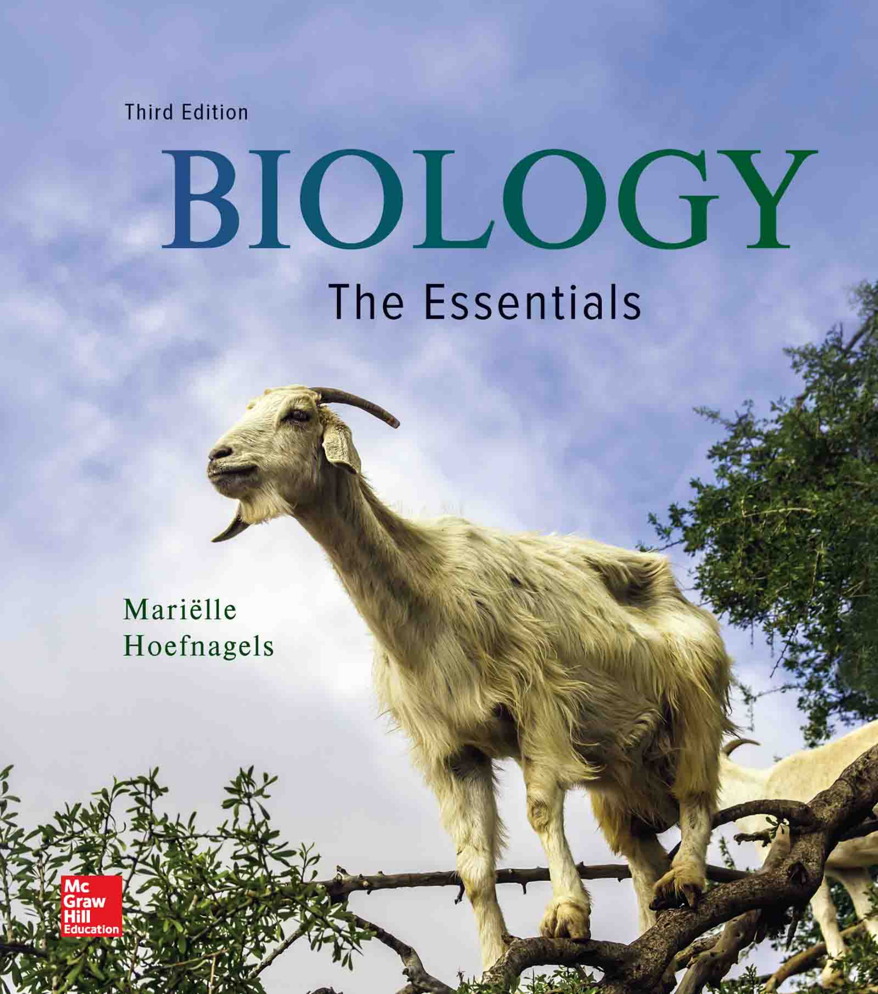
Third Edition

BIOLOGY

The Essentials

Mariëlle
Hoefnagels



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THE ESSENTIALS

Mariëlle Hoefnagels

THE UNIVERSITY OF OKLAHOMA

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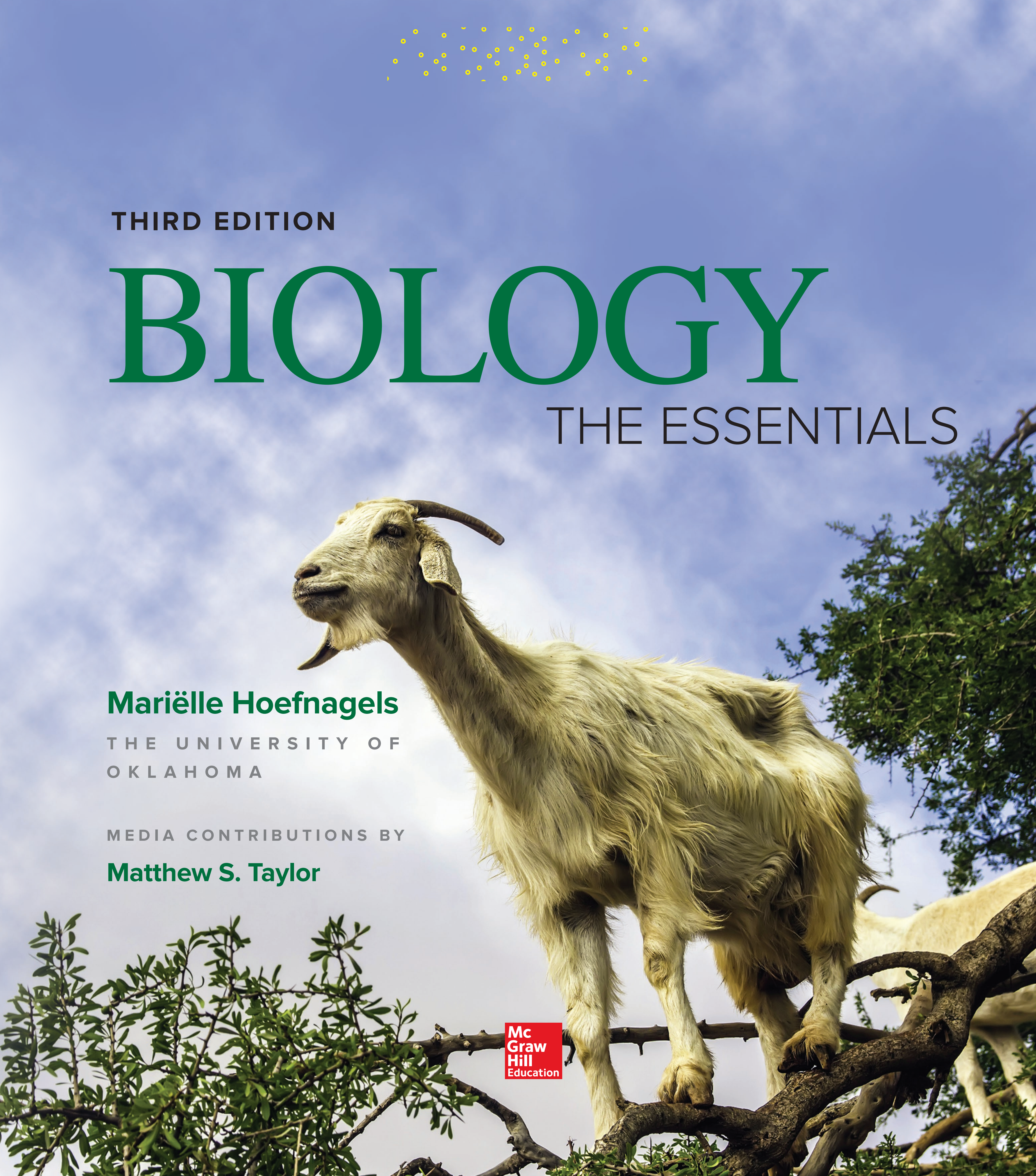

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Brief Contents

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About the Author

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Mariëlle Hoefnagels is a professor in the Department of Biology and the Department of Microbiology and Plant Biology at the University of Oklahoma, where she teaches courses in introductory biology, mycology, and science writing. She has received the University of Oklahoma General Education Teaching Award and the Longmire Prize (the Teaching Scholars Award from the College of Arts and Sciences). She has also been awarded honorary memberships in several student honor societies.

Dr. Hoefnagels received her BS in environmental science from the University of California at Riverside, her MS in soil science from North Carolina State University, and her PhD in plant pathology from Oregon State University. Her dissertation work focused on the use of bacterial biological control agents to reduce the spread of fungal pathogens on seeds. In addition to authoring *Biology: The Essentials* and *Biology: Concepts and Investigations,* her recent publications have focused on creating investigative teaching laboratories and integrating technology into introductory biology classes. She also maintains a blog on teaching nonmajors biology, and she frequently gives presentations on study skills and related topics to student groups across campus.

DEDICATION

To my students

Mariëlle Hoefnagels

An Introduction for Students Using This Textbook

I have been teaching nonmajors biology at the University of Oklahoma since 1997 and over that time have encountered many students who fear science in general and biology in particular. The complexity, abstractions, and unfamiliar terms can be overwhelming, and some students believe they can't do well because they're just not "into science." In writing this book, I have focused on students and what you need to be successful in a nonmajors biology class.

In my experience, a big part of the problem is that many students just don't have the right study skills—they focus too much on superficial learning such as memorizing definitions, but they don't immediately grasp the power of *understanding* the material. I've created the following features to help you make the transition from memorizing to understanding.

- **Concept Maps** A new *Survey the Landscape* concept map at the start of each chapter illustrates how the pieces of the entire unit fit together. Each chapter ends with a *Pull It Together* concept map that makes connections between key terms within the chapter. Using these concept maps together will help you understand how the major topics covered throughout the book relate to one another.
- **Learn How to Learn** Each chapter in this book contains a tip that focuses on study skills that build understanding. Don't try to implement them all at once; choose one that appeals to you and add more as you determine what works best for you.
- **What's the Point?** This brief introduction helps explain the importance of the chapter topic. A companion feature is *What's the Point? Applied,* which appears near the end of each chapter and builds on the chapter's content by explaining a wide-ranging topic that is relevant to your life.

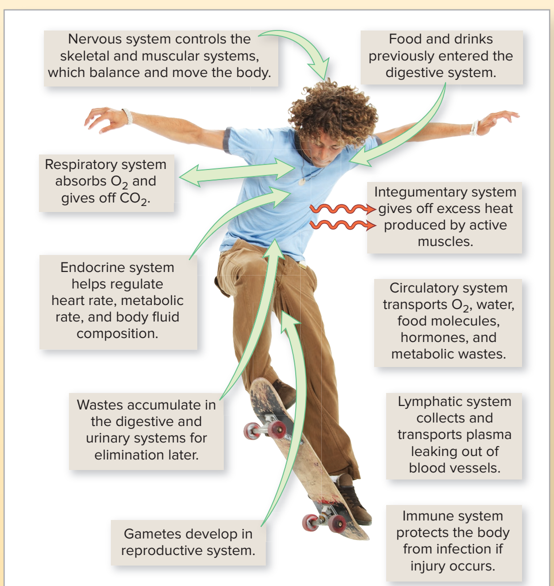
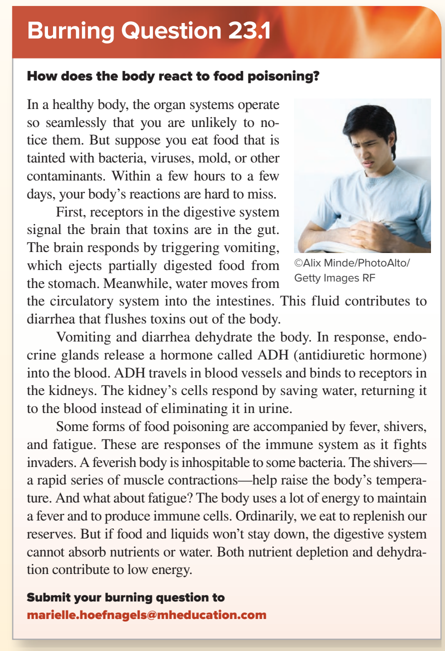


Figure 23.12 **Organ System Functions: A Summary.**

Photo: ©James Woodson/Getty Images RF

- **Summary Illustrations** Created specifically for the summary, these figures tie together the material in a visual way to help you learn relationships among the topics in the chapter. See if you can explain the relationships in your own words, then go back to review any sections you have trouble explaining.
- **Progress Bars** The bars found at the bottom of most pages should help you keep in mind where you are in the chapter's big picture.
- **Why We Care** These boxes reinforce the applications of specific topics to the real world.
- **Burning Question** In this feature, I answer questions from students who are either in my classes or who have written to me with a "burning question" of their own.


Burning Question 23.1

How does the body react to food poisoning?

In a healthy body, the organ systems operate so seamlessly that you are unlikely to notice them. But suppose you eat food that is tainted with bacteria, viruses, mold, or other contaminants. Within a few hours to a few days, your body's reactions are hard to miss.

First, receptors in the digestive system signal the brain that toxins are in the gut. The brain responds by triggering vomiting, which ejects partially digested food from the stomach. Meanwhile, water moves from the circulatory system into the intestines. This fluid contributes to diarrhea that flushes toxins out of the body.

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Vomiting and diarrhea dehydrate the body. In response, endocrine glands release a hormone called ADH (antidiuretic hormone) into the blood. ADH travels in blood vessels and binds to receptors in the kidneys. The kidney's cells respond by saving water, returning it to the blood instead of eliminating it in urine.

Some forms of food poisoning are accompanied by fever, shivers, and fatigue. These are responses of the immune system as it fights invaders. A feverish body is inhospitable to some bacteria. The shivers—a rapid series of muscle contractions—help raise the body's temperature. And what about fatigue? The body uses a lot of energy to maintain a fever and to produce immune cells. Ordinarily, we eat to replenish our reserves. But if food and liquids won't stay down, the digestive system cannot absorb nutrients or water. Both nutrient depletion and dehydration contribute to low energy.

Submit your burning question to marielle.hoefnagels@mheducation.com

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- **Miniglossaries** Most chapters have one or more miniglossaries, brief lists of key terms that help you define and distinguish between interrelated ideas. You can use the miniglossaries to create flashcards, concept maps, and other study aids.
- **Scientific Literacy** These new thought questions at the end of each chapter will help you practice thinking like a scientist about relevant social, political, or ethical issues.
- **Connect®** The content in this textbook is integrated with a wide variety of digital tools available in Connect that will help you learn the connections and relationships that are critical to understanding how biology really works.

Although developing study skills is a major step on the pathway to success, a student's mindset is important too. If you believe that you can develop your talents for biology—even if it takes some hard work—then you set the stage for a successful semester. Anyone can be a "science person."

I hope that you enjoy this text and find that the study tips and tools help you develop an understanding of biology.

Mariëlle Hoefnagels

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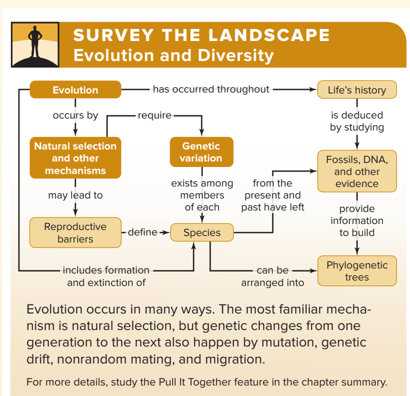
Author's Guide to Using This Textbook

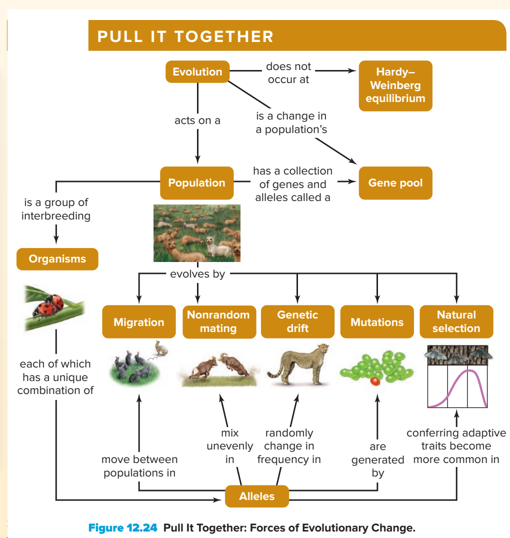
This guide lists key chapter features and describes some of the ways that I use them in my own classes.

> **Learn How to Learn**
> **Focus on Understanding, Not Memorizing**
> When you are learning the language of biology, be sure to concentrate on how each new term fits with the others. Are you studying multiple components of a complex system? Different steps in a process? The levels of a hierarchy? As you study, always make sure you understand how each part relates to the whole. For example, you might jot down brief summaries in the margins of your notes, or you could use lists of boldfaced terms in a chapter to make your own concept map.

Learn How to Learn study tips help students develop their study skills.

Each chapter has one *Learn How to Learn* study tip, and a complete list is in Appendix F. I present a *Study Minute* in class each week, with examples of how to use these study tips.





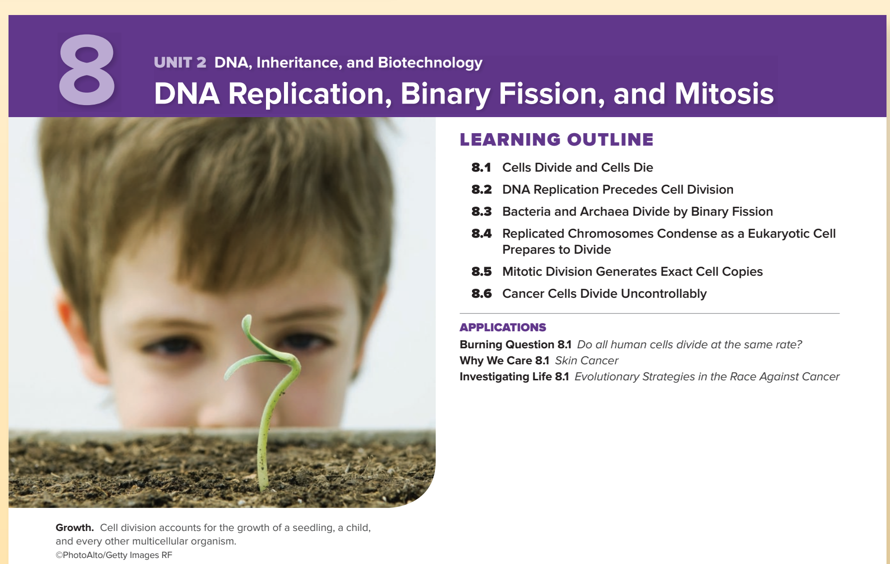
Concept maps help students see the big picture.

New *Survey the Landscape* concept maps at the start of each chapter illustrate how the pieces of the entire unit fit together. These new figures integrate with the existing *Pull It Together* concept maps in the chapter summary.

After spending class time discussing the key points in constructing concept maps, I have my students draw concept maps of their own.

The *Learning Outline* introduces the chapter's main headings and helps students keep the big picture in mind.

Each heading is a complete sentence that summarizes the most important idea of the section. Students can also flip to the end of the chapter before starting to read; the chapter summary and *Pull It Together* concept map can serve as a review or provide a preview of what's to come.



Investigating Life 12.1 | Bacterial Evolution Goes "Hog Wild" on the Farm

Although infectious diseases were once the leading cause of human death, antibiotics had made many bacteria-caused diseases manageable by the mid-1900s. Since that time, bacteria have become resistant not only to the original penicillin but also to the many manufactured antibiotics that followed it. Now antibiotic-resistant bacteria are common, creating new obstacles for physicians treating infectious disease.

Medical practices contribute to the rise of antibiotic-resistant bacteria, but so do farms. Antibiotics promote rapid animal growth when added to the food of cattle, chickens, swine, and other livestock. This practice comes at a cost to public health. The animals' manure contains not only antibiotics but also bacteria that are resistant to the drugs. These microbes swap genes with their neighbors (see figure 8.7). Farms have therefore become breeding grounds for antibiotic-resistant bacteria.

To learn more about this problem, researchers from China and the United States collected manure from three Chinese pig farms where antibiotics are used. Control manure came from pigs that had never been exposed to the drugs. When the team tallied the number of resistance genes in bacterial DNA extracted from each sample, they found that manure from antibiotic-treated animals had many more resistance genes than did control manure (figure 12.A).

But farmers often compost pig manure and then spread it on their croplands. Do the genes persist under those conditions? To find out, the researchers collected samples from compost piles and from the soil in nearby fields. DNA analysis revealed that compost and soil from farms using antibiotics had more diverse resistance genes than did soil from a forest.

These results have serious implications, and not just for farm workers. Since composted animal manure is spread over fields, crops may become contaminated with antibiotic-resistant bacteria. Meat from treated livestock may also harbor resistance genes. When we eat the crops or the meat, bacteria in our intestines may take up the resistance genes.

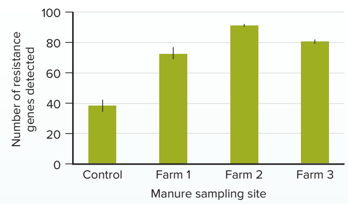


Figure 12.A Antibiotic Resistance on the Farm. The diversity of antibiotic-resistance genes was significantly higher in the manure of antibiotic-fed pigs than in that of untreated animals. Error bars represent the standard error of the mean (see appendix B).

Changes in government policy and consumer awareness may soon decrease the use of antibiotics on farms. As demand for meat from antibiotic-free animals grows, farmers will have an economic incentive to find alternatives to the drugs. The need for change is urgent because some antibiotics may become useless if current practices continue. Evolution never stops, but a thorough understanding of natural selection and bacteria can help us slow the rise of antibiotic resistance.

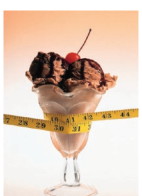
Source: Zhu, Yong-Guan, and seven coauthors, including James M. Tiedje. 2013. Diverse and abundant antibiotic resistance genes in Chinese swine farms. *Proceedings of the National Academy of Sciences*, vol. 110, pages 3435–3440.

***Investigating Life* boxes focus on what introductory science students need:** an understanding of the process of science, an ability to interpret data, and an awareness of how scientific research contributes to our understanding of evolution.

Each box describes a real experiment focusing on an evolutionary topic related to the chapter's content. The studies touch on concepts found in other units; you can encourage students to draw a concept map illustrating the relationships between ideas. You might also use the case as a basis for discussion of the nature of science.

Assignable Connect activities contain questions focused on the process of science, data interpretation, and how the study contributed to our understanding of evolution.

What's the **Point?**



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"I wish I had your metabolism!" Perhaps you have overheard a calorie-counting friend make a similar comment to someone who stays slim on a diet of fattening foods.

In that context, the word *metabolism* means how fast a person burns food. But biochemists define metabolism as all of the chemical reactions that build and break down molecules within any cell. How are these two meanings related?

Interlocking networks of metabolic reactions supply the energy that every cell needs to stay alive. In humans, teams of metabolizing cells perform specialized functions such as digestion, muscle movement, hormone production, and countless other activities. It all takes a reliable energy supply—food, which each of us "burns" at a different rate.

This chapter describes the fundamentals of metabolism, including how cells organize, regulate, and fuel the chemical reactions that sustain life.

***What's the Point?* and *What's the Point? Applied* boxes help relate chapter topics to life outside the classroom.**

These boxes can be used as a starting point for traditional lecture or as the basis for class discussion.

What's the **Point?** APPLIED

Metabolism describes all the chemical reactions in a cell. Because our cells always lose energy as heat, they require constant energy input to continue fueling their reactions. So the familiar definition of metabolism—how fast a person burns calories in food—relates to the rate at which cellular reactions are occurring. What can you do to make your cells use the energy in food more quickly?

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Exercise speeds up the body's energy metabolism in several ways. Immediately after exercise, cells work to rebuild ATP and other energy reserves, so caloric demands are high. Also, body temperature remains elevated for hours after exercise, speeding chemical reactions and contributing to increased metabolism. Regular exercise also increases the size of muscle cells, which require more energy than fat cells even when at rest. Exercise also increases the abundance of enzymes and other proteins that regulate energy metabolism. For example, proteins that transport fatty acids into cells become more numerous after one to two weeks of exercise, providing cells with easier access to energy.

Caffeine may also accelerate metabolism. Although caffeine contains zero calories, many people can attest to the "energy boost" that it provides. Caffeine increases the release of fatty acids into the blood and raises the heart rate, giving cells quick access to energy reserves. However, studies have shown that getting too little sleep (a side effect of excess caffeine) disturbs normal metabolism.

Finally, metabolism slows down when the body receives too few calories. Hormones then signal the body that it is entering a starved state. In response, cells begin to conserve energy via several mechanisms. One way to keep your metabolism high is therefore to maintain your blood sugar level by eating multiple small, healthy meals throughout the day.

***Burning Questions* cover topics that students wonder about.**

Every chapter in the book answers one or more *Burning Questions,* encouraging readers to ask questions of their own. I ask my students to write down a Burning Question on the first day of class. I answer all of them during the semester, whenever a relevant topic comes up in class.

Burning Question 5.1

Why do leaves change colors in the fall?

Most leaves are green throughout a plant's growing season, although there are exceptions; some ornamental plants, for example, have yellow or purple foliage. The familiar green color comes from chlorophyll *a*, the most abundant pigment in photosynthetic plant parts.

But the leaf also has other photosynthetic pigments. Carotenoids contribute brilliant yellow, orange, and red hues. Purple pigments, such as anthocyanins, are not photosynthetically active, but they do protect leaves from damage by ultraviolet radiation.

Carotenoids are less abundant than chlorophyll, so they usually remain invisible to the naked eye during the growing season. As winter approaches, however, deciduous plants prepare to shed their leaves. Anthocyanins accumulate while chlorophyll degrades, and the now "unmasked" accessory pigments reveal their colors for a short time as a spectacular autumn display. These pigments soon disappear as well, and the dead leaves turn brown and fall to the ground.

Spring brings a flush of fresh green leaves. The energy to produce the foliage comes from glucose the plant produced during the last growing season and stored as starch. The new leaves make food throughout the spring and summer, so the tree can grow—both above the ground and below—and produce fruits and seeds.

As the days grow shorter and cooler in autumn, the cycle will continue, and the colorful pigments will again participate in one of nature's great disappearing acts.

Submit your burning question to
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(leaves): ©Carlos E. Santa Maria/Shutterstock RF

The chapter summary highlights key points and terminology from the chapter.

Chapter summary illustrations help students see the big picture.

CHAPTER SUMMARY

9.1 Why Sex?

- **Asexual reproduction** is reproduction without sex. **Sexual reproduction** produces offspring by mixing traits from two parents.
- Asexual reproduction can be successful in a stable environment, but a changing environment selects for sexual reproduction.

9.2 Diploid Cells Contain Two Homologous Sets of Chromosomes

- **Diploid cells** have two full sets of **chromosomes,** one from each parent. A **karyotype** is a chart that displays all of the chromosomes from one cell.
- In humans, the **sex chromosomes** (X and Y) determine whether an individual is male or female. The 22 **homologous pairs** of **autosomes** do not determine sex.
- Homologous chromosomes share the same size, banding pattern, and centromere location, but they differ in the **alleles** they carry.

9.3 Meiosis Is Essential in Sexual Reproduction

- **Meiosis** halves the genetic material to produce **haploid cells. Fertilization** occurs when **gametes** fuse, forming the diploid **zygote. Mitotic** cell division produces the body's cells during growth and development. Figure 9.13 summarizes the events of a sexual life cycle.

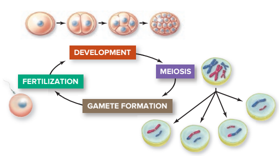

Figure 9.13 Sexual Life Cycle Events.

- **Somatic** cells do not participate in reproduction, whereas diploid **germ cells** produce haploid sex cells.

9.4 In Meiosis, DNA Replicates Once, but the Nucleus Divides Twice

- The events of meiosis ensure that gametes are haploid and genetically variable (figure 9.14).
- During **interphase,** which precedes meiosis, the cell grows and copies its DNA.
- **Spindle** proteins move the chromosomes throughout meiosis. Homologous pairs of chromosomes align during **prophase I,** line up double-file at the cell's center during **metaphase I,** then split apart during **anaphase I.** The chromosomes arrive at the poles in **telophase I,** and the cell often divides **(cytokinesis).**
- The two products of meiosis I each enter meiosis II. The chromosomes condense during **prophase II.** During **metaphase II,** they line up single-file at the cell's equator. The sister chromatids are separated in **anaphase II,** and the chromosomes arrive at the poles in **telophase II.** Cytokinesis then occurs once more to yield four haploid cells.

9.5 Meiosis Generates Enormous Variability

A. Crossing Over Shuffles Alleles

- **Crossing over,** which occurs in prophase I, produces variability when portions of homologous chromosomes switch places. After crossing over, the chromatids carry new combinations of alleles.

B. Homologous Pairs Are Oriented Randomly During Metaphase I

- Every possible orientation of homologous pairs of chromosomes at metaphase I is equally likely. As a result, one person can produce over 8 million genetically different gametes.

C. Random Fertilization Multiplies the Diversity

- Because any sperm can fertilize any egg cell, a human couple can produce over 70 trillion genetically different offspring.
- Identical (monozygotic) twins arise when a zygote splits into two embryos. Fraternal (dizygotic) twins develop from separate zygotes.

9.6 Mitosis and Meiosis Have Different Functions: A Summary

- Mitotic division produces identical copies of a cell and occurs throughout life.
- Meiosis produces genetically different haploid cells. It occurs only in specialized cells and only during some parts of the life cycle.

9.7 Errors Sometimes Occur In Meiosis

A. Polyploidy Means Extra Chromosome Sets

- **Polyploid** cells have one or more extra sets of chromosomes.

B. Nondisjunction Results in Extra or Missing Chromosomes

- **Nondisjunction** is the failure of homologous chromosomes or sister chromatids to separate, causing gametes to have incorrect chromosome numbers. A sex chromosome abnormality is typically less severe than an incorrect number of autosomes.

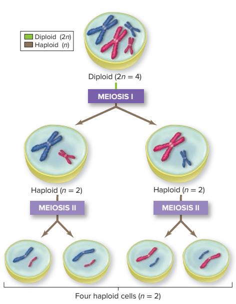

Figure 9.14 Summary of Meiosis.

SCIENTIFIC LITERACY

Review Burning Question 10.1, which describes the inheritance pattern of the metabolic disease called PKU. Today, genetic testing for many disorders is relatively easy and inexpensive. Do prospective parents have an obligation to determine how likely they are to conceive a child with a genetic disorder? What are some possible drawbacks of learning more about one's own genetics? What are some possible advantages to oneself and to society?

New *Scientific Literacy* questions help students understand where biology intersects with ethics, politics, and social issues.

***Write It Out* and *Mastering Concepts* questions are useful for student review or as short in-class writing assignments.**

I compile them into a list of *Guided Reading Questions* that help students focus on material I cover in class. I also use them as discussion questions in Action Centers, where students can come for additional help with course material.

7.5 Mastering Concepts

1. Which steps in gene expression require energy?
2. Why do cells regulate which genes are expressed?
3. How does a repressor protein help regulate the expression of a bacterial operon?
4. Explain how epigenetic modifications change the likelihood of transcription.
5. What is the role of transcription factors in gene expression?

Figure It Out

Compare the number of molecules of ATP generated from 100 glucose molecules undergoing aerobic respiration versus fermentation.

Answer: 3600 (theoretical yield) for aerobic respiration; 200 for fermentation.

***Figure It Out* questions reinforce chapter concepts and typically have numeric answers (supporting student math skills).**

Students can work on these in small groups, in class, or in Action Centers. Most could easily be used as clicker questions as well.

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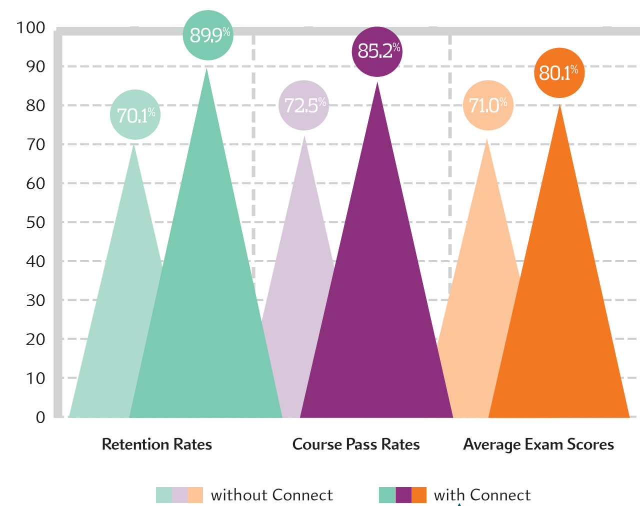

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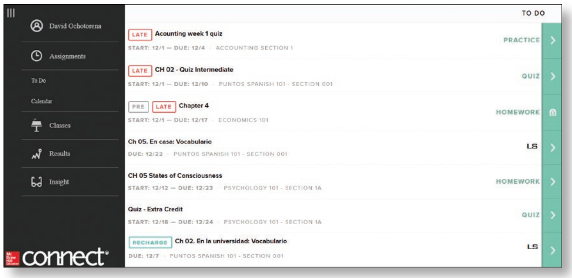

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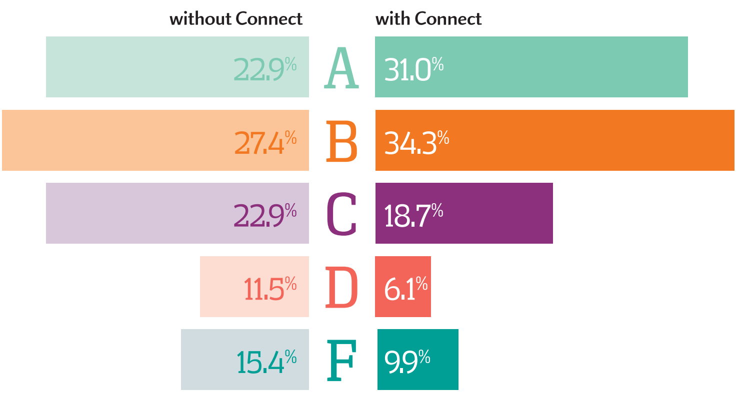

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Changes by Chapter

Chapter 1 (The Scientific Study of Life):

Developed new miniglossary comparing sexual and asexual reproduction; revised figure 1.12 to include experimental design.

Chapter 2 (The Chemistry of Life):

Clarified definitions in miniglossary of matter; added periodic table entry and definitions to figure 2.4; developed new table 2.3 to summarize water's characteristics; improved illustration of cellulose in figure 2.19 to show hydrogen bonds; omitted vitamin D as an example of a steroid; updated nutrition label in *What's the Point? Applied* to conform with latest FDA guidelines; wrote new *Investigating Life* on defensive chemicals in ants; simplified and improved summary figures for clarity.

Chapter 3 (Cells):

Clarified functions of free-floating and membrane-bound ribosomes. Added the following ebook-specific learning tools: table summarizing cell junctions; table summarizing the structures in eukaryotic cells.

Chapter 4 (The Energy of Life):

Explained how kinetic energy relates to an object's temperature; made small changes to section 4.1 to clarify the passage on energy transformations; clarified definition of negative feedback; improved illustrations of plant cells in figure 4.17. Added the following ebook-specific learning tool: table showing types of energy.

Chapter 5 (Photosynthesis):

Expanded miniglossary of leaf anatomy; revised caption of figure 5.5 to clarify components of photosystems (based on SmartBook user data); improved description of electron transport chain in the light reactions; clarified passage on C_4 pathway; wrote new *Investigating Life* on solar-powered salamanders. Added the following ebook-specific learning tool: table summarizing photosynthetic pigments.

Chapter 6 (Respiration and Fermentation):

Changed chapter title to complement "Photosynthesis" chapter title; revised caption of figure 6.2 to include the role of electron carriers (based on SmartBook user data); clarified in several places throughout the chapter that *proton* is synonymous with *hydrogen ion* (H^+); improved figure 6.9 to show how nitrogen from amino acids becomes a metabolic waste (based on SmartBook user data). Added the following ebook-specific learning tools: table showing where respiration occurs in prokaryotes and eukaryotes; table comparing respiration and photosynthesis.

Chapter 7 (DNA Structure and Gene Function):

Omitted the implication that transcription is a stage of protein synthesis (i.e., proteins are produced only in translation); added new miniglossary to help students understand the relationships between nucleotides, genes, chromosomes, and genomes (based on SmartBook user data); clarified that each cell contains many different tRNA molecules; improved figure 7.8 by zooming in on the codon/anticodon interaction (based on SmartBook user data); added photo of translation to complement the translation art in figure 7.9; expanded coverage of epigenetics, both in the main narrative and in *Burning Question 7.1*; added Ebola and Zika viruses to table 7.2, which lists viruses that infect humans; improved viral replication figure 7.18 to show receptors on the entire cell surface; wrote new subsection within section 7.8 explaining how influenza causes symptoms; improved and expanded miniglossary of viruses; clarified *Investigating Life* section and reworked figure 7.A to include evolutionary tree; improved summary figures 7.25, 7.26, and 7.28; added summary table 7.3 comparing viruses and cells. Added the following ebook-specific learning tools: table describing three types of RNA; tables summarizing the stages of transcription and translation (based on SmartBook user data); table summarizing regulated points in protein production.

Chapter 8 (DNA Replication, Binary Fission, and Mitosis):

Improved definitions in miniglossary of cell division; used the words *align* and *line up* consistently (in referring to chromosome movements) to conform with changes in chapter 9; modified *Burning Question 8.1* to include cancer cells; briefly mentioned newer cancer therapies (such as immunotherapy); wrote new *Investigating Life* essay that explains how evolutionary principles can be used in planning chemotherapy; added miniglossary of cell division terms to chapter summary.

Chapter 9 (Sexual Reproduction and Meiosis):

Used the words *align, line up,* and *orient* consistently (when referring to chromosome movements); explicitly listed in the narrative three mechanisms that generate genetic variability and added new *Figure It Out* problem in section 9.5 (based on SmartBook user data); defined recombinant and parental chromatids to improve consistency with chapter 10 and added both terms to a miniglossary; revised figure 9.15 (*Pull It Together*) to improve the connections among the terms.

Chapter 10 (Patterns of Inheritance):

Clarified some headings and subheadings to better reflect chapter content; changed alleles for yellow and green seeds from *G* and *g* to *Y* and *y* in art and narrative; clarified cookbook analogy by relating it back to chapter 7; added an explanation for why certain alleles are recessive; clarified that cells with incorrect chromosome numbers may not have exactly two alleles per gene; reworked *Burning Question 10.1* to focus more on the warning label; improved miniglossary of genetic terms by adding some terms and revising others; improved illustration of test cross (figure 10.8); clarified explanation of the product rule; more clearly distinguished recombinant chromatids from recombinant offspring (based on SmartBook user data); clarified explanation of ABO blood group system; improved explanations of pleiotropy and many gene/one phenotype situations; connected environmental effects on gene expression to epigenetics; reworked figure 10.25 to add the frequency of each possible skin color phenotype; updated *Investigating Life* essay to include two-toxin strategy for slowing the evolution of Bt-resistant insects; added new summary figure 10.26 to show the connection between mutations and Punnett squares; improved summary figure 10.27 to better illustrate the light bulb analogy. Added the following ebook-specific learning tools: new figure depicting the P, F1, and F2 generations (based on SmartBook user data); new summary figure showing a timeline that includes the main genetics-related events described in the chapter.

Chapter 11 (DNA Technology):

Expanded passage on ethical issues related to transgenic organisms; added content on high-throughput DNA sequencing methods; updated data on DNA exonerations; added content on cloning in plants, including a new illustration (figure 11.10); added new subsection to section 11.4 on CRISPR-Cas9, including a new illustration (figure 11.15).

Chapter 12 (Forces of Evolutionary Change):

Improved figure 12.8 to show the connection between natural selection and DNA; added table listing misconceptions about evolution and showing how a biologist would address each (based on SmartBook user data); added new *Burning Question* about whether there is a "pinnacle of evolution"; modified figure 12.13 to make the Hardy–Weinberg equations more prominent; modified figure 12.14 to include three phenotypes for directional selection; clarified the distinction between the bottleneck effect and natural selection; wrote new *Investigating Life* on antibiotic-resistant bacteria from livestock; reworked figure 12.24 (*Pull It Together*) to make it more informative.

Chapter 13 (Evidence of Evolution):

Added the proposed Anthropocene epoch to geologic timescale (figure 13.2); improved figure 13.15 for clarity and to add a lemur example. Added the following ebook-specific learning tools: miniglossary of estimating a fossil's age; miniglossary of comparative anatomy.

Chapter 14 (Speciation and Extinction):

Made small changes to several evolutionary trees to ensure consistent use of the word *ancestor*; added terms to miniglossary of speciation and extinction; revised *Why We Care 14.1* to add new illustration and information about why extinctions are important; wrote new *Burning Question 14.2* ("Did rabbits come from frogs?"); clarified the relationship between genus and species (based on SmartBook user data); wrote a new *Investigating Life* essay on plant "protection rackets." Added the following ebook-specific learning tools: miniglossary of reproductive barriers; new figure showing multiple ways to depict the same evolutionary relationships.

Chapter 15 (Evolution and Diversity of Microbial Life):

Made small changes to several evolutionary trees to ensure consistent use of the word *ancestor*; clarified that the outer membrane is considered part of the cell wall in bacteria; added miniglossary of prokaryote anatomy and revised miniglossary of prokaryote diversity; reworked figure 15.12 to clarify aerobic and anaerobic habitats; foreshadowed in section 15.2C that proteobacteria and cyanobacteria are related to the bacteria participating in endosymbiosis, then returned to that idea in section 15.3A and in figure 15.19; clarified explanation of nitrogen fixation; referred specifically to human microbiota; wrote new *Burning Question 15.2* about areas on Earth without life; added new figure 15.21 to illustrate the evolution of multicellularity; clarified basidiomycete life cycle in figure 15.35; added illustration (figure 15.37) showing fungi in everyday life; based on heat map data, clarified the differences between arbuscular mycorrhizae and ectomycorrhizae and between endophytes and mycorrhizae; revised figure 15.40 to show resources exchanged between the partners in a lichen. Added the following ebook-specific learning tools: miniglossary of types of algae; table of plasmodial and cellular slime mold life cycles; miniglossary of types of protozoa; miniglossary of fungal anatomy; miniglossary of fungal partnerships.

Chapter 16 (Evolution and Diversity of Plants):

In section 16.1's narrative, clarified relationship between zygote and sporophyte (based on SmartBook user data); reworked figure 16.10 to clarify that fern gametophytes do not self-fertilize; in section 16.4, clarified that ovules develop into seeds in narrative and corresponding art. Added the following ebook-specific learning tool: table listing key plant-adaptations.

Chapter 17 (Evolution and Diversity of Animals):

Clarified arrows depicting gastrulation in figure 17.5; added new miniglossary of arthropod diversity; modified figure 17.30 to better highlight the three groups of primates; clarified that *Ardipithecus* species are extinct and mentioned the recently discovered *H. naledi* fossils; added evolutionary tree to figure 17.C (*Investigating Life*).

Chapter 18 (Populations):

Updated demographic data for the world population in art and narrative; improved explanation of the demographic transition and added new illustration (figure 18.14); updated information on China's one-child policy. Added the following ebook-specific learning tool: miniglossary of population growth.

Chapter 19 (Communities and Ecosystems):

Made small corrections to convection cells in figure 19.4; added new figure 19.14 to illustrate mutualism and commensalism; updated data about mercury in tuna; added new *Burning Question 19.2,* comparing bottled water with tap water; clarified the meaning of the word *eutrophication*; wrote new *Investigating Life* essay on monarch butterfly migration.

Chapter 20 (Preserving Biodiversity):

Added the term *Anthropocene* and a new illustration (figure 20.2) illustrating where human impacts on the biosphere are most intense; mentioned the acronym HIPPO at the start of the chapter; added landfills as a source of water pollution; improved narrative and figure 20.9 explaining acid deposition; updated narrative and improved figure 20.10 explaining greenhouse effect; added graph to figure 20.12 showing decline in the extent of Arctic sea ice; added advice for people who fish to *Burning Question 20.5*; clarified figure 20.19 (*Pull It Together*). Added the following ebook-specific learning tools: table listing consequences of global climate change; miniglossary of pollution.

Chapter 21 (Plant Form and Function):

Added art of shoot apical meristem to figure 21.15; clarified that *axillary bud* and *lateral bud* are synonymous; wrote new *Burning Question 21.2* about controlled burns; clarified that hormones are present in xylem sap; added photo of a wilted plant (figure 21.21) and a corresponding description of why plants wilt when soil is too dry.

Chapter 22 (Reproduction and Development of Flowering Plants):

Clarified passage on flower structure; added miniglossary of the angiosperm life cycle (based on SmartBook user data); clarified passage on coevolution between flowers and pollinators; clarified role of cotyledons in eudicots and monocots; added photo of coconut to figure 22.9 to show a water-dispersed fruit; added new *Why We Care 22.1* on "talking plants"; annotated figure 22.15 to show how photoperiod affects flowering time.

Chapter 23 (Animal Tissues and Organ Systems):

Modified art for simple columnar epithelium in figure 23.2 to better match the accompanying photo; added new *Burning Question 23.1* on the body's reaction to food poisoning; clarified narrative and figure 23.8 to identify the stimulus, sensor, control center, and effector(s); added miniglossary of negative feedback; clarified definition of ectotherm. Added the following ebook-specific learning tools: miniglossary of animal anatomy and physiology; miniglossary of animal tissues; miniglossary of temperature homeostasis.

Chapter 24 (The Nervous System and the Senses):

Added new miniglossary of neuron anatomy; clarified definitions of *membrane potential* and *resting potential* (based on SmartBook user data); clarified why the inside of a resting neuron has a net negative charge; labeled the voltage meters in figures 24.4 and 24.5 to clarify their function; added context to figure 24.13 illustrating the blood–brain barrier; added information about concussions to section 24.6; wrote new *Burning Question 24.2* explaining whether we use 10% of our brain; improved figure 24.19 by showing context for the olfactory bulb and olfactory epithelium; added new miniglossary of vision; clarified in figure 24.24 that the overlying membrane in the cochlea does not consist of cells; expanded description of cochlear implants. Added the following ebook-specific learning tools: miniglossary of membrane potentials; miniglossary of smell and taste; miniglossary of hearing.

Chapter 25 (The Endocrine System):

Added paragraph about negative feedback loops to section 25.1; clarified that internal hormone receptors may be in the cytosol or in the nucleus and elaborated that steroid hormones may either stimulate or inhibit protein production (based on SmartBook user data); completed descriptions of effects of ADH and oxytocin in figure 25.4; reworked *Burning Question 25.1* to focus on endocrine disruptors; adjusted labels in figure 25.7 to add the role of the hypothalamus as a sensor; adjusted labels in figure 25.9 to add the role of the pancreas as a sensor; reworked figure 25.11 showing the correlation between obesity and diabetes; reworked the *What's the Point? Applied* box to focus on chronic stress. Added the following ebook-specific learning tool: summary table of hormones and their functions.

Chapter 26 (The Skeletal and Muscular Systems):

Clarified illustration of scoliosis (figure 26.3); revised figures in section 26.4 for clarity and improved page layout; improved description of the sarcomere and of the cross bridges in the sliding filament model; added a paragraph about sports balms to *Burning Question 26.2*; added miniglossary of the muscular system to the chapter summary. Added the following ebook-specific learning tool: table outlining the steps of muscle contraction.

Chapter 27 (The Circulatory and Respiratory Systems):

Improved consistency between ABO blood type passage in section 27.1 and related material in section 10.6; clarified the roles of the pulmonary and systemic circulation, especially with regard to O_2 and CO_2 (based on SmartBook user data); wrote new *Burning Question 27.3* on extreme exercise; added terms to the miniglossary of circulation; clarified blood pressure monitors in figure 27.13. Added the following ebook-specific learning tools: miniglossary of the heartbeat; miniglossary of breathing.

Chapter 28 (The Digestive and Urinary Systems):

Improved consistency in the use of *ions* and *salts* throughout the chapter (based on SmartBook user data); added information about how a high-fiber diet lowers cholesterol and helps regulate blood sugar; updated figure 28.4 to reflect new nutrition label regulations; added *Burning Question 28.1* about fad diets; clarified that the stomach does not absorb the proteins it begins to digest (based on SmartBook user data); clarified illustration of the large intestine (figure 28.19).

Chapter 29 (The Immune System):

Improved explanation of lymph; clarified narrative, figure 29.7, and figure 29.10 to show clonal selection for both T cells and B cells; added paragraph about cancer immunotherapy; reworked figure 29.13 illustrating the effects of immunodeficiencies; clarified that mast cells and basophils participate in allergies; added new *Burning Question 29.2* about tick-transmitted meat allergies; added narrative about “retraining” the immune system in children with peanut allergies.

Chapter 30 (Animal Reproduction and Development):

Clarified description of external fertilization; improved explanation of how oocytes enter uterine tubes; changed *sexually transmitted diseases* to *sexually transmitted infections* to recognize that not all infections lead to visible disease symptoms; added a labeled sperm cell to figure 30.12 to remind students where the acrosome is (based on SmartBook user data); clarified two descriptions in table 30.4; improved the explanation and illustration (figure 30.15) of the placenta’s structure and function; added labels to clarify the stages of childbirth in figure 30.18; added new summary figure 30.20 to illustrate the paths of sperm and egg cells. Added the following ebook-specific learning tools: miniglossary of embryonic support structures; new summary table showing a timeline of human development (based on SmartBook user data).

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It takes an army of people to make a textbook, and while I don't work with everyone directly, I greatly appreciate the contributions of each person who makes it possible.

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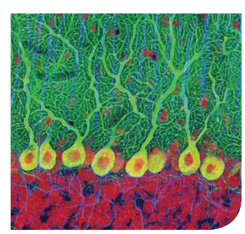

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THIRD EDITION

BIOLOGY

THE ESSENTIALS

1

UNIT 1 Science, Chemistry, and Cells

The Scientific Study of Life

Biology Is Everywhere. Central Park is an oasis of green in New York City, but life thrives in the city's streets and buildings too.

LEARNING OUTLINE

APPLICATIONS

Burning Question 1.1 *Are viruses alive?*

Why We Care 1.1 *It's Hard to Know What's Bad for You*

Burning Question 1.2 *Why am I here?*

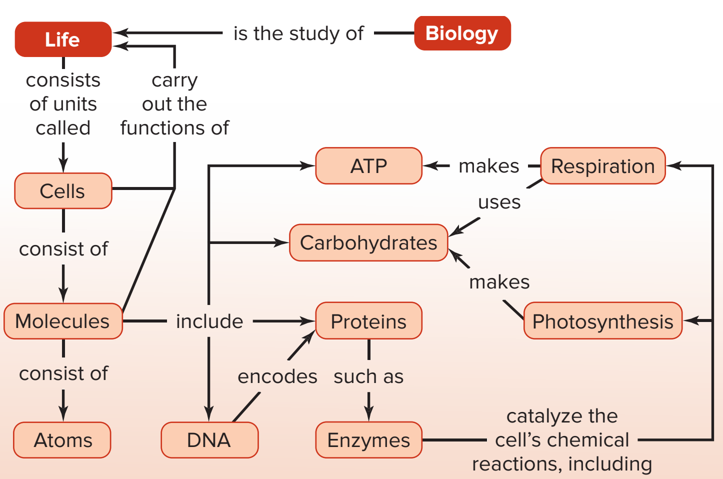
Investigating Life 1.1 *The Orchid and the Moth*

Learn How to Learn

Real Learning Takes Time

You got good at basketball, running, dancing, art, music, or video games by putting in lots of practice. Likewise, you will need to commit time to your biology course if you hope to do well. To get started, look for the Learn How to Learn tip in each chapter of this textbook. Each hint is designed to help you use your study time productively. With practice, you'll discover that all concepts in biology are connected. The Survey the Landscape figure in every chapter highlights each chapter's place in the "landscape" of the entire unit. Use it, along with the more detailed Pull It Together concept map in the chapter summary, to see how each chapter's content fits into the unit's big picture.

SURVEY THE LANDSCAPE
Science, Chemistry, and Cells



Organisms from all three branches of life share a unique combination of characteristics. Biologists are scientists who use evidence to test hypotheses about life.

For more details, study the Pull It Together feature in the chapter summary.

What's the **Point?**

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Imagine a biologist. If you are like many people, you may have pictured someone in a lab coat, carefully recording a mouse's reaction to some new drug. But this view of biology as something that happens only in a laboratory is much too limited. Indeed, we need not even leave home to study biology. Life is in parks, backyards, and the strips between streets and sidewalks. It's also in office buildings and restaurants, not only because we are alive but also because countless microorganisms live everywhere, smaller than the eye can see. The food you have eaten today was (until recently, anyway) alive. Biology really is everywhere.

Biology is frequently in the news, in the form of stories about fossils, weight loss, cancer, genetics, climate change, and the environment. Topics such as these enjoy frequent media coverage because this is an exciting time to study biology. Not only is the field changing rapidly, but its new discoveries and applications might change your life. DNA technology has brought us genetically engineered bacteria that can manufacture pharmaceutical drugs—and genetically engineered corn plants that produce their own pesticides. One day, physicians may routinely cure inherited diseases by supplementing faulty DNA with a functional "patch."

This book will bring you a taste of modern biology and help you make sense of the science-related news you see every day. Chapter 1 begins your journey by introducing the scope of biology and explaining how science teaches us what we know about life.

1.1 What Is Life?

Welcome to biology, the scientific study of life. The second half of this chapter explores the meaning of the term *scientific,* but first we will consider the question, "What is life?" We all have an intuitive sense of what life is. If we see a rabbit on a rock, we know that the rabbit is alive and the rock is not. But it is difficult to state just what makes the rabbit alive. Likewise, in the instant after an individual dies, we may wonder what invisible essence has transformed the living into the dead.

One way to define life is to list its basic components. The **cell** is the basic unit of life; every **organism,** or living individual, consists of one or more cells. Every cell has an outer membrane that separates it from its surroundings. This membrane encloses the water and other chemicals that carry out the cell's functions. One of those biochemicals, deoxyribonucleic acid (DNA), is the informational molecule of life (figure 1.1). Cells use genetic instructions—as encoded in DNA—to produce proteins, which enable cells to carry out their functions in tissues, organs, and organ systems.

A list of life's biochemicals, however, provides an unsatisfying definition of life. After all, placing DNA, water, proteins, and a membrane in a test tube does not create life. And a crushed insect still contains all of the biochemicals that it had immediately before it died.

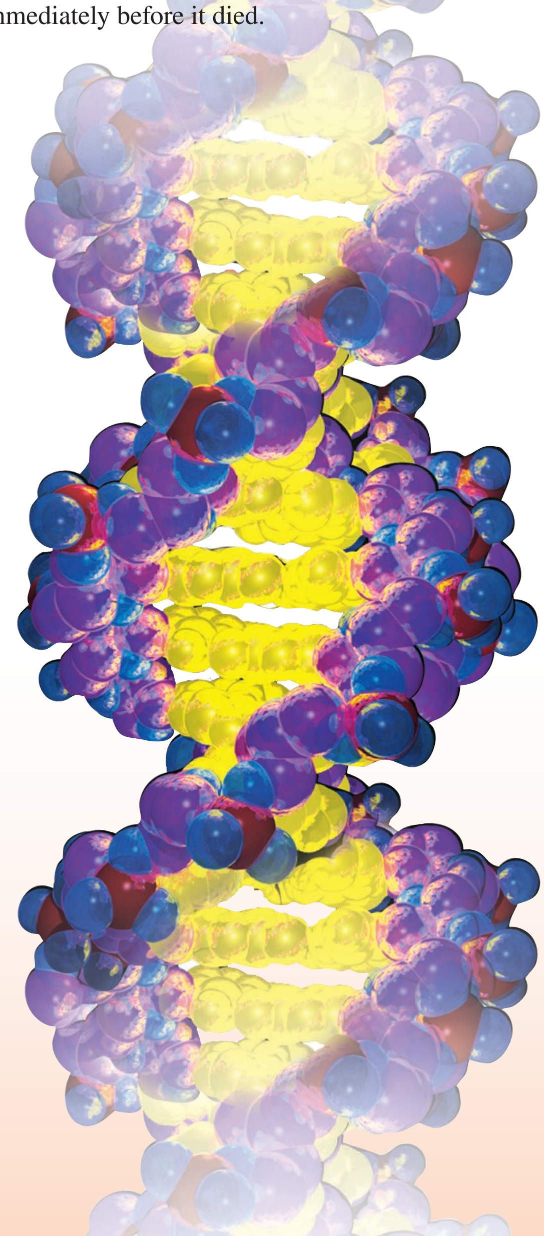

Figure 1.1 Informational Molecule of Life. All cells contain DNA, a series of "recipes" for proteins that each cell can make.
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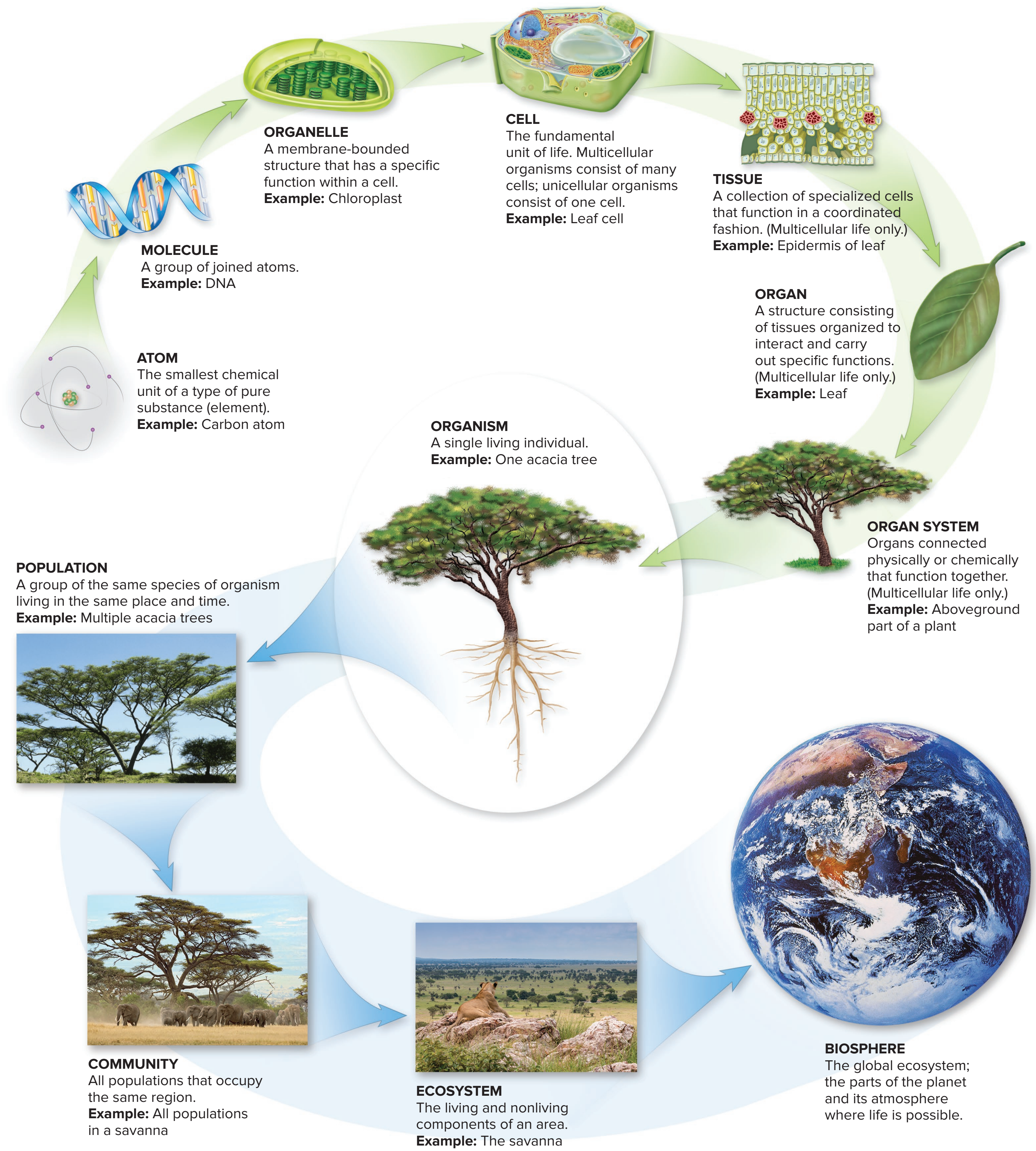


Figure 1.2 Life's Organizational Hierarchy. This diagram applies life's organizational hierarchy to a multicellular organism (an acacia tree). Green arrows represent the hierarchy up to the level of the organism; blue arrows represent levels that include multiple organisms. Photos: (population): ©Gregory G. Dimijian, M.D./Science Source; (community): ©Daryl Balfour/Gallo Images/Getty Images; (ecosystem): ©Bas Vermolen/Getty Images; (biosphere): ©StockTrek/Getty Images

In the absence of a concise definition, scientists have settled on five qualities that, in combination, constitute life. Table 1.1 summarizes them, and the rest of section 1.1 describes each one in more detail. An organism is a collection of structures that function together and exhibit all of these qualities (see Burning Question 1.1). Note, however, that each trait in table 1.1 may also occur in nonliving objects. A rock crystal is highly organized, but it is not alive. A fork placed in a pot of boiling water absorbs heat energy and passes it to the hand that grabs it, but this does not make the fork alive. A fire can "reproduce" and grow, but it lacks most of the other characteristics of life. It is the *combination* of these five characteristics that makes life unique.

TABLE 1.1 Characteristics of Life: A Summary

Characteristic	Example
Organization	Atoms make up molecules, which make up cells, which make up tissues, and so on.
Energy use	A kitten uses the energy from its mother's milk to fuel its own growth.
Maintenance of internal constancy (homeostasis)	Your kidneys regulate your body's water balance by adjusting the concentration of your urine.
Reproduction, growth, and development	An acorn germinates, develops into an oak seedling, and, at maturity, reproduces sexually to produce its own acorns.
Evolution	Increasing numbers of bacteria survive treatment with antibiotic drugs.

A. Life Is Organized

Just as the city where you live belongs to a county, state, and nation, living matter also consists of parts organized in a hierarchical pattern (figure 1.2). At the smallest scale, all living structures are composed of particles called **atoms,** which bond together to form **molecules.** These molecules can form **organelles,** which are compartments that carry out specialized functions in cells (note that not all cells contain organelles). Many organisms consist of single cells. In multicellular organisms such as the tree illustrated in figure 1.2, however, the cells are organized into specialized **tissues** that make up **organs.** Multiple organs are linked into an individual's **organ systems.**

We have now reached the level of the organism, which may consist of just one cell or of many cells organized into tissues, organs, and organ systems. Organization in the living world extends beyond the level of the individual organism as well. A **population** includes members of the same species occupying the same place at the same time. A **community** includes the populations of different species in a region, and an **ecosystem** includes both the living and nonliving components of an area. Finally, the **biosphere** consists of all parts of the planet that can support life.

Biological organization is apparent in all life. Humans, eels, and evergreens, although outwardly very different, are all organized into specialized cells, tissues, organs, and organ systems. Single-celled bacteria, although less complex than animals or plants, still contain DNA, proteins, and other molecules that interact in highly organized ways.

An organism, however, is more than a collection of successively smaller parts. **Emergent properties** are new functions that arise from interactions among a system's components, much as flour, sugar, butter, and chocolate can become brownies—something not evident from the parts themselves. Figure 1.3 shows another example of emergent properties: the thoughts and memories produced by interactions among the neurons in a person's brain. For an emergent property, the whole is greater than the sum of the parts.

Emergent properties explain why structural organization is closely tied to function. Disrupt a structure, and its function ceases. Brain damage, for instance, disturbs the interactions between brain cells and can interfere with memory, coordination, and other brain functions. Likewise, if a function is interrupted, the corresponding structure eventually breaks down, much as unused muscles begin to waste away. Biological function and form are interdependent.

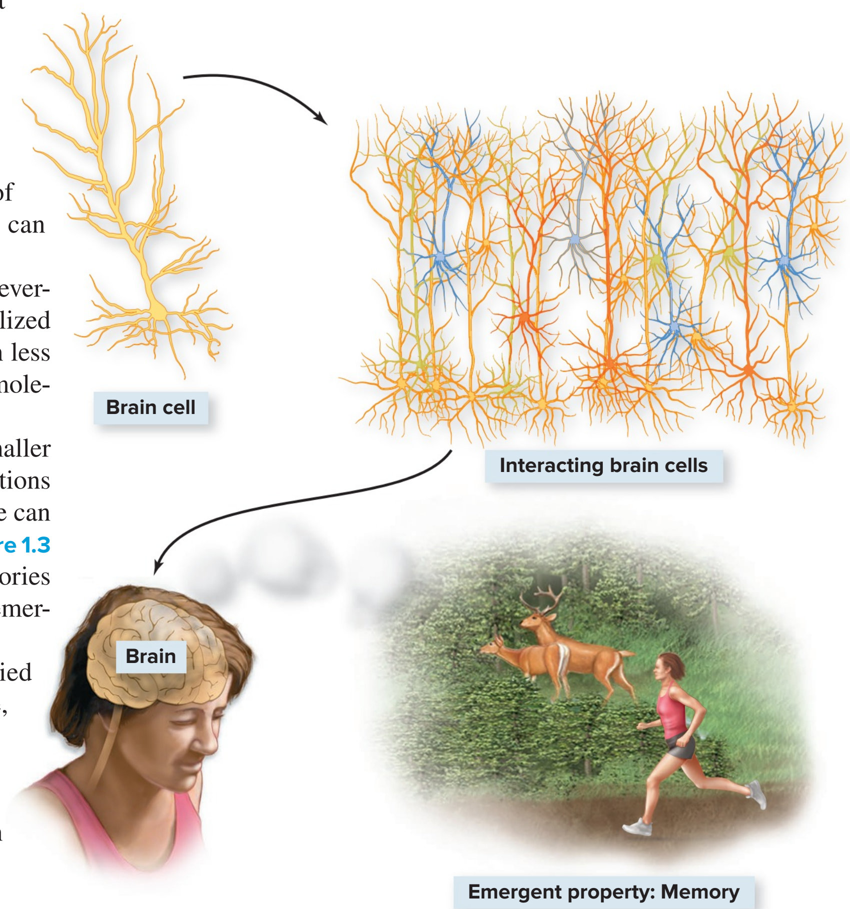


Figure 1.3 An Emergent Property—From Cells to Memories. Highly branched cells interact to form a complex network in the brain. Memories, consciousness, and other qualities of the mind emerge only when these cells interact in a certain way.

B. Life Requires Energy

Inside each cell, countless chemical reactions sustain life. These reactions, collectively called metabolism, allow organisms to acquire and use energy and nutrients to build new structures, repair old ones, and reproduce.

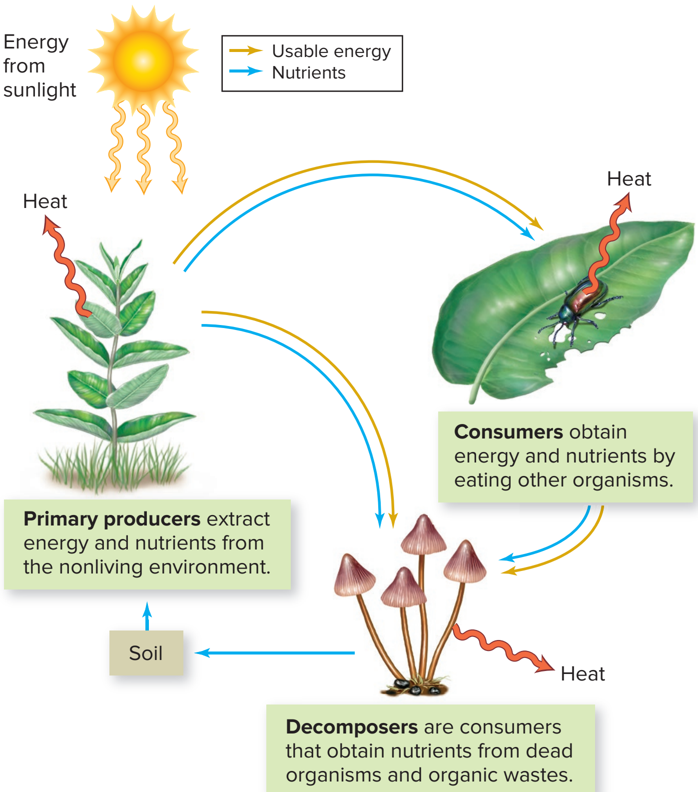


Figure 1.4 Life Is Connected. All organisms extract energy and nutrients from the nonliving environment or from other organisms. Decomposers recycle nutrients back to the nonliving environment. At every stage along the way, heat is lost to the surroundings.

Biologists divide organisms into broad categories, based on their source of energy and raw materials (figure 1.4). **Primary producers,** also called *autotrophs,* make their own food by extracting energy and nutrients from nonliving sources. The most familiar primary producers are the plants and microbes that capture light energy from the sun, but some bacteria can derive chemical energy from rocks. **Consumers,** in contrast, obtain energy and nutrients by eating other organisms, living or dead; consumers are also called *heterotrophs* (*hetero-* means "other"). You are a consumer, relying on energy and atoms from food to stay alive. **Decomposers** are heterotrophs that absorb energy and nutrients from wastes or dead organisms. These organisms, which include fungi and some bacteria, recycle nutrients to the nonliving environment.

Within an ecosystem, organisms are linked into elaborate food webs, beginning with primary producers and continuing through several levels of consumers (including decomposers). But energy transfers are never 100% efficient; some energy is always lost to the surroundings in the form of heat (see figure 1.4). Because no organism can use it as an energy source, heat represents a permanent loss from the cycle of life. All ecosystems therefore depend on a continuous stream of energy from an outside source, usually the sun. ⓘ *food webs,* section 19.6A

C. Life Maintains Internal Constancy

The conditions inside cells must remain within a constant range, even if the surrounding environment changes. For example, a cell must maintain a certain temperature; it will die if it becomes too hot or too cold. The cell must also take in nutrients, excrete wastes, and regulate its many chemical reactions to prevent a shortage or surplus of essential substances. **Homeostasis** is this state of internal constancy, or equilibrium.

Because cells maintain homeostasis by counteracting changes as they occur, organisms must be able to sense and react to stimuli. To illustrate this idea, consider the mechanisms that help maintain your internal temperature at about 37°C (figure 1.5). When you go outside on a cold day, you may begin to shiver; heat from these muscle movements warms the body. In severe cold, your lips and fingertips may turn blue as your circulatory system sends blood away from your body's surface. Conversely, on a hot day, sweat evaporating from your skin helps cool your body.

a. b.

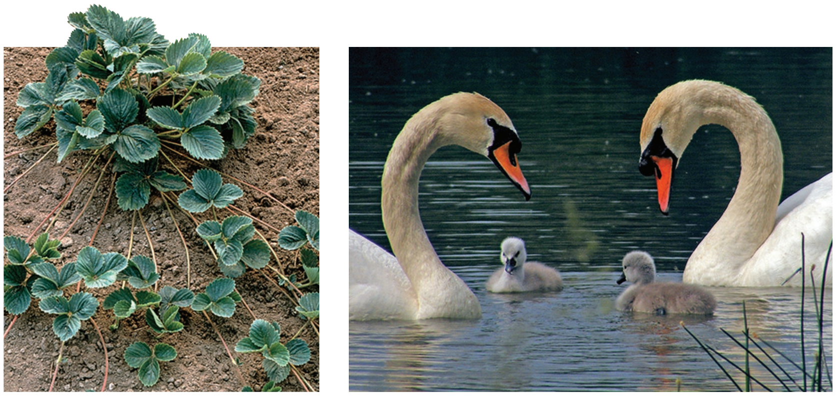
Figure 1.5 Temperature Homeostasis. (a) Shivering and (b) sweating are responses that maintain body temperature within an optimal range.

D. Life Reproduces, Grows, and Develops

Organisms reproduce, making other individuals that are similar to themselves (figure 1.6). Reproduction transmits DNA from generation to generation; this genetic information defines the inherited characteristics of the offspring.

Reproduction occurs in two basic ways: asexually and sexually. In **asexual reproduction,** genetic information comes from only one parent, and all offspring are virtually identical. One-celled organisms such as bacteria reproduce asexually by doubling and then dividing the contents of the cell. Many multicellular organisms also reproduce asexually. A strawberry plant, for instance, produces "runners" that sprout leaves and roots, forming new plants that are identical to the parent. Fungi produce countless asexual spores, visible as the green, white, or black powder on moldy bread or cheese. Some animals, including sponges, reproduce asexually when a fragment of the parent animal detaches and develops into a new individual.

In **sexual reproduction,** genetic material from two parents unites to form an offspring, which has a new combination of inherited traits. By mixing genes at each generation, sexual reproduction results in tremendous diversity in a



a. b.

Figure 1.6 Asexual and Sexual Reproduction. (a) Identical plantlets develop along the runners of a wild strawberry plant. (b) Two swans protect their offspring, the products of sexual reproduction.

Miniglossary | Reproduction

Asexual reproduction	Only one parent passes genetic information to offspring; produces genetically identical offspring (except for mutations); adaptive in unchanging environments
Sexual reproduction	Genetic material from two parents combines to form offspring; produces genetically variable offspring; adaptive in changing environments

population. Genetic diversity, in turn, enhances the chance that some individuals will survive even if conditions change. Sexual reproduction is therefore a very successful strategy, especially in an environment where conditions change frequently; it is extremely common among plants, animals, and fungi.

If each offspring is to reproduce, it must grow and develop to adulthood. Each young swan in figure 1.6, for example, started as a single fertilized egg cell. That cell divided over and over, developing into an embryo. Continued cell division and specialization yielded the newly hatched swans, which will eventually mature into adults that can also reproduce—just like their parents.

E. Life Evolves

One of the most intriguing questions in biology is how organisms become so well-suited to their environments. A beaver's enormous front teeth, which never stop growing, are ideal for gnawing wood. Tubular flowers have exactly the right shapes for the beaks of their hummingbird pollinators. Some organisms have color patterns that enable them to fade into the background (figure 1.7).

These examples, and countless others, illustrate adaptations. An **adaptation** is an inherited characteristic or behavior that enables an organism to survive and reproduce successfully in its environment.

Where do these adaptive traits come from? The answer lies in natural selection. The simplest way to think of natural selection is to consider two facts. First, populations produce many more offspring than will survive to reproduce; these organisms must compete for limited resources such as food and habitat. A single mature oak tree may produce thousands of acorns in one season, but only a few are likely to germinate, develop, and reproduce. The rest die. Second, no organism is exactly the same as any other. Genetic mutations—changes in an organism's DNA sequence—generate variability in all organisms, even those that reproduce asexually.

Of all the offspring in a population, which ones will outcompete the others and live long enough to reproduce? The answer is those with the best adaptations to the current environment; conversely, the poorest competitors are most likely to die before reproducing. A good definition of **natural selection,** then, is the enhanced reproductive success of certain individuals from a population based on inherited characteristics.

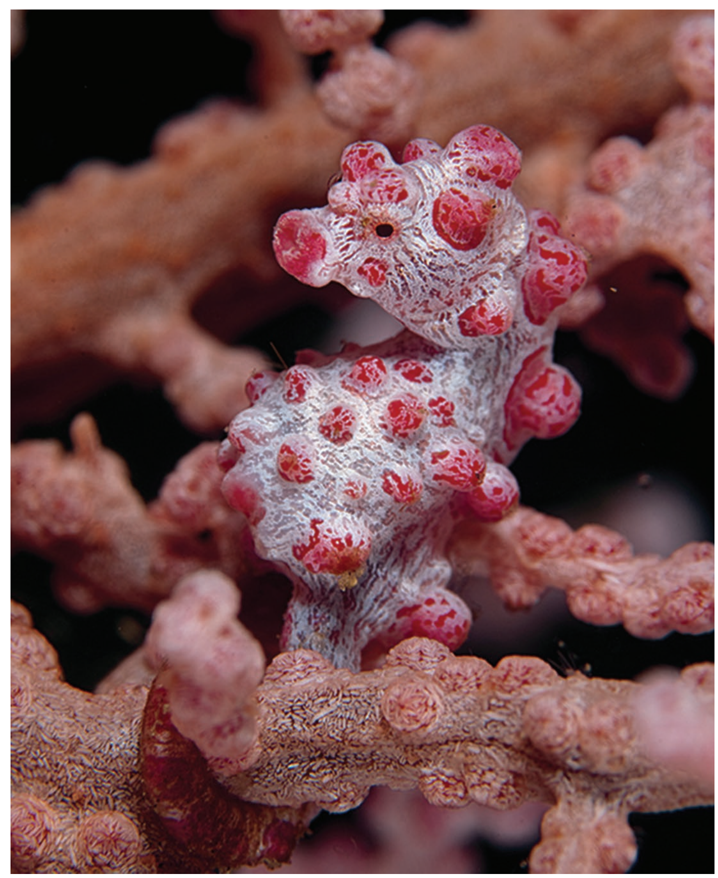
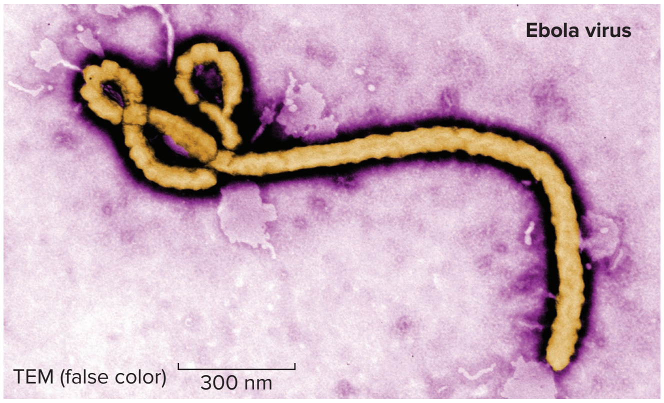


Figure 1.7 Hiding in Plain Sight. This pygmy seahorse is barely visible in its coral habitat, thanks to its unique body shape, skin color, and texture.

Burning Question 1.1

Are viruses alive?



Source: CDC/Frederick Murphy

Many people combine viruses and bacteria into the category of "germs." This terminology makes sense because both viruses and bacteria are microscopic and can cause disease. But they are not the same thing.

A bacterium is a cell, complete with a membrane, cytoplasm, DNA, and proteins. Viruses, on the other hand, are not cells. Instead, the simplest virus consists of a protein shell surrounding a small amount of genetic material. Other viruses have more complex features, but no virus has the structure or functions of a cell.

Most biologists do not consider a virus to be alive because it does not metabolize, respond to stimuli, or reproduce on its own. Instead, a virus must enter a living host cell to manufacture more of itself.

Nevertheless, viruses do have some features in common with life, including evolution. Each time a virus replicates inside a host cell, random mutations occur in its genetic information. The resulting variability among the new viruses is subject to natural selection. That is, some variants are better than others at infecting and replicating in host cells. Many mutant viruses die out, but others pass their successful gene versions to the next generation. Over time, natural selection shapes the genetic composition of each viral population.

Submit your burning question to
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Figure 1.8 shows one example of natural selection. The illustration shows a population of bacteria in which a mutation has occurred in one cell. If antibiotics are present, the drug kills most of the unmutated cells. The mutated cell, however, is unaffected and can reproduce. After many generations of exposure to the drug, antibiotic-resistant cells are common.

The same principle applies to all populations. In general, individuals with the best combinations of genes survive and reproduce, while those with less suitable characteristics fail to do so. Over many generations, individuals with adaptive traits make up most or all of the population.

But the environment is constantly changing. Continents shift, sea levels rise and fall, climates warm and cool. What happens to a population when the selective forces that drive natural selection change? Only some organisms survive: those with the "best" traits in the *new* environment. Features that may once have been rare become more common as the reproductive success of individuals with those traits improves. Notice, however, that this outcome depends on variability within the population. If no individual can reproduce in the new environment, the species may go extinct.

Natural selection is one mechanism of **evolution,** which is a change in the genetic makeup of a population over multiple generations. Although evolution can also occur in other ways, natural selection is the mechanism that selects for adaptations. Charles Darwin became famous in the 1860s after he published a book describing the theory of evolution by natural selection; another naturalist, Alfred Russel Wallace, independently developed the same idea at around the same time.

Evolution is the single most powerful idea in biology. As unit 3 describes in detail, the similarities among existing organisms strongly suggest that all species descend from a common ancestor. Evolution has molded the life that has populated the planet since the first cells formed almost 4 billion years ago, and it continues to act today.

1.1 Mastering Concepts

1. List life's organizational hierarchy from smallest to largest, starting with atoms and ending with the biosphere.
2. The bacteria in figure 1.8 reproduce asexually, yet they are evolving. What is their source of genetic variation?

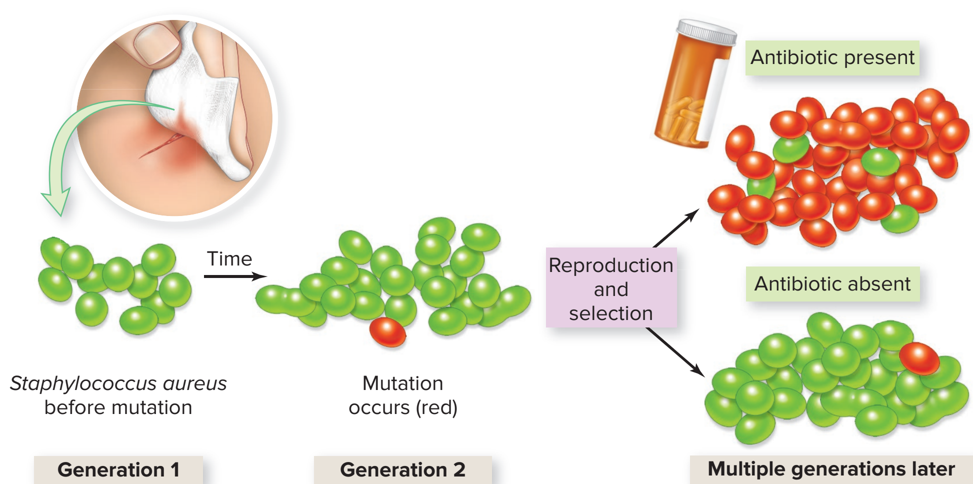

Figure 1.8 Natural Selection. *Staphylococcus aureus* (commonly called "staph") is a bacterium that causes skin infections. A bacterium undergoes a random genetic mutation that (by chance) makes the cell resistant to an antibiotic. The presence of the antibiotic increases the reproductive success of the resistant cell and its offspring. After many generations, nearly all of the bacteria in the population are antibiotic-resistant. Conversely, if antibiotics are absent, the antibiotic-resistance trait remains rare.

1.2 The Tree of Life Includes Three Main Branches

Biologists have been studying life for centuries, documenting the existence of everything from bacteria to blue whales. An enduring problem has been how to organize the ever-growing list of known organisms into meaningful categories. **Taxonomy** is the science of naming and classifying organisms.

The basic unit of classification is the **species,** which designates a distinctive "type" of organism. Closely related species are grouped into the same **genus.** Together, the genus and a specific descriptor denote the unique, two-word scientific name of each species. A human, for example, is *Homo sapiens.* (Note that scientific names are always italicized and that the genus—but not the specific descriptor—is capitalized.) Scientific names help taxonomists and other biologists communicate with one another.

But taxonomy involves more than simply naming species. Taxonomists also strive to classify organisms according to what we know about evolutionary relationships; that is, how recently one type of organism shared an ancestor with another type. The more recently they diverged from a shared ancestor, the more closely related we presume the two types of organisms to be (figure 1.9). Researchers infer these relationships by comparing anatomical, behavioral, cellular, genetic, and biochemical characteristics.

Genetic evidence suggests that all species fall into one of three **domains,** the broadest (most inclusive) taxonomic category. Figure 1.10 depicts the three domains: **Bacteria, Archaea,** and **Eukarya.** The species in domains Bacteria and Archaea are superficially similar to one another; all are prokaryotes, meaning that their DNA is free in the cell and not confined to an organelle called a nucleus. Major differences in DNA sequences separate these two domains from each other. The third domain, Eukarya, contains all species of eukaryotes, which are unicellular or multicellular organisms whose cells contain a nucleus.

ⓘ *prokaryotes and eukaryotes*, section 3.2

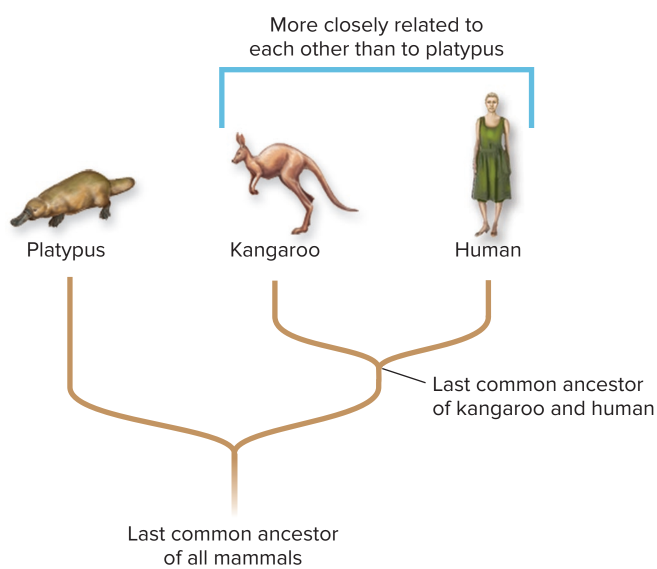

Figure 1.9 Simple Evolutionary Tree. The common ancestor of kangaroos and humans lived more recently than did the common ancestor that both groups share with a platypus. This diagram depicts one tiny twig in the overall tree of life.

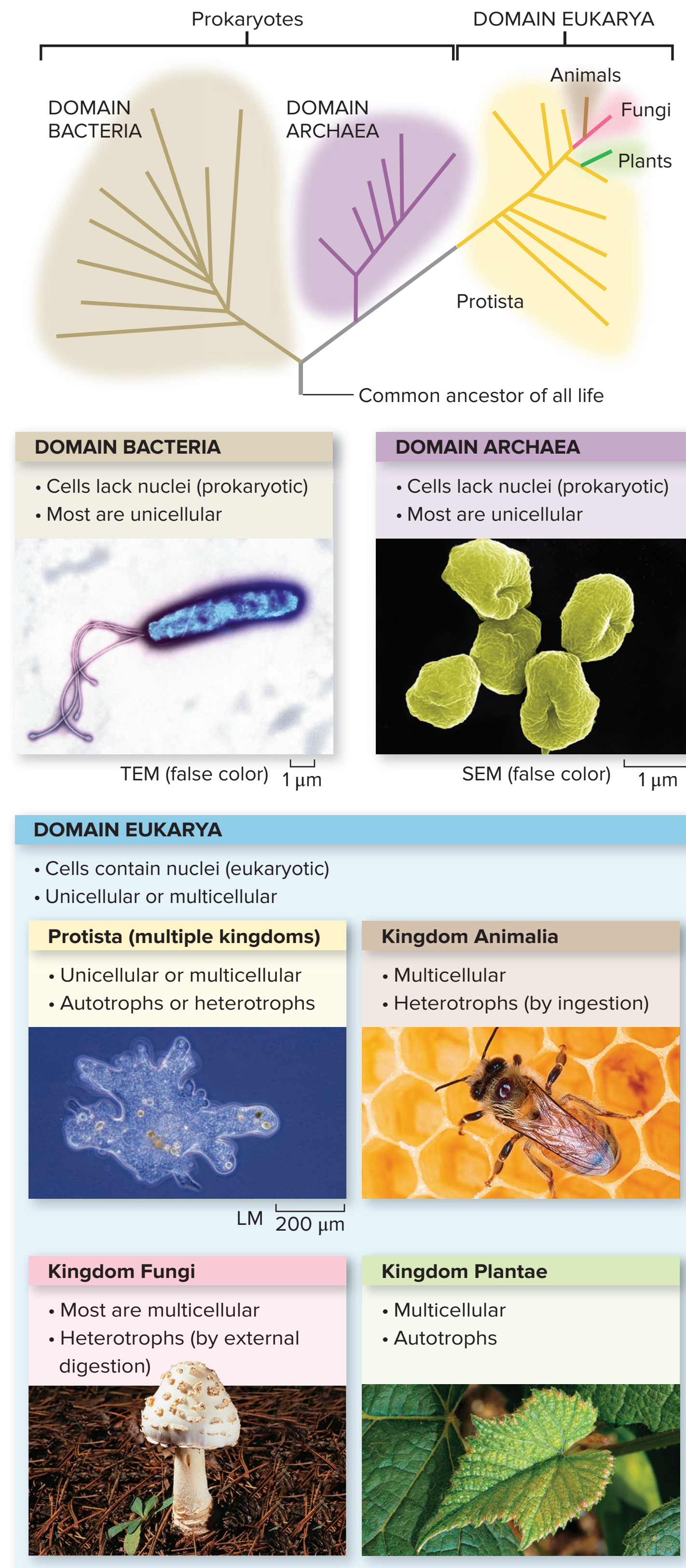

Figure 1.10 Life's Diversity. The three domains of life arose from a hypothetical common ancestor, shown at the base of the evolutionary tree.