forgets to eat lunch, her liver releases stored sugar to keep blood sugar levels within normal limits. Many organisms depend on behavior to regulate their internal environment. These behaviors are controlled by the nervous system, and are usually not consciously controlled. The same student may realize that she is hungry and decide to visit the local diner. A lizard may raise its internal temperature by basking in the sun or cool down by moving into the shade.

Living Things Respond

Living things interact with the environment as well as with other living things. Even unicellular organisms can respond to their environment. In some, the beating of microscopic hairs or, in others, the snapping of whiplike tails moves them toward or away from light or chemicals. Multicellular organisms can manage more complex responses. A vulture can detect a carcass a kilometer away and soar toward dinner. A

FIGURE 1.3 Acquiring nutrients and energy.

a. An eagle ingesting fish. **b.** A human eating an apple. **c.** A cypress tree capturing sunlight. **d.** An amoeba engulfing food. **e.** A fungus feeding on a tree. **f.** A bison eating grass.

monarch butterfly can sense the approach of fall and begin its flight south where resources are still abundant.

The ability to respond often results in movement: the leaves of a land plant turn toward the sun, and animals dart toward safety. Appropriate responses help ensure survival of the organism and allow it to carry on its daily activities. All together, these activities are termed the behavior of the organism. Organisms display a variety of behaviors as they maintain homeostasis and search and compete for energy, nutrients, shelter, and mates. Many organisms display complex communication, hunting, and defense behaviors.

Living Things Reproduce and Develop

Life comes only from life. Every type of living thing can **reproduce,** or make another organism like itself (Fig. 1.4). Bacteria, protists, and other unicellular organisms simply split in two. In most multicellular organisms, the reproductive process begins with the pairing of a sperm from one partner and an egg from the other partner. The union of sperm and egg, followed by many cell divisions, results in an immature stage, which grows and develops through various stages to become the adult.

An embryo develops into a humpback whale or a purple iris because of a blueprint inherited from its parents. The instructions, or blueprint, for an organism's metabolism and organization are encoded in genes. The **genes,** which contain specific information for how the organism is to be ordered, are made of long molecules of DNA (deoxyribonucleic acid). DNA has a shape resembling a spiral staircase with millions of steps. Housed within this spiral staircase is the genetic code that is shared by all living things.

When living things reproduce, their genes are passed on to the next generation. Random combinations of sperm and egg, each of which contains a unique collection of genes, ensure that the new individual has new and different characteristics. The DNA of organisms, over time, also undergoes mutations (changes) that may be passed on to the next generation. These events help to create a staggering diversity of life, even within a group of otherwise identical organisms. Sometimes, organisms inherit characteristics that allow them to be more suited to their way of life.

Living Things Have Adaptations

Adaptations [L. *ad*, toward, and *aptus*, suitable] are modifications that make organisms better able to function in a particular environment. For example, penguins are adapted to an aquatic existence in the Antarctic. An extra layer of downy feathers is covered by short, thick feathers that form a waterproof coat. Layers of blubber also keep the birds warm in cold water. Most birds have forelimbs proportioned for flying, but penguins have stubby, flattened wings suitable for swimming. Their feet and tails serve as rudders in the water, but the flat feet also allow them to walk on land. Rockhopper penguins have a bill adapted to eating small shellfish.

FIGURE 1.4 Rockhopper penguins with their offspring.

Rockhopper penguins, which are named for their skill in leaping from rock to rock, produce one or two offspring at a time. Both male and female have a brood patch, a feather-free area of skin containing many blood vessels, which keeps the egg(s) warm when either parent sits on the nest.

Penguins also have many behavioral adaptations to living in the Antarctic. Penguins often slide on their bellies across the snow in order to conserve energy when moving quickly. Their eggs—one or at most two—are carried on the feet, where they are protected by a pouch of skin. This also allows the birds to huddle together for warmth while standing erect and incubating eggs.

From penguins to fire ants, life on Earth is very diverse because over long periods of time, organisms respond to ever-changing environments by developing new adaptations. **Evolution** [L. *evolutio*, an unrolling] includes the way in which populations of organisms change over the course of many generations to become more suited to their environments. Evolution constantly reshapes the species, providing a way for organisms to persist, despite a changing environment.

Check Your Progress 1.1

1. What are common characteristics of living organisms?
2. In what ways do viruses (p. 356) not specifically meet all of the above characteristics?
3. What adaptations would suit an organism, such as a cactus, to life in a desert?

1.2 Evolution, the Unifying Concept of Biology

Despite diversity in form, function, and lifestyle, organisms share the same basic characteristics. As mentioned, they are all composed of cells organized in a similar manner. Their genes are composed of DNA, and they carry out the same metabolic reactions to acquire energy and maintain their organization. The unity of living things suggests that they are descended from a common ancestor—the first cell or cells.

An evolutionary tree is like a family tree (Fig. 1.5). Just as a family tree shows how a group of people have descended from one couple, an evolutionary tree traces the ancestry of life on Earth to a common ancestor. One couple can have diverse children, and likewise a population can be a common ancestor to several other groups, each adapted to a particular set of environmental conditions. In this way, over time, diverse life-forms have arisen. Evolution may be considered the unifying concept of biology because it explains so many aspects of biology, including how living organisms arose from a single ancestor.

Organizing Diversity

Because life is so diverse, it is helpful to group organisms into categories. **Taxonomy** [Gk. *tasso*, arrange, and *nomos*, usage] is the discipline of identifying and grouping organisms according to certain rules. Taxonomy makes sense out of the bewildering variety of life on Earth and is meant to provide valuable insight into evolution. As more is learned about living things, including the evolutionary relationships between species, taxonomy changes. DNA technology is now being used to revise current information and to discover previously unknown relationships between organisms.

Several of the basic classification categories, or *taxa*, going from least inclusive to most inclusive, are **species, genus, family, order, class, phylum, kingdom,** and **domain** (Table 1.1). The least inclusive category, species [L. *species*, model, kind], is defined as a group of interbreeding individuals. Each successive classification category above species contains more types of organisms than the preceding one. Species placed within one genus share many specific characteristics and are the most closely related, while species placed in the same kingdom share only general characteristics with one another. For example, all species in the genus *Pisum* look pretty much the same—that is, like pea plants—but species in the plant kingdom can be quite varied, as is evident when we compare grasses to trees. Species placed in different domains are the most distantly related.

TABLE 1.1

Levels of Classification

Category	*Human*	*Corn*
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Anthophyta
Class	Mammalia	Monocotyledones
Order	Primates	Commelinales
Family	Hominidae	Poaceae
Genus	*Homo*	*Zea*
Species*	*H. sapiens*	*Z. mays*

*To specify an organism, you must use the full binomial name, such as *Homo sapiens*.

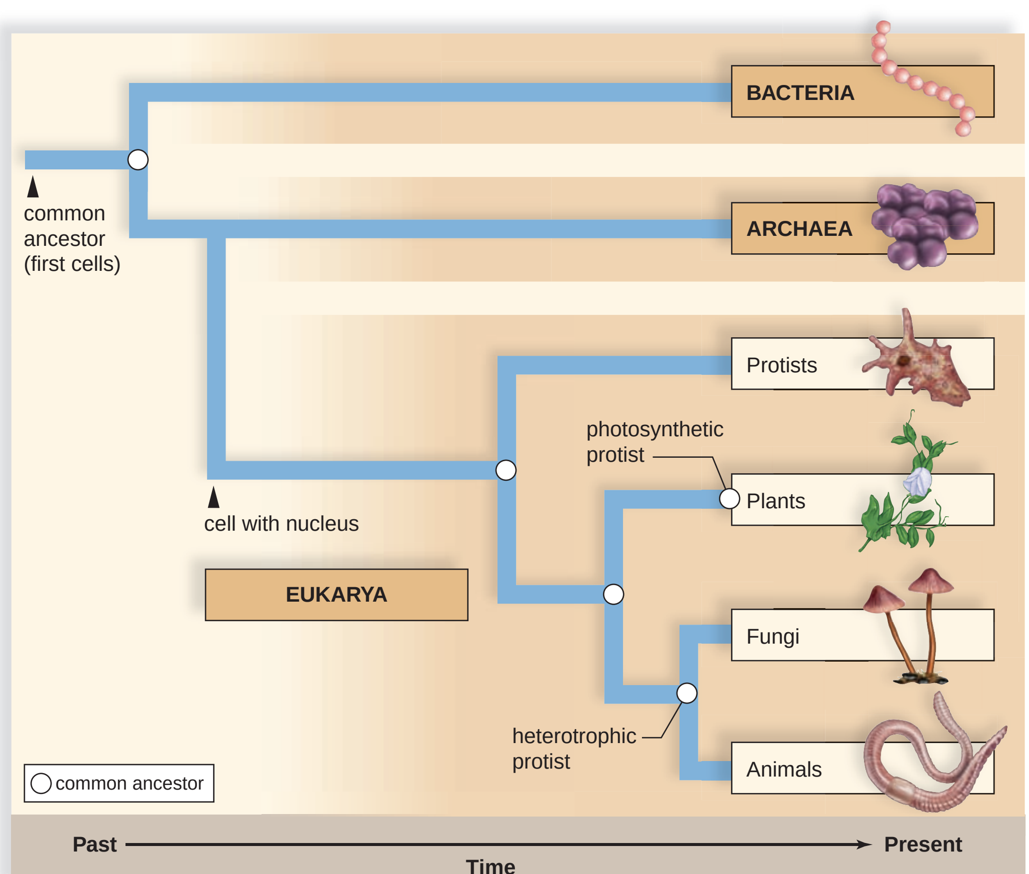


FIGURE 1.5 Evolutionary tree of life.

As existing organisms change over time, they give rise to new species. Evolutionary studies show that all living organisms arose from a common ancestor about 4 billion years ago. Domain Archaea includes prokaryotes capable of surviving in extreme environments, such as those with high salinity and temperature and low pH. Domain Bacteria includes metabolically diverse prokaryotes widely distributed in various environments. The domain Eukarya includes both unicellular and multicellular organisms that possess a membrane-bounded nucleus.

Domains

Biochemical evidence suggests that there are only three domains: **domain Bacteria, domain Archaea,** and **domain Eukarya.** Figure 1.5 shows how the domains are believed to be related. Both domain Bacteria and domain Archaea may have evolved from the first common ancestor soon after life began. These two domains contain the **prokaryotes,** which lack the membrane-bounded nucleus found in the **eukaryotes** of domain Eukarya. However, archaea organize their DNA differently than bacteria, and their cell walls and membranes are chemically more similar to eukaryotes than to bacteria. So, the conclusion is that eukarya split off from the archaeal line of descent.

Prokaryotes are structurally simple but metabolically complex. Archaea (Fig. 1.6) can live in aquatic environments that lack oxygen or are too salty, too hot, or too acidic for most other organisms. Perhaps these environments are similar to those of the primitive Earth, and archaea (Gk. *archae*, ancient) are the least evolved forms of life, as their name implies. Bacteria (Fig. 1.7) are variously adapted to living almost anywhere—in the water, soil, and atmosphere, as well as on our skin and in our mouths and large intestines.

Taxonomists are in the process of deciding how to categorize archaea and bacteria into kingdoms. Domain Eukarya, on the other hand, contains four major groups of organisms (Fig. 1.8). **Protists,** which now comprise a number of kingdoms, range from unicellular forms to a few multicellular ones. Some are photosynthesizers, and some must acquire their food. Common protists include algae, the protozoans, and the water molds. Figure 1.5 shows that plants, fungi, and animals most likely evolved from protists. **Plants** (kingdom Plantae) are multicellular photosynthetic organisms. Example plants include azaleas, zinnias, and pines. Among the **fungi**

- Prokaryotic cells of various shapes
- Adaptations to extreme environments
- Absorb or chemosynthesize food
- Unique chemical characteristics

Methanosarcina mazei, an archaeon 1.6 µm

FIGURE 1.6 Domain Archaea.

- Prokaryotic cells of various shapes
- Adaptations to all environments
- Absorb, photosynthesize, or chemosynthesize food
- Unique chemical characteristics

Escherichia coli, a bacterium 1.5 µm

FIGURE 1.7 Domain Bacteria.

Protists

- Algae, protozoans, slime molds, and water molds
- Complex single cell (sometimes filaments, colonies, or even multicellular)
- Absorb, photosynthesize, or ingest food

Paramecium, a unicellular protozoan

KINGDOM: Fungi

- Molds, mushrooms, yeasts, and ringworms
- Mostly multicellular filaments with specialized, complex cells
- Absorb food

Coprinus, a shaggy mane mushroom

KINGDOM: Plants

- Certain algae, mosses, ferns, conifers, and flowering plants
- Multicellular, usually with specialized tissues, containing complex cells
- Photosynthesize food

Passiflora, passion flower, a flowering plant

KINGDOM: Animals

- Sponges, worms, insects, fishes, frogs, turtles, birds, and mammals
- Multicellular with specialized tissues containing complex cells
- Ingest food

Vulpes, a red fox

FIGURE 1.8 Domain Eukarya.

(kingdom Fungi) are the familiar molds and mushrooms that, along with bacteria, help decompose dead organisms. **Animals** (kingdom Animalia) are multicellular organisms that must ingest and process their food. Aardvarks, jellyfish, and zebras are representative animals.

Scientific Name

Biologists use **binomial nomenclature** [L. *bi*, two, and *nomen*, name] to assign each living thing a two-part name called a scientific name. For example, the scientific name for mistletoe is *Phoradendron tomentosum*. The first word is the genus, and the second word is the specific epithet of a species within a genus. The genus may be abbreviated (e.g., *P. tomentosum*) and the species may simply be indicated if it is unknown (e.g., *Phoradendron* sp.). Scientific names are universally used by biologists to avoid confusion. Common names tend to overlap and often are in the language of a particular country. But scientific names are based on Latin, a universal language that not too long ago was well known by most scholars.

Evolution Is Common Descent with Modification

The phrase "common descent with modification" sums up the process of evolution because it means that, as descent occurs from common ancestors, so do modifications that cause organisms to be adapted to the environment. Through many observations and experiments, Charles Darwin came to the conclusion that **natural selection** was the process that made modification—that is, adaptation—possible.

Natural Selection

During the process of natural selection, some aspect of the environment selects which traits are more apt to be passed on to the next generation. The selective agent can be an abiotic agent (part of the physical environment, such as altitude) or it can be a biotic agent (part of the living environment, such as a deer). Figure 1.9 shows how the dietary habits of deer might eventually affect the characteristics of the leaves of a particular land plant.

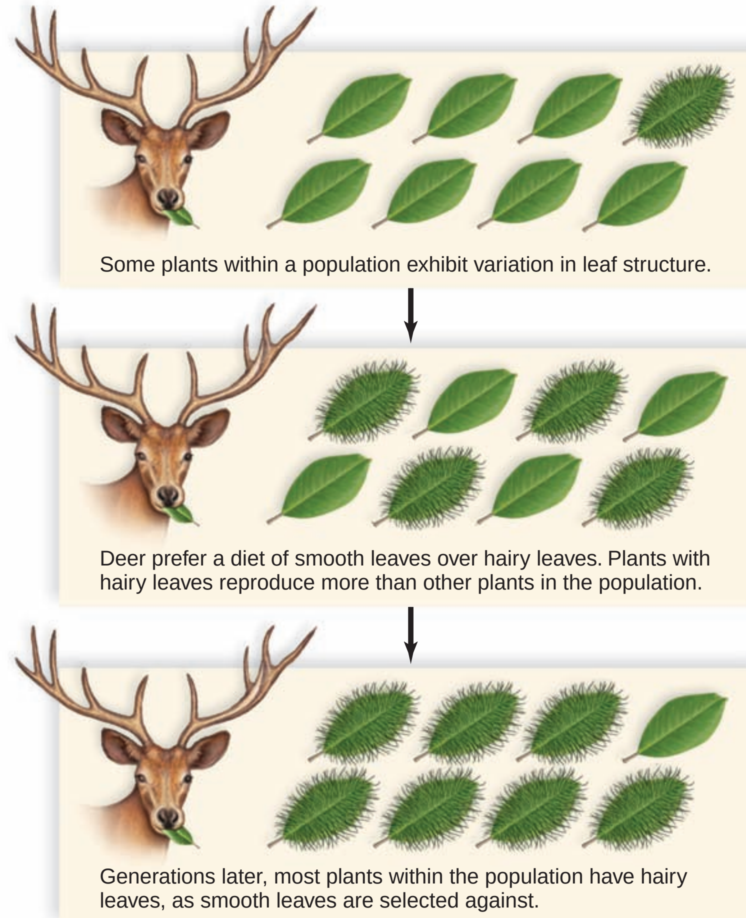


FIGURE 1.9 **Natural selection.**

Natural selection selects for or against new traits introduced into a population by mutations. Over many generations, selective forces such as competition, predation, and the physical environment alter the makeup of a population to more suit its environment and lifestyle.

Mutations fuel natural selection because mutation introduces variations among the members of a population. In Figure 1.9, a plant species generally produces smooth leaves, but a mutation occurs that causes one plant to have leaves that are covered with small extensions or "hairs." The plant with hairy leaves has an advantage because the deer (the selective agent) prefer to eat smooth leaves and not hairy leaves. Therefore, the plant with hairy leaves survives best and produces more seeds than most of its neighbors. As a result, generations later most plants of this species produce hairy leaves.

As with this example, Darwin realized that although all individuals within a population have the ability to reproduce, not all do so with the same success. Prevention of reproduction can run the gamut from an inability to capture resources, as when long-neck, but not short-neck, giraffes can reach their food source, to an inability to escape being eaten because long legs but not short legs can carry an animal to safety. Whatever the example, it can be seen that living things with advantageous traits can produce more offspring than those that lack them. In this way, living things change over time, and these changes are passed on from one generation to the next. Over long periods of time, the introduction of newer, more advantageous traits into a population may drastically reshape a species. Natural selection tends to sculpt a species to fit its environment and lifestyle and can create new species from existing ones. The end result is the diversity of life classified into the three domains of life (see Fig. 1.5).

Check Your Progress 1.2

1. List the levels of taxonomic classification from most inclusive to least inclusive.
2. What differences might be used to distinguish the various kingdoms of domain Eukarya?
3. Explain how natural selection results in new adaptations within a species.

1.3 How the Biosphere Is Organized

The organization of life extends beyond the individual organism to the **biosphere,** the zone of air, land, and water at the surface of the Earth where organisms exist (see Fig. 1.2). Individual organisms belong to a **population,** which is all the members of a species within a particular area. The populations of a **community** interact among themselves and with the physical environment (e.g., soil, atmosphere, and chemicals), thereby forming an **ecosystem.**

Figure 1.10 depicts a grassland inhabited by populations of rabbits, mice, snakes, hawks, and various types of land plants. These populations exchange gases with and give off heat to the atmosphere. They also take in water from and give off water to the physical environment. In addition, populations interact by forming food chains in which one population feeds on another. Mice feed on plants and seeds, snakes feed on mice, and hawks feed on rabbits and snakes, for example. Interactions between the various food chains make up a food web.

Ecosystems are characterized by chemical cycling and energy flow, both of which begin when photosynthetic plants, aquatic algae, and some bacteria take in solar energy and inorganic nutrients to produce food in the form of organic nutrients. The gray arrows in Figure 1.10 represent chemical cycling—chemicals move from one population to another in a food chain, until with death and decomposition, inorganic nutrients are returned to living plants once again. The yellow to red arrows represent energy flow. Energy flows from the sun through plants and other members of the food chain as one population feeds on another. With each transfer some energy is lost as heat. Eventually, all the energy taken in by photosynthesizers has dissipated into the atmosphere. Because energy flows and does not cycle, ecosystems could not stay in existence without a constant input of solar energy and the ability of photosynthesizers to absorb it.

The Human Population

Humans possess the unique ability to modify existing ecosystems, which can greatly upset their natural nutrient cycles. When an ecosystem's natural energy flow has been disrupted by eliminating food sources for other animal populations even the human population can eventually suffer harm. Humans clear forests or grasslands to grow crops; later, they build houses on what was once farmland; and finally, they convert small towns into cities. Coastal ecosystems are most vulnerable. As they are developed, humans send sediments, sewage, and other pollutants into the sea. Human activities destroy valuable coastal wetlands, which serve as protection against storms and as nurseries for a myriad of invertebrates and vertebrates.

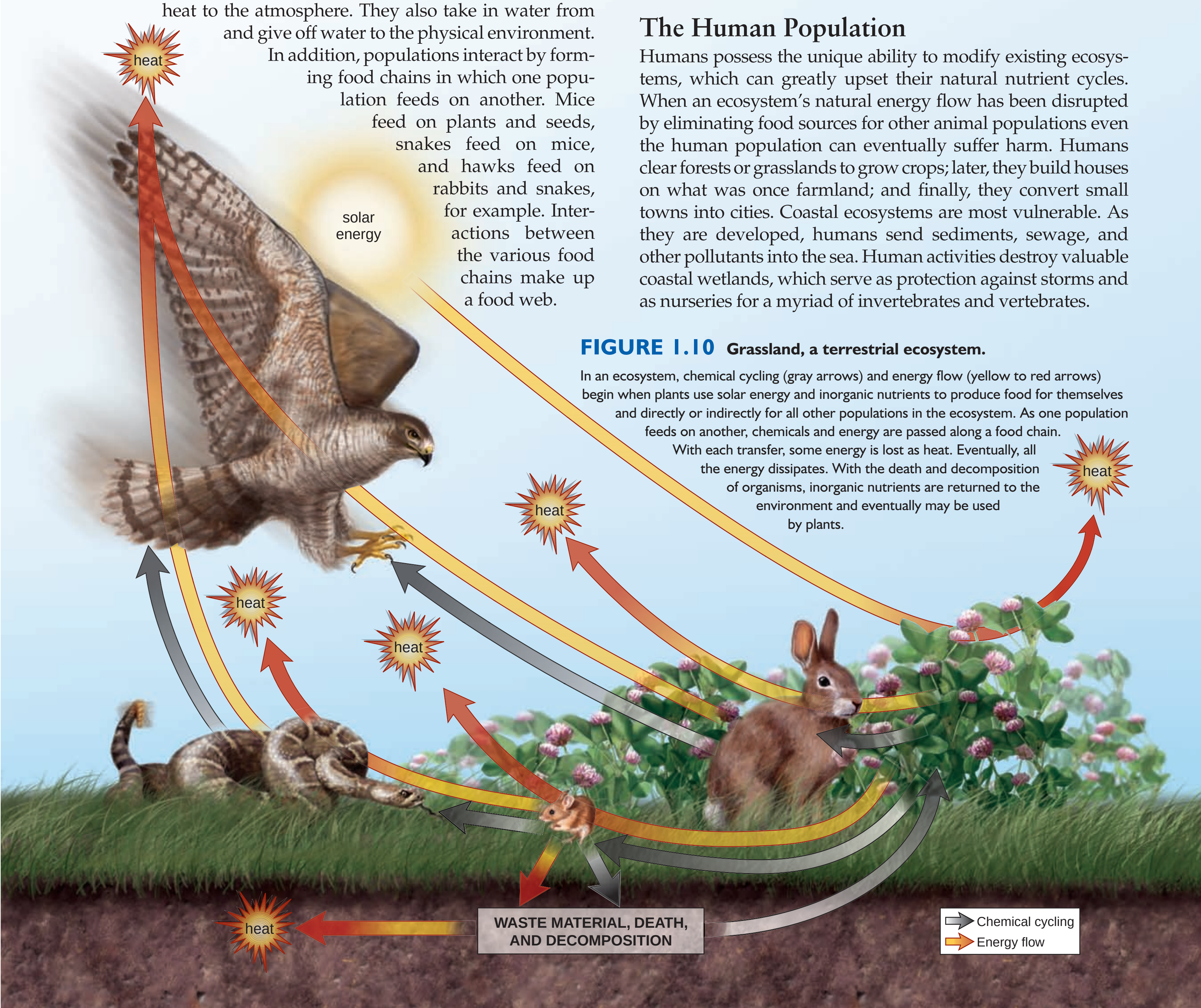


FIGURE 1.10 Grassland, a terrestrial ecosystem.

In an ecosystem, chemical cycling (gray arrows) and energy flow (yellow to red arrows) begin when plants use solar energy and inorganic nutrients to produce food for themselves and directly or indirectly for all other populations in the ecosystem. As one population feeds on another, chemicals and energy are passed along a food chain. With each transfer, some energy is lost as heat. Eventually, all the energy dissipates. With the death and decomposition of organisms, inorganic nutrients are returned to the environment and eventually may be used by plants.

Biodiversity

The two most biologically diverse ecosystems—tropical rain forests and coral reefs—are home to many organisms. These ecosystems are also threatened by human activities. The canopy of the tropical rain forest alone supports a variety of organisms including orchids, insects, and monkeys. Coral reefs, which are found just offshore of the continents and islands of the Southern Hemisphere, are built up from calcium carbonate skeletons of sea animals called corals. Reefs provide a habitat for many animals, including jellyfish, sponges, snails, crabs, lobsters, sea turtles, moray eels, and some of the world's most colorful fishes (Fig. 1.11*a*). Like tropical rain forests, coral reefs are severely threatened as the human population increases in size. Some reefs are 50 million years old, and yet in just a few decades, human activities have destroyed 10% of all coral reefs and seriously degraded another 30% (Fig. 1.11*b*). At this rate, nearly three-quarters could be destroyed within 50 years. Similar statistics are available for tropical rain forests.

Destruction of healthy ecosystems has many unintended effects. For example, we depend on them for food, medicines, and various raw materials. Draining the natural wetlands of the Mississippi and Ohio rivers and the construction of levees has worsened flooding problems, making once fertile farmland undesirable. The destruction of South American rain forests has killed many species that may have yielded the next miracle drug and has also decreased the availability of many types of lumber.

We are only now beginning to realize that we depend on ecosystems even more for the services they provide. Just as chemical cycling occurs within a single ecosystem, so all ecosystems keep chemicals cycling throughout the entire biosphere. The workings of ecosystems ensure that the environmental conditions of the biosphere are suitable for the continued existence of humans. And several studies show that ecosystems cannot function properly unless they remain biologically diverse.

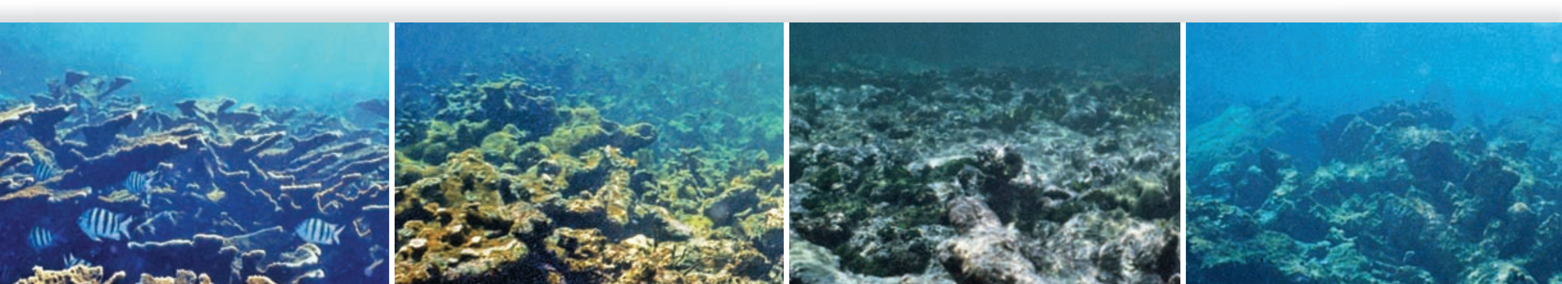
Biodiversity is the total number and relative abundance of species, the variability of their genes, and the different ecosystems in which they live. The present biodiversity of our planet has been estimated to be as high as 15 million species, and so far, less than 2 million have been identified and named. **Extinction** is the death of a species or larger classification category. It is estimated that presently we are losing as many as 400 species per day due to human activities. For example, several species of fishes have all but disappeared from the coral reefs of Indonesia and along the African coast because of overfishing. Many biologists are alarmed about the present rate of extinction and hypothesize it may eventually rival the rates of the five mass extinctions that have occurred during our planet's history. The last mass extinction, about 65 million years ago, caused many plant and animal species, including the dinosaurs, to become extinct.

It would seem that the primary bioethical issue of our time is preservation of ecosystems. Just as a native fisherman who assists in overfishing a reef is doing away with his own food source, so are we as a society contributing to the destruction of our home, the biosphere. If instead we adopt a conservation ethic that preserves the biosphere, we would help ensure the continued existence of our own species.

Check Your Progress 1.3

1. How do various communities interact to form an ecosystem?
2. What are some unintentional ways in which human activities affect ecosystems?
3. Why might ecosystems with high biodiversity be more vulnerable to destruction by human activities?

a. Healthy coral reef



1975 Minimal coral death

1985 Some coral death with no fish present

1995 Coral bleaching with limited chance of recovery

2004 Coral is black from sedimentation; bleaching still evident

b.

FIGURE 1.11 Coral reef, a marine ecosystem.

a. Coral reefs, a type of ecosystem found in tropical seas, contain many diverse forms of life, a few of which are shown here. **b.** Various human activities have caused catastrophic damage to this coral reef off the coast of Florida, as shown over the course of 19 years. Preserving biodiversity is a modern-day challenge of great proportions.

1.4 The Process of Science

The process of science pertains to **biology,** the scientific study of life. Biology consists of many disciplines and areas of specialty because life has numerous aspects. Some biological disciplines are cytology, the study of cells; anatomy, the study of structure; physiology, the study of function; botany, the study of plants; zoology, the study of animals; genetics, the study of heredity; and ecology, the study of the interrelationships between organisms and their environment.

Religion, aesthetics, ethics, and science are all ways in which human beings seek order in the natural world. Science differs from these other ways of knowing and learning because the scientific process uses the **scientific method,** a standard series of steps used in gaining new knowledge that is widely accepted among scientists. The steps of the scientific method are often applicable to other situations, and begin with observation (Fig. 1.12).

Observation

Scientists believe that nature is orderly and measurable—that natural laws, such as the law of gravity, do not change with time, and that a natural event, or **phenomenon,** can be understood more fully through observation. Scientists use all of their senses in making **observations.** The behavior of chimpanzees can be observed through visual means, the disposition of a skunk can be observed through olfactory means, and the warning rattles of a rattlesnake provide auditory information of imminent danger. Scientists also extend the ability of their senses by using instruments; for example, the microscope enables us to see objects that could never be seen by the naked eye. Finally, scientists may expand their understanding even further by taking advantage of the knowledge and experiences of other scientists. For instance, they may look up past studies at the library or on the Internet, or they may write or speak to others who are researching similar topics.

Nevertheless, chance alone can help a scientist get an idea. The most famous case pertains to penicillin. When examining a petri dish, Alexander Fleming observed an area around a mold that was free of bacteria. Upon investigating, Fleming found that the mold, a *Penicillium* species, produced an antibacterial substance he called penicillin, and he thought that perhaps penicillin would be useful in humans. This discovery changed medicine and has saved countless lives.

Hypothesis

After making observations and gathering knowledge about a phenomenon, a scientist uses inductive reasoning. **Inductive reasoning** occurs whenever a person uses creative thinking to combine isolated facts into a cohesive whole. In this way, a scientist comes up with a **hypothesis,** a possible explanation for a natural event. The hypothesis is a statement that can be tested in a manner suited to the process of science.

All of a scientist's past experiences, no matter what they might be, will most likely influence the formation of a

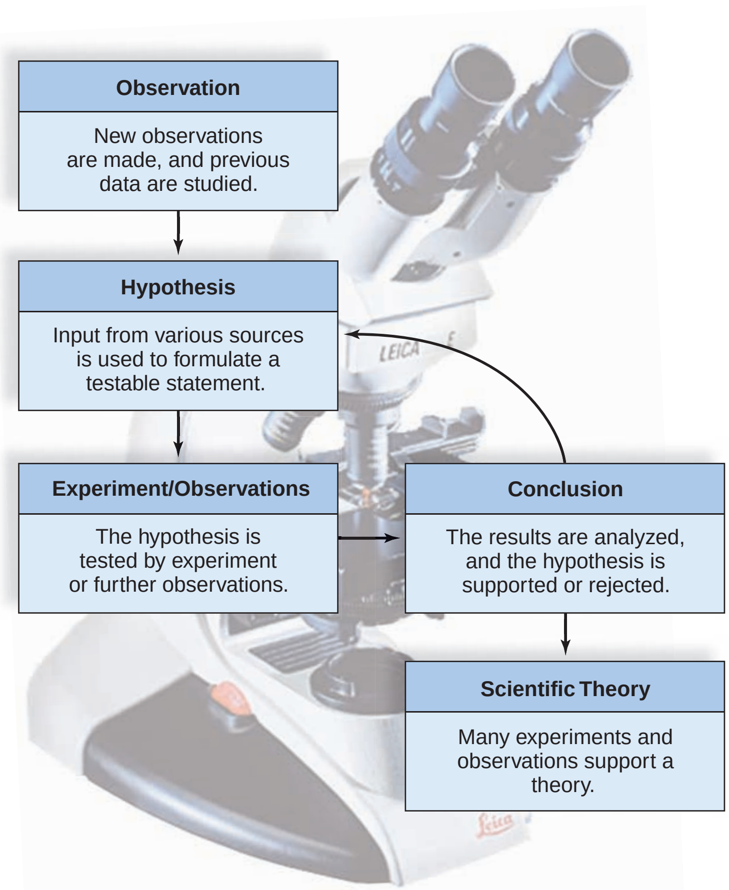


FIGURE 1.12 Flow diagram for the scientific method.

On the basis of new and/or previous observations, a scientist formulates a hypothesis. The hypothesis is tested by further observations and/or experiments, and new data either support or do not support the hypothesis. The return arrow indicates that a scientist often chooses to retest the same hypothesis or to test a related hypothesis. Conclusions from many different but related experiments may lead to the development of a scientific theory. For example, studies pertaining to development, anatomy, and fossil remains all support the theory of evolution.

hypothesis. But a scientist only considers hypotheses that can be tested. Moral and religious beliefs, while very important to the lives of many people, differ between cultures and through time and may not be testable.

Experiments/Further Observations

Testing a hypothesis involves either conducting an **experiment** or making further observations. To determine how to test a hypothesis, a scientist uses deductive reasoning. **Deductive reasoning** involves "if, then" logic. For example, a scientist might reason, if organisms are composed of cells, then microscopic examination of any part of an organism should reveal cells. We can also say that the scientist has made a **prediction** that the hypothesis can be supported by doing microscopic studies. Making a prediction helps a scientist know what to do next.

The manner in which a scientist intends to conduct an experiment is called the **experimental design.** A good experimental design ensures that scientists are testing what they want to test and that their results will be meaningful. It is always best for an experiment to include a control group. Often, a control group, or simply the **control,** goes through all the steps of an experiment but lacks the factor (is not exposed to the factor) being tested.

In some cases, scientists may use a **model** as a representation of the actual object because altering the actual object may be physically impossible, very expensive, or morally questionable. Later in this section, a scientist uses bluebird models because it would have been impossible to get live birds to cooperate. Computer models are used to decide how human activities will affect climate, because of expense, ethical concerns, and physical limitations. Scientists often use mice instead of humans for medical research because of ethical concerns. Bacteria are used in much genetic research because they are inexpensive to grow and reproduce very quickly. While these models are usually relevant and give useful information, they are themselves still hypotheses in need of testing to ensure that they are valid representations.

Data

The results of an experiment are referred to as the **data.** Data should be observable and objective, rather than subjective. Mathematical data are often displayed in the form of a graph or table. Many studies, such as the one discussed in the Science Focus on page 13, rely on statistical data. As a hypothetical example, let's say an investigator wants to know if eating onions can prevent women from getting osteoporosis (weak bones). The scientist conducts a survey asking women about their onion-eating habits and then correlates this data with the condition of their bones. Other scientists critiquing this study would want to know: How many women were surveyed? How old were the women? What were their exercise habits? What proportion of the diet consisted of onions? And what criteria were used to determine the condition of their bones? Should the investigators conclude that eating onions does protect a woman from osteoporosis, other scientists might want to know the statistical probability of error. The probability of error is a mathematical calculation based on the conditions and methods of the experiment. If the results are significant at a 0.30 level, then the probability that the correlation is incorrect is 30% or less. (This would be considered a high probability of error.) The greater the variance in the data, the greater the probability of error. Even if this study had a low probability of error, it would be considered hypothetical until we learn of some ingredient in onions that has a direct biochemical or physiological effect on bones. Therefore, scientists must be skeptics who always pressure one another to continue investigating a particular topic.

Conclusion

Scientists must analyze the data in order to reach a **conclusion** as to whether the hypothesis is supported or not (see Fig. 1.12). Because science progresses, the conclusion of one experiment can lead to the hypothesis for another experiment, as represented by the return arrow in Figure 1.12. Results that do not support one hypothesis can often help a scientist formulate another hypothesis to be tested. Scientists report their findings in scientific journals so that their methodology and data are available to other scientists for critique. Experiments and observations must be repeatable—that is, the reporting scientist and any scientist who repeats the experiment must get the same results, or else the data are suspect.

Scientific Theory

The ultimate goal of science is to understand the natural world in terms of **scientific theories,** which are concepts that join together well-supported and related hypotheses. In ordinary speech, the word *theory* refers to a speculative idea. In contrast, a scientific theory is supported by a broad range of observations, experiments, and data often from a variety of disciplines. Some of the basic theories of biology are:

Theory	*Concept*
Cell	All organisms are composed of cells, and new cells only come from preexisting cells.
Homeostasis	The internal environment of an organism stays relatively constant—within a range that is protective of life.
Gene	Organisms contain coded information that dictates their form, function, and behavior.
Ecosystem	Organisms are members of populations, which interact with each other and the physical environment within a particular locale.
Evolution	All living things have a common ancestor, but each is adapted to a particular way of life.

As stated earlier, the theory of evolution is the unifying concept of biology because it pertains to many different aspects of living things. For example, the theory of evolution enables scientists to understand the history of living things, and the anatomy, physiology, and embryological development of organisms. Even behavior can be described through evolution, as we shall see in a study discussed later in this chapter.

The theory of evolution has been a fruitful scientific theory, meaning that it has helped scientists generate new hypotheses. Because this theory has been supported by so many observations and experiments for over 100 years, some biologists refer to the **principle** of evolution, a term sometimes used for theories that are generally accepted by an overwhelming number of scientists. The term **law** instead of principle is preferred by some. For instance, in a subsequent chapter concerning energy relationships, we will examine the laws of thermodynamics.

science focus

The Benefits and Limitations of Statistical Studies

Many of the studies published in scientific journals and reported in the news are statistical studies, so it behooves us to be aware of their benefits and limitations. At the start, you should know that a statistical study will gather numerical information from various sources and then try to make sense out of it, for the purpose of coming to a conclusion.

Example of a Statistical Study

Let's take a look at a study that allows us to conclude that babies conceived 18 months to five years after a previous birth are healthier than those conceived at shorter or longer intervals. In other words, spacing children about two to five years apart is a good idea (Fig. 1A). Here is how the authors collected their data and the results they published in the *Journal of the American Medical Association*.*

Objective. To determine if there is an association between birth spacing and a healthy baby when data are corrected for maternal characteristics or socioeconomic status.

Data. The authors collected data from studies performed around the world in 1966 through January 2006. The studies were published in various journals, reported on at professional meetings, or were known to the authors by personal contact. The authors gathered a very large pool of data that included over 11 million pregnancies from 67 individual studies. Twenty of the studies were from the United States, with the remaining 47 coming from 61 different countries. The authors attempted to adjust the data (by elimination of certain data) for factors such as mother's age, wealth, access to prenatal care, and breast-feeding. These adjustments allow the findings to be applied to both developed and developing countries.

Conclusion.

1. A pregnancy that begins less than six months after a previous birth has a 77% higher chance of being preterm and a 39% higher chance of lower birth weight.
2. For up to 18 months between pregnancies, the chance of a preterm birth decreases by 2% per month, and the chance of a low-weight birth decreases by 3% per month as the 18-month time period is approached.
3. Babies conceived after 59 months have the same risk as those conceived in the less-than-six-months group.
4. The optimum spacing between pregnancies appears to be 18 months to five years after a previous birth.

FIGURE 1A Does spacing pregnancies lead to healthier children? A recent statistical study suggests that it does. If so, which mother, left or right, may have a healthier younger child?

The study leader, Agustin Conde-Agudelo, said, "Health officials should counsel women who have just given birth to delay their next conception by 18 to 59 months."

Limitations of Experimental Studies

The expression "statistical study" is a bit of a misnomer because most scientists collect quantitative data and use them to come to a conclusion. However, if we compare this study to experimental studies, we can see that the experimental studies include both a control group and test groups. The groups are treated the same except for the experimental variable. Obviously, you wouldn't be able to divide women of the same childbearing age into various groups and tell each group when they will conceive their children for the purpose of deciding the best interval between pregnancies for the health of the newborn. So, what is the next best thing? Do a statistical study utilizing data already available about women who became pregnant at different intervals.

A statistical study is really a correlation study. In our example, the authors studied the correlation between birth spacing and the health of a newborn. The more data collected from more varied sources make a correlation study more reliable. The study by Conde-Agudelo has a very large sample size, which goes a long way to validating the results. Even so, a correlation does not necessarily translate to causation. So, it is not surprising that Dr. Mark A. Klebanoff, director of the National Institute of Child Health and Human Development, commented that many factors will affect birth spacing and that the study is not detailed enough to take all factors into consideration. Is any statistical study detailed enough? Most likely not.

Benefits of Statistical Studies

Before we give up on statistical studies, let's consider that they do provide us with information not attainable otherwise. Regardless of whether we understand the intricacies of statistical analysis, statistical studies do allow scientists to gain information and insights into many problems. True, further study is needed to find out if the observed correlation does mean causation, but science is always a work in progress, with additional findings being published every day.

* Agustin Conde-Agudelo, MD, MPH, Anyeli Rosas-Bermudez, MPH, Ana Cecilia Kafury-Goeta, MD. "Birth Spacing and Risk of Adverse Perinatal Outcomes." *JAMA*, 2006;295:1809–23. Abstract.

Using the Scientific Method

Scientists using the scientific method often do controlled studies to ensure that the outcome is due to the **experimental variable** or independent variable, the component or factor being tested. The result is called the **responding variable** or dependent variable because it is due to the experimental variable:

Experimental Variable (Independent Variable)	Responding Variable (Dependent Variable)
Factor of the experiment being tested	Result or change that occurs due to the experimental variable

Observation

Researchers doing this study knew that nitrogen fertilizer in the short run enhances yield and increases food supplies. However, excessive nitrogen fertilizer application can cause pollution by adding toxic levels of nitrates to water supplies. Also, applying nitrogen fertilizer year after year may alter soil properties to the point that crop yields may decrease, instead of increase. Then the only solution is to let the land remain unplanted for several years until the soil recovers naturally.

An alternative to the use of nitrogen fertilizers is the use of legumes, plants such as peas and beans, that increase soil nitrogen. Legumes provide a home for bacteria that convert atmospheric nitrogen to a form usable by the plant. The bacteria live in nodules on the roots (Fig. 1.13). The bacteria supply the plant with nitrogen compounds, and in turn, the plant passes the product of photosyntheis to the nodules.

Numerous legume crops can be rotated (planted every other season) with any number of cereal crops. The nitrogen added to the soil by the legume crop is a natural fertilizer that increases the yield of cereal crops. The particular rotation used by farmers tends to depend on the location, climate, and market demand. In this study, researchers perform an experiment in which method of fertilization is the experimental variable and enhanced yield is the responding variable.

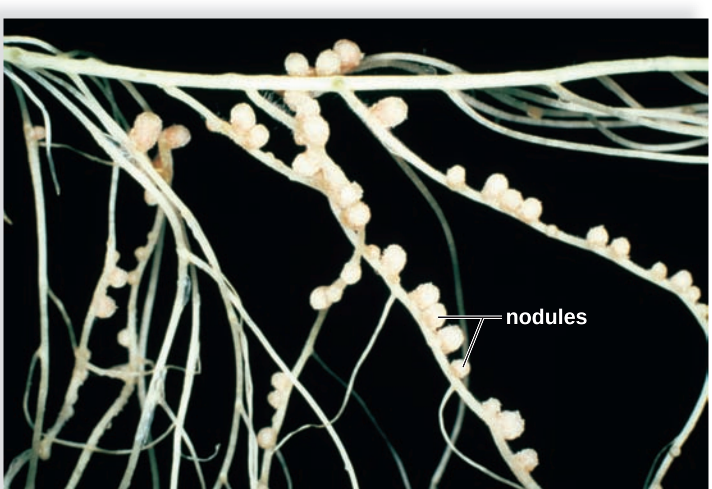


FIGURE 1.13 Root nodules.

Bacteria that live in nodules on the roots of legumes, such as pea plants, convert nitrogen in the air to a form that land plants can use to make proteins and other nitrogen-containing molecules.

Hypothesis

Researchers doing this study knew that the pigeon pea plant is a legume with a high rate of atmospheric nitrogen conversion. This plant is widely grown as a food crop in India, Kenya, Uganda, Pakistan, and other subtropical countries. Researchers formulated the hypothesis that a pigeon pea/winter wheat rotation would be a reasonable alternative to the use of nitrogen fertilizer to increase the yield of winter wheat.

> Hypothesis: A pigeon pea/winter wheat rotation will cause winter wheat production to increase as well as or better than the use of nitrogen fertilizer.
>
> Prediction: Wheat biomass following the growth of pigeon peas will surpass wheat biomass following nitrogen fertilizer treatment.

Experiment

In this study, the investigators decided on the following experimental design (Fig. 1.14*a*):

Control Pots

- Winter wheat was planted in pots of soil that received no fertilization treatment—that is, no nitrogen fertilizer and no preplanting of pigeon peas.

Test Pots

- Winter wheat was grown in clay pots in soil treated with nitrogen fertilizer equivalent to 45 kilograms (kg)/hectare (ha).
- Winter wheat was grown in clay pots in soil treated with nitrogen fertilizer equivalent to 90 kg/ha.
- Pigeon pea plants were grown in clay pots in the summer. The pigeon pea plants were then tilled into the soil and winter wheat was planted in the same pots.

To ensure a controlled experiment, the conditions for the control pots and the test pots were identical; the plants were exposed to the same environmental conditions and watered equally. During the following spring, the wheat plants were dried and weighed to determine wheat biomass production in each of the pots.

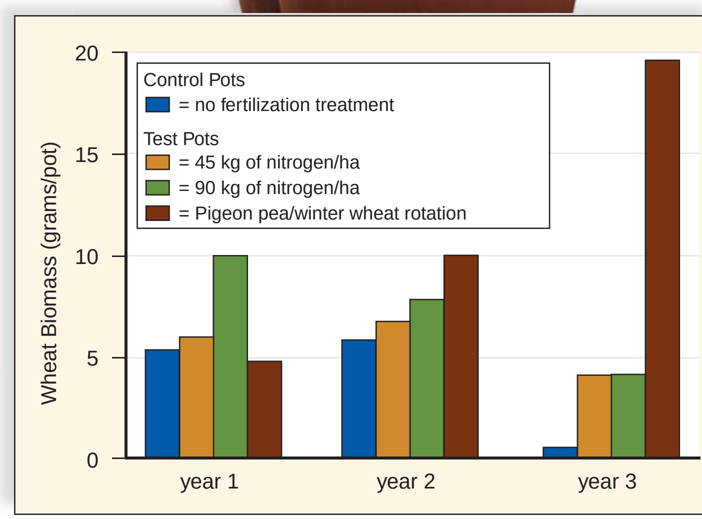
Data

After the first year, wheat biomass was higher in certain test pots than in the control pots (Fig. 1.14*b*). Specifically, test pots with 45 kg/ha of nitrogen fertilizer (orange) had only slightly more wheat biomass production than the control pots, but test pots that received 90 kg/ha treatment (green) demonstrated nearly twice the biomass production of the control pots. To the surprise of investigators, wheat production following summer planting of pigeon peas did not demonstrate as high a biomass production as the control pots.

Conclusion and Further Investigation

Wheat biomass following the growth of pigeon peas is not as great as that obtained with nitrogen fertilizer treatments, meaning that the data from the experiment did not support the investigators' hypothesis. This is not an


a. Control pots and test pots of three types



b. Results

FIGURE 1.14 Pigeon pea/winter wheat rotation study.

a. Experiment involves control pots and test pots of three types: test pots that received 45 kg/ha of nitrogen; test pots that received 90 kg/ha of nitrogen; and test pots in which pigeon peas rotated with winter wheat. **b.** The graph compares wheat biomass for each of three years. Wheat biomass in test pots that received the most nitrogen fertilizer (green) declined while wheat biomass in test pots with pigeon pea/winter wheat rotation (brown) increased dramatically.

uncommon event in scientific investigations. However, the investigators decided to continue the experiment using the same design and the same pots as before, to see if the buildup of residual soil nitrogen from pigeon peas would eventually increase wheat biomass. So they proposed a new hypothesis.

> Hypothesis: A sustained pigeon pea/winter wheat rotation will eventually cause an increase in winter wheat production.
>
> Prediction: Wheat biomass following two years of pigeon pea/winter wheat rotation will surpass wheat biomass following nitrogen fertilizer treatment.

After two years, the yield following 90 kg/ha nitrogen treatment (green) was not as much as it was the first year (Fig. 1.14*b*). Indeed, wheat biomass following summer planting of pigeon peas (brown) was the highest of all treatments, suggesting that buildup of residual nitrogen from pigeon peas had the potential to provide fertilization for winter wheat growth.

> Conclusion: The hypothesis is supported. At the end of two years, the yield of winter wheat following a pigeon pea/winter wheat rotation was better than for the other type pots.

The researchers continued their experiment for still another year. After three years, winter wheat biomass production had decreased in the control pots and in the pots treated with nitrogen fertilizer. Pots treated with nitrogen fertilizer still had increased wheat biomass production compared with the control pots but not nearly as much as pots following summer planting of pigeon peas. Compared to the first year, wheat biomass increased almost fourfold in pots having a pigeon pea/winter wheat rotation (brown, Fig. 1.14*b*). The researchers suggested that the soil was improved by the organic matter as well as the addition of nitrogen from the pigeon peas. The researchers published their results in a scientific journal.[1]

[1] Bidlack, J. E., Rao, S. C., and Demezas, D. H. 2001. Nodulation, nitrogenase activity, and dry weight of chickpea and pigeon pea cultivars using different *Bradyrhizobium* strains. *Journal of Plant Nutrition* 24:549–60.

A Field Study

A scientist, David Barash, while observing the mating behavior of mountain bluebirds (Fig. 1.15*a, b*), formulated the hypothesis that aggression of the male varies during the reproductive cycle. To test this hypothesis, he reasoned that he should evaluate the intensity of male aggression at three stages: after the nest is built, after the first egg is laid, and after the eggs hatch.

> Hypothesis: Male bluebird aggression varies during the reproductive cycle.
> Prediction: Aggression intensity will change after the nest is built, after the first egg is laid, and after hatching.

Testing the Hypothesis

For his experiment, Barash decided to measure aggression intensity by recording the "number of approaches per minute" a male made toward a rival male and his own female mate. To provide a rival, Barash posted a male bluebird model near the nests while resident males were out foraging. The aggressive behavior (approaches) of the resident male was noted during the first 10 minutes of the male's return (Fig. 1.15*c*). To give his results validity, Barash included a control group. For his control, Barash posted a male robin model instead of a male bluebird near certain nests.

Resident males of the control group did not exhibit any aggressive behavior, but resident males of the experimental groups did exhibit aggressive behavior. Barash graphed his mathematical data (Fig. 1.15*d*). By examining the graph, you can see that the resident male was more aggressive toward the rival male model than toward his female mate, and that he was most aggressive while the nest was under construction, less aggressive after the first egg was laid, and least aggressive after the eggs hatched.

The Conclusion

The results allowed Barash to conclude that aggression in male bluebirds is related to their reproductive cycle. Therefore, his hypothesis was supported. If male bluebirds were always aggressive, even toward male robin models, his hypothesis would not have been supported.

> Conclusion: The hypothesis is supported. Male bluebird aggression does vary during the reproductive cycle.

Barash reported his experiment in *The American Naturalist*.[2] In this article, Barash gave an evolutionary interpretation to his results. It was adaptive, he said, for male bluebirds to be less aggressive after the first egg is laid because by then the male bird is "sure the offspring is his own." It was maladaptive for the male bird to waste energy being aggressive after hatching because his offspring are already present.

Check Your Progress 1.4

1. What is the benefit of an experimental control?
2. How might using a model affect the conclusions drawn from an experiment?
3. What are the possible disadvantages of the peer review system?

[2] Barash, D.P. 1976. Male response to apparent female adultery in the mountain bluebird (*Sialia currucoides*): an evolutionary interpretation. *The American Naturalist* 110:1097–1101.

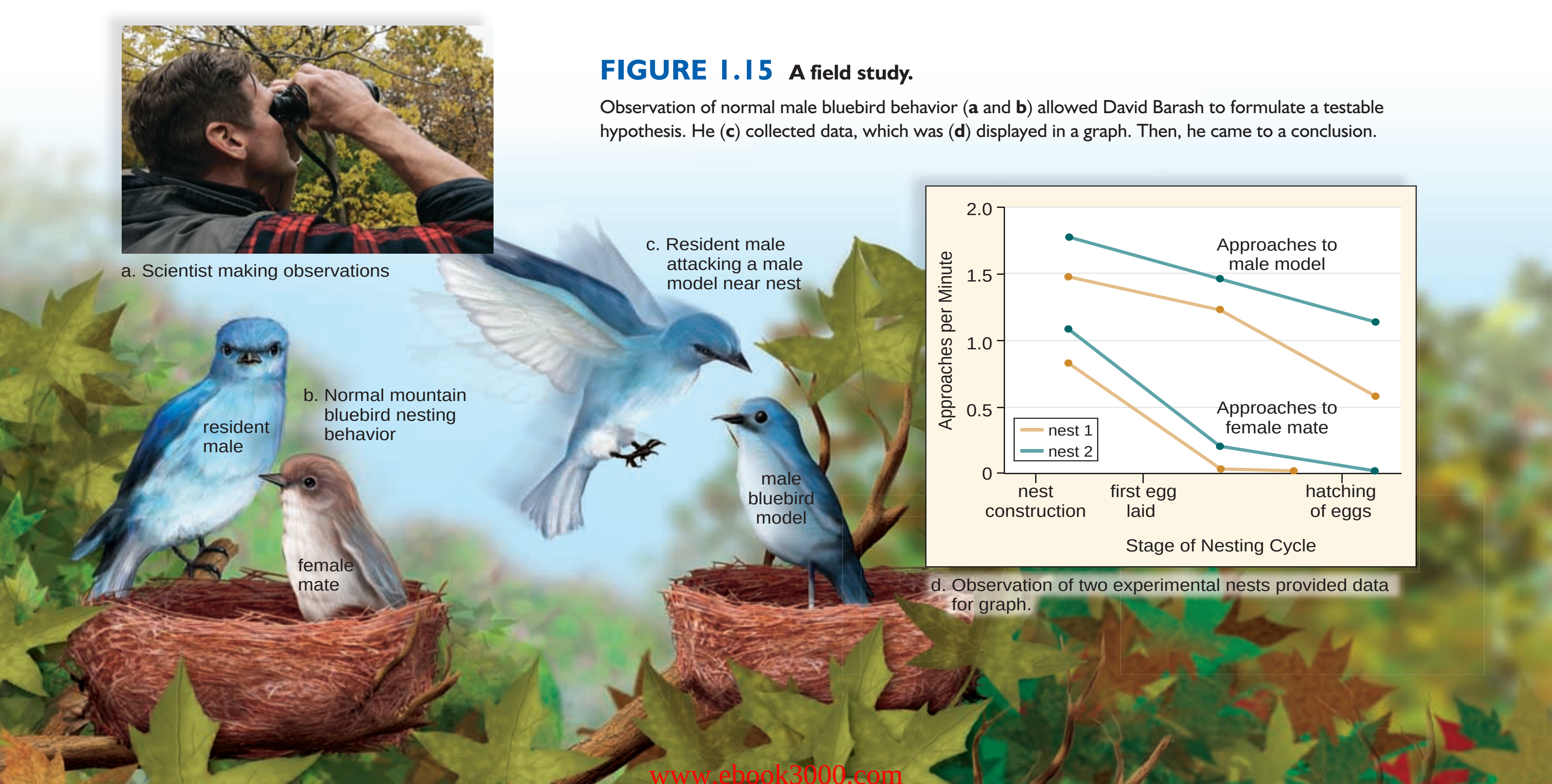


FIGURE 1.15 A field study.

Observation of normal male bluebird behavior (**a** and **b**) allowed David Barash to formulate a testable hypothesis. He (**c**) collected data, which was (**d**) displayed in a graph. Then, he came to a conclusion.

Connecting the Concepts

The diversity of life on Earth is staggering, but organisms are united by a number of common features that define them as living. Among these features is the ability to adapt, and descent with modification occurs when these adaptations are passed from one generation to the next over long periods of time. Evolution is a unifying theory in biology that accounts for the differences that divide and the unity that joins all living things. All living things are organized and function similarly because they share a common evolution extending back through time to the first cells on Earth.

What we know about biology and what we'll learn in the future result from objective observation and testing of the natural world through the scientific method. The ultimate goal of science is to understand the natural world in terms of theories—conceptual schemes supported by abundant research. Scientists should provide the public with as much information as possible, especially when such issues as recombinant DNA technology or human impacts on the biosphere are being debated. Then they, along with other citizens, can help make intelligent decisions about what is most likely best for society. Everyone has a responsibility to decide how to use scientific knowledge so that it benefits all living things, including the human species.

This textbook was written to help you understand the scientific process and learn the basic concepts of general biology so that you will be better informed. This chapter has introduced you to the levels of biological organization, from the cell to the biosphere. The cell, the simplest of living things, is composed of nonliving molecules. Therefore, we must begin our study of biology with a brief look at cellular chemistry. In the next two chapters, you will study some important inorganic and organic molecules as they relate to cells. Then, you will learn how the cell makes use of energy and materials to maintain itself and to reproduce.

summary

1.1 How to Define Life

Although living things are diverse, they have certain characteristics in common. Living things (a) are organized, and their levels of organization extend from the cell to ecosystems; (b) need an outside source of materials and energy; (c) respond to external stimuli; (d) reproduce and develop, passing on genes to their offspring; and (e) have adaptations suitable to their way of life in a particular environment. Together, these characteristics unify life on Earth.

1.2 Evolution, the Unifying Concept of Biology

Life on Earth is diverse, but the theory of evolution unifies life and describes how all living organisms evolved from a common ancestor. Taxonomists assign each living thing an italicized binomial name that consists of the genus and the specific epithet. From the least inclusive to the most inclusive category, each species belongs to a genus, family, order, class, phylum, kingdom, and finally domain.

The three domains of life are Archaea, Bacteria, and Eukarya. The first two domains contain prokaryotic organisms that are structurally simple but metabolically complex. Domain Eukarya contains the protists, fungi, plants, and animals. Protists range from unicellular to multicellular organisms and include the protozoans and most algae. Among the fungi are the familiar molds and mushrooms. Plants are well known as the multicellular photosynthesizers of the world, while animals are multicellular and ingest their food. An evolutionary tree shows how the domains are related by way of common ancestors.

Natural selection describes the process by which living organisms are descended from a common ancestor. Mutations occur within a population, creating new traits. The agents of natural selection, present in both biological and physical environments, shape species over time and may create new species from existing ones.

1.3 How the Biosphere Is Organized

Within an ecosystem, populations interact with one another and with the physical environment. Nutrients cycle within and between ecosystems, but energy flows unidirectionally and is eventually lost as unusable forms. Adaptations of organisms allow them to play particular roles within an ecosystem.

1.4 The Process of Science

When studying the natural world, scientists use the scientific process. Observations, along with previous data, are used to formulate a hypothesis. New observations and/or experiments are carried out in order to test the hypothesis. A good experimental design includes an experimental variable and a control group. The experimental and observational results are analyzed, and the scientist comes to a conclusion as to whether the results support the hypothesis or do not support the hypothesis.

Several conclusions in a particular area may allow scientists to arrive at a theory, such as the cell theory, the gene theory, or the theory of evolution. The theory of evolution is a unifying concept of biology.

understanding the terms

protist 7
reproduce 5
responding variable 14
scientific method 11
scientific theory 12
species 6
taxonomy 6
unicellular 2

Match the terms to these definitions:

a. _______________ All of the chemical reactions that occur in a cell during growth and repair.
b. _______________ Changes that occur among members of a species with the passage of time, often resulting in increased adaptation to the prevailing environment.
c. _______________ Component in an experiment that is manipulated as a means of testing it.
d. _______________ Process by which plants use solar energy to make their own organic food.
e. _______________ Sample that goes through all the steps of an experiment but lacks the factor being tested.

reviewing this chapter

1. What are the common characteristics of life listed in the chapter? 2–5
2. Describe the levels of biological organization. 2
3. Why do living things require an outside source of nutrients and energy? Describe these sources. 4
4. What is passed from generation to generation when organisms reproduce? What has to happen to the hereditary material DNA for evolution to occur? 5
5. How does evolution explain both the unity and the diversity of life? 5–6
6. What are the categories of classification? How does the domain Eukarya differ from domain Bacteria and domain Archaea? 6
7. Explain the scientific name of an organism. 6
8. How does natural selection result in adaptation to the environment? 8
9. What is an ecosystem, and why should human beings preserve ecosystems? 9–10
10. Describe the series of steps involved in the scientific method. 11–12
11. What is the ultimate goal of science? Give an example that supports your answer. 12
12. Give an example of a controlled study. Name the experimental variable and the responding variable. 14–15
13. What is a field study, and how does it differ from a controlled study? How are they similar? 16

testing yourself

Choose the best answer for each question.

1. Which of these is not a property of all living organisms?
   a. organization
   b. acquisition of materials and energy
   c. care for their offspring
   d. reproduction
   e. responding to the environment
2. Describe an emergent property that might arise when moving from a single neuron (nerve cell) to nervous tissue.
3. The level of organization that includes cells of similar structure and function would be
   a. an organ.
   b. a tissue.
   c. an organ system.
   d. an organism.
4. The color, temperature, and foul odor of the flowers of the titan arum are examples of
   a. obtaining materials
   b. adaptations
   c. organizations
   d. homeostasis
5. Which of the following is an example of adaptation?
   a. In a very wet year, some plants grow unusually tall stalks and large leaves.
   b. Over millions of years, the eyes of cave salamanders lose their function.
   c. An escaped dog joins a pack of wild dogs and begins interbreeding with them.
   d. A harsh winter kills many birds within a population, especially the smallest ones.
6. Energy is brought into ecosystems by which of the following?
   a. fungi and other decomposers
   b. cows and other organisms that graze on grass
   c. meat-eating animals
   d. organisms that photosynthesize, such as plants
   e. All of these are correct.
7. We use the scientific method every day. Suppose one morning that your car does not start. Which of the following is a testable hypothesis stemming from this observation?
   a. I'm going to be late.
   b. My battery is dead.
   c. Check to see if I left the lights on.
   d. Kick the tires.
   e. I will add a quart of oil.
8. Which of the following statements is a hypothesis?
   a. Will increasing my cat's food increase her weight?
   b. Increasing my cat's food consumption will result in a 25% increase in her weight.
   c. I will feed my cat more food.
   d. My cat has gained weight; therefore, she is eating more food.
9. After formulating a hypothesis, a scientist
   a. proves the hypothesis true or false.
   b. tests the hypothesis.
   c. decides how to best avoid having a control.
   d. makes sure environmental conditions are just right.
   e. formulates a scientific theory.
10. The experimental variable in the bluebird experiment was the
    a. use of a model male bluebird.
    b. observations of the experimenter.
    c. various behavior of the males.
    d. identification of what bluebirds to study.
    e. All of these are correct.
11. The control group in the pigeon pea/winter wheat experiment was the pots that were
    a. planted with pigeon peas.
    b. treated with nitrogen fertilizer.
    c. not treated.
    d. not watered.
    e. Both c and d are correct.
12. Which of the following are agents of natural selection?
    a. changes in the environment
    b. competition among individuals for food and water
    c. predation by another species
    d. competition among members of a population for prime nesting sites
    e. All of these are correct.

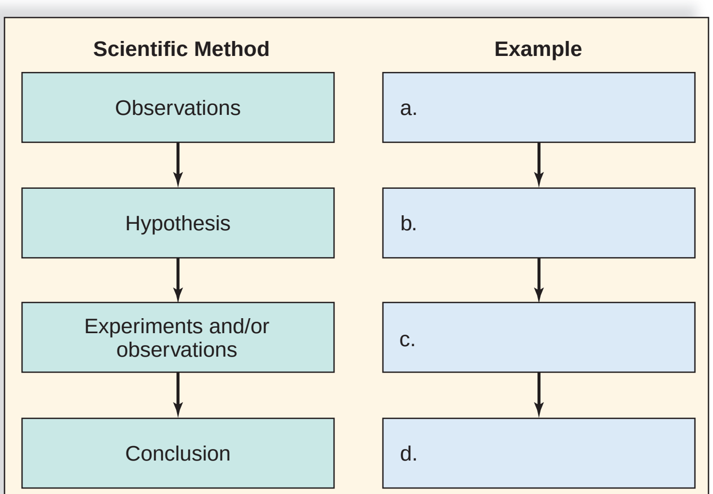
13. Which of the following is an example of natural selection?
    a. In a very wet year, some plants grow unusually tall stalks and large leaves.
    b. After several unusually cold winters, squirrels with an extra layer of fat have more offspring.
    c. Squirrels may have long or short tails.
    d. Dogs with longer legs are able to run faster than dogs with shorter legs.
14. Which of the following statements regarding evolution is false?
    a. Adaptations may be physical or behavioral.
    b. Natural selection always results in organisms becoming more adapted to the environment.
    c. A trait selected for may suddenly become selected against when the environment changes.
    d. Some traits are neither selected for nor against.

For questions 15–17, write a brief answer.

15. Why is it said that all energy used by living organisms originates from the sun?
16. Carbon dioxide emissions have been blamed for climate change by many scientists. How might excessive amounts of carbon dioxide affect nutrient cycling?
17. Would the accidental introduction of a new species to an ecosystem necessarily have a negative effect on biodiversity? Why or why not?

thinking scientifically

1. An investigator spills dye on a culture plate and notices that the bacteria live despite exposure to sunlight. He decides to test if the dye is protective against ultraviolet (UV) light. He exposes one group of culture plates containing bacteria and dye and another group containing only bacteria to UV light. The bacteria on all plates die. Complete the following diagram.



2. You want to grow large tomatoes and notice that a name-brand fertilizer claims to produce larger produce than a generic brand. How would you test this claim?
3. A scientist wishes to test her hypothesis that a commonly used drug causes heart attacks in some individuals. What kind of study should she initiate? What would you expect her experimental and responding variables to be?

bioethical issue

Oil Drilling in the Arctic

Established by an act of Congress in 1980, the Arctic National Wildlife Refuge (ANWR) covers a total of 19 million acres of northernmost Alaska far above the Arctic Circle. ANWR is home to a variety of wildlife, such as caribou, migratory birds, grizzly and polar bears, wolves, and musk oxen. But it is also home to substantial oil reserves, which has led to an ongoing contentious debate over its future: Should Congress allow development of ANWR for oil exploration and drilling?

Those who favor oil drilling in ANWR insist that first and foremost, the impact on the land would be minimal. The affected area would be roughly the size of an airport in a total area roughly the size of the state of South Carolina. They contend that the effect would mainly be underground because new techniques allow us to go lower and spread out beneath the surface to get the oil. Waste treatment and disposal methods have also improved. Acquiring the oil, advocates say, would also protect jobs and national security in the United States by lessening dependence on often hostile foreign countries for oil, and would have the added benefit of insulating the U.S. economy from oil price spikes and supply shocks.

Those who do not favor oil drilling in ANWR are eager to point out that at current levels of consumption, the oil coming from ANWR would hardly have a noticeable impact on prices and supply levels. Furthermore, they believe that the best solution to the current energy crunch would be for U.S. citizens to adopt simple energy conservation measures and invest in research on alternative fuels. They suggest that this would save many times the oil that could come from drilling in the Arctic refuge and that, by using a renewable energy resource, the environment in the lower 48 states would be protected, in addition to protecting the wildlife in the Arctic National Wildlife Refuge. Using renewable energy would lessen the need for foreign oil, and would also protect our national security.

Should Congress approve oil drilling in ANWR? Or should Congress invest in alternative and renewable energy forms, and insist that citizens adopt energy conservation measures? Should public tax monies be made available to Congress for oil exploration or for investment in alternative energy sources?

Biology website

The companion website for *Biology* provides a wealth of information organized and integrated by chapter. You will find practice tests, animations, videos, and much more that will complement your learning and understanding of general biology.

http://www.mhhe.com/maderbiology10