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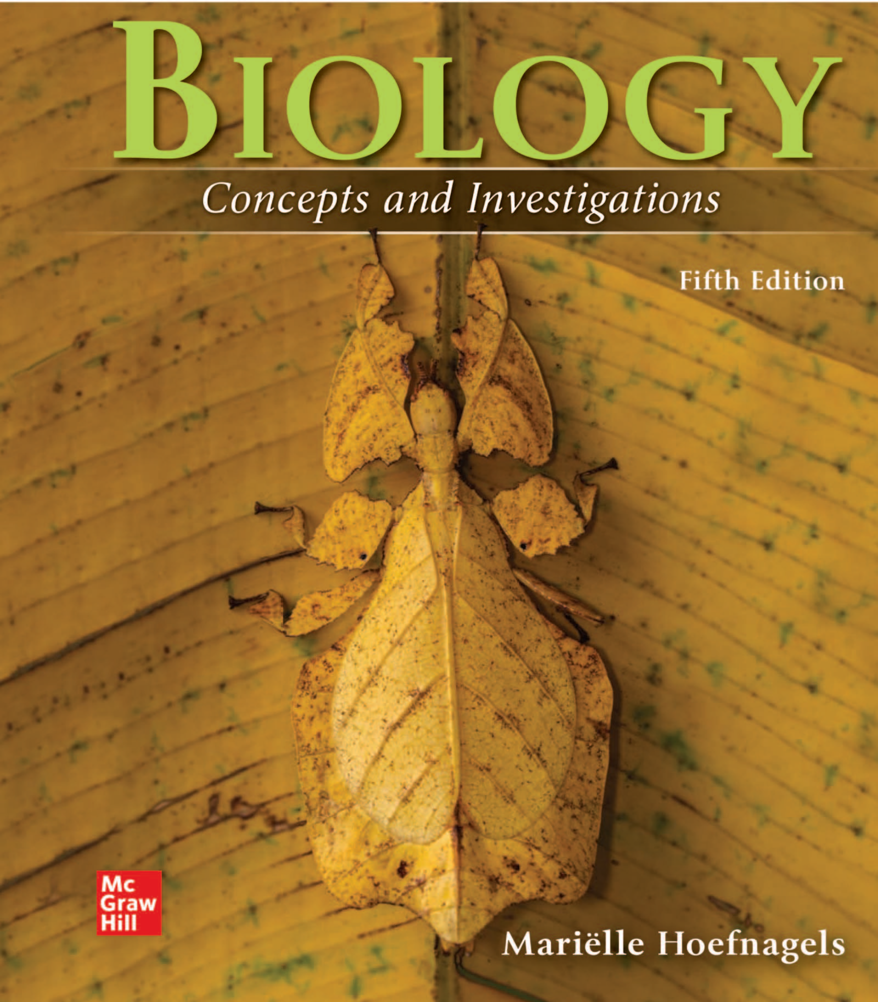
BIOLOGY

Concepts and Investigations

Fifth Edition



Mariëlle Hoefnagels

Mc Graw Hill

BIOLOGY

Concepts and Investigations

Fifth Edition

Mariëlle Hoefnagels
THE UNIVERSITY OF OKLAHOMA

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McGraw Hill

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Brief Contents

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About the Author

Davenport Photos

Mariëlle Hoefnagels is a full 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 and science writing. She has received the University of Oklahoma General Education Teaching Award, the Longmire Prize (the Teaching Scholars Award from the College of Arts and Sciences), and the Holden Faculty Award (to recognize outstanding faculty who teach freshmen and sophomores). Her textbook *Biology: Concepts and Investigations,* 4th edition, was recognized with a 2018 Textbook Excellence Award from the Textbook and Academic Authors Association. She has also been awarded honorary memberships in several student honor societies.

Dr. Hoefnagels received her B.S. in environmental science from the University of California at Riverside, her M.S. in soil science from North Carolina State University, and her Ph.D. 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: Concepts and Investigations* and *Biology: The Essentials*, her recent publications have focused on creating investigative teaching laboratories and methods for teaching experimental design in beginning and advanced biology classes. She frequently gives presentations on study skills and related topics to student groups.

Preface

For years, biology instructors have recognized that we need to turn away from teaching methods that reward students who memorize and regurgitate superficial knowledge. Instead, we need to emphasize deeper learning that requires students to understand and apply course content. This idea is precisely what I have tried to achieve since I started teaching at the University of Oklahoma in 1997, and it has been a guiding principle in the creation of my books and digital material as well.

This edition retains what users have always loved about this book: the art program, readable narrative, handy study tips, Investigating Life essays, tutorial animations, and concept maps. In this edition, I have explicitly connected the unit-wide Survey the Landscape concept map at the start of each chapter to the more detailed, chapter-specific Pull It Together concept map at each chapter's end. Not only does each Survey the Landscape now direct the student's attention to the Pull It Together concept map, but the latter includes a specially labeled question directing the reader's attention back to the Survey the Landscape's "big picture" view. The objective remains the same: to help students see the "forest" *and* the "trees."

One way to motivate students to learn is to help them see that biology is all around them: in food, medicine, pets, water, gardens, parks, and even vacant lots. For students interested in environmental quality, biology forms a foundation for understanding issues ranging in scale from the quality of local tap water to the changing global climate. The Burning Question and Apply It Now boxes support my efforts to help readers learn why biology matters. Each chapter now also includes one or more Scientific Literacy questions. These new thought questions at the end of each chapter will help students practice thinking like a scientist about relevant social, political, or ethical issues.

We continue to acknowledge the growing numbers of instructors and students who are embracing digital textbooks. SmartBook® user data from thousands of students using the fourth edition helped us to identify passages that needed clarification. The user data also guided us as we created a carefully selected array of digital Learning Resources to accompany many probes in SmartBook. In addition, many chapters have bonus features for ebook users, including new digital-only miniglossaries, tables, figures, and live-action videos of plants, fungi, and animals; see the Changes by Chapter section for a complete listing of our new additions.

Ebook users will notice another new feature that supports the goal of bringing biology into student lives: a set of 12 relevancy modules that explain core biology content in the context of timely topics. Relevancy module topics span the book's units, from the process of science (Himalayan salt lamps) to organic chemistry (chocolate) to metabolism (weight gain) to cell division (cancer) to evolution (antibiotic resistance) to plant biology (mega crops) to animal biology (running a marathon) to ecology (climate change), and more. Depending on their teaching goals, instructors can assign a module before or after covering the core content and use it as a jumping-off point for class discussions or homework assignments.

I believe that one set of tools and techniques does not work in every classroom. For that reason, my team and I are proud to create a package that gives you the flexibility to teach introductory biology in a way that works best for you. The following sections illustrate the features and resources for this edition that can help you meet your teaching goals.

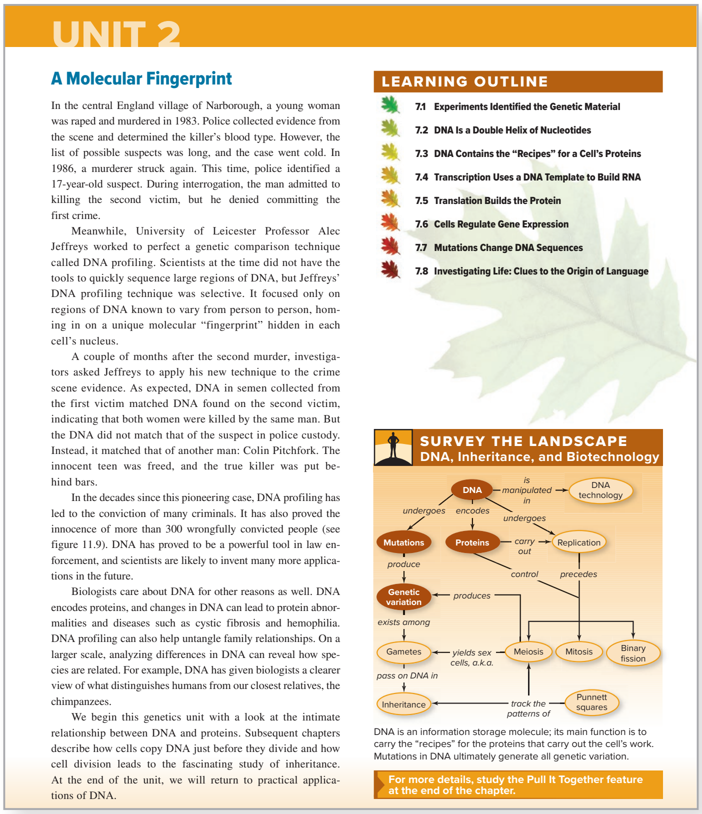
I hope that you and your students enjoy this text and that it helps cultivate an understanding of, and deep appreciation for, biology.

Mariëlle Hoefnagels
The University of Oklahoma

Author's Guide *to Using this Textbook*

Davenport Photos

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



UNIT 2

A Molecular Fingerprint

In the central England village of Narborough, a young woman was raped and murdered in 1983. Police collected evidence from the scene and determined the killer's blood type. However, the list of possible suspects was long, and the case went cold. In 1986, a murderer struck again. This time, police identified a 17-year-old suspect. During interrogation, the man admitted to killing the second victim, but he denied committing the first crime.

Meanwhile, University of Leicester Professor Alec Jeffreys worked to perfect a genetic comparison technique called DNA profiling. Scientists at the time did not have the tools to quickly sequence large regions of DNA, but Jeffreys' DNA profiling technique was selective. It focused only on regions of DNA known to vary from person to person, homing in on a unique molecular "fingerprint" hidden in each cell's nucleus.

A couple of months after the second murder, investigators asked Jeffreys to apply his new technique to the crime scene evidence. As expected, DNA in semen collected from the first victim matched DNA found on the second victim, indicating that both women were killed by the same man. But the DNA did not match that of the suspect in police custody. Instead, it matched that of another man: Colin Pitchfork. The innocent teen was freed, and the true killer was put behind bars.

In the decades since this pioneering case, DNA profiling has led to the conviction of many criminals. It has also proved the innocence of more than 300 wrongfully convicted people (see figure 11.9). DNA has proved to be a powerful tool in law enforcement, and scientists are likely to invent many more applications in the future.

Biologists care about DNA for other reasons as well. DNA encodes proteins, and changes in DNA can lead to protein abnormalities and diseases such as cystic fibrosis and hemophilia. DNA profiling can also help untangle family relationships. On a larger scale, analyzing differences in DNA can reveal how species are related. For example, DNA has given biologists a clearer view of what distinguishes humans from our closest relatives, the chimpanzees.

We begin this genetics unit with a look at the intimate relationship between DNA and proteins. Subsequent chapters describe how cells copy DNA just before they divide and how cell division leads to the fascinating study of inheritance. At the end of the unit, we will return to practical applications of DNA.

LEARNING OUTLINE

7.1 Experiments Identified the Genetic Material
7.2 DNA Is a Double Helix of Nucleotides
7.3 DNA Contains the "Recipes" for a Cell's Proteins
7.4 Transcription Uses a DNA Template to Build RNA
7.5 Translation Builds the Protein
7.6 Cells Regulate Gene Expression
7.7 Mutations Change DNA Sequences
7.8 Investigating Life: Clues to the Origin of Language

SURVEY THE LANDSCAPE
DNA, Inheritance, and Biotechnology

DNA is an information storage molecule; its main function is to carry the "recipes" for the proteins that carry out the cell's work. Mutations in DNA ultimately generate all genetic variation.

For more details, study the Pull It Together feature at the end of the chapter.

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.

The gradual change in leaf colors as a chapter unfolds indicates where the student is in the chapter's big picture.

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.

Concept maps help students see the big picture.

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.

PULL IT TOGETHER

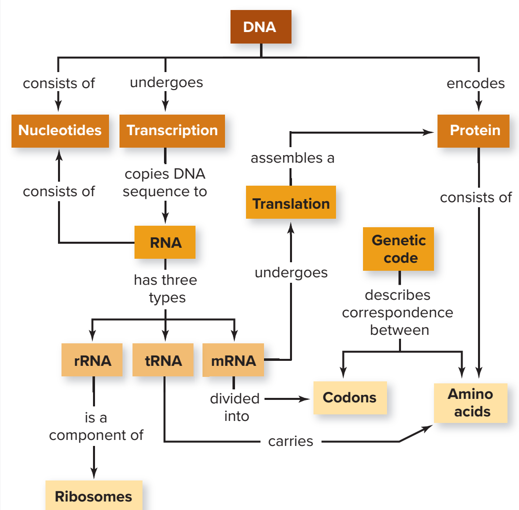


Figure 7.28 **Pull It Together: DNA Structure and Gene Function.**

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.

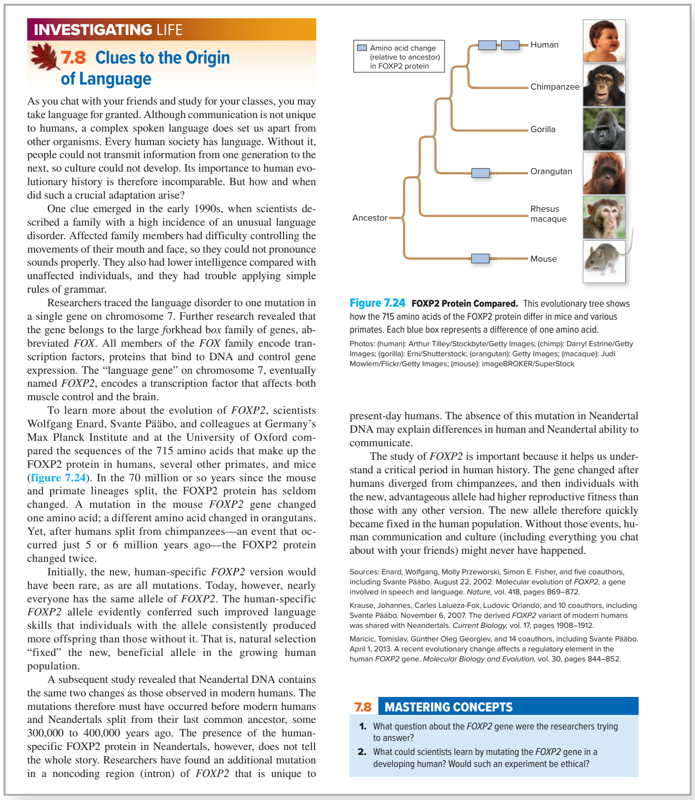
I present a *Study Minute* in class each week, with examples of how to use these study tips.

LEARN HOW TO LEARN
Pause at the Checkpoints
As you read, get out a piece of paper and see if you can answer the Figure It Out and Mastering Concepts questions. If not, you may want to study a bit more before you move on. Each section builds on the material that came before, and mastering one chunk at a time will make it much easier to learn whatever comes next.

Investigating Life describes a real experiment focusing on an evolutionary topic related to each chapter's content.

Each Investigating Life section concludes with critical thinking questions that can be used as an in-class group activity. 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 experiment as a basis for discussion of the nature of science.

Connect interactive and test bank questions focus on the Investigating Life studies. Questions assess students' understanding of the science behind the Investigating Life experiment and their ability to integrate those concepts with information from other units.



INVESTIGATING LIFE

7.8 Clues to the Origin of Language

As you chat with your friends and study for your classes, you may take language for granted. Although communication is not unique to humans, a complex spoken language does set us apart from other organisms. Every human society has language. Without it, people could not transmit information from one generation to the next, so culture could not develop. Its importance to human evolutionary history is therefore incomparable. But how and when did such a crucial adaptation arise?

One clue emerged in the early 1990s, when scientists described a family with a high incidence of an unusual language disorder. Affected family members had difficulty controlling the movements of their mouth and face, so they could not pronounce sounds properly. They also had lower intelligence compared with unaffected individuals, and they had trouble applying simple rules of grammar.

Researchers traced the language disorder to one mutation in a single gene on chromosome 7. Further research revealed that the gene belongs to the large *f*orkhead b*ox* family of genes, abbreviated *FOX*. All members of the *FOX* family encode transcription factors, proteins that bind to DNA and control gene expression. The "language gene" on chromosome 7, eventually named *FOXP2*, encodes a transcription factor that affects both muscle control and the brain.

To learn more about the evolution of *FOXP2*, scientists Wolfgang Enard, Svante Pääbo, and colleagues at Germany's Max Planck Institute and at the University of Oxford compared the sequences of the 715 amino acids that make up the FOXP2 protein in humans, several other primates, and mice (figure 7.24). In the 70 million or so years since the mouse and primate lineages split, the FOXP2 protein has seldom changed. A mutation in the mouse *FOXP2* gene changed one amino acid; a different amino acid changed in orangutans. Yet, after humans split from chimpanzees—an event that occurred just 5 or 6 million years ago—the FOXP2 protein changed twice.

Initially, the new, human-specific *FOXP2* version would have been rare, as are all mutations. Today, however, nearly everyone has the same allele of *FOXP2*. The human-specific *FOXP2* allele evidently conferred such improved language skills that individuals with the allele consistently produced more offspring than those without it. That is, natural selection "fixed" the new, beneficial allele in the growing human population.

A subsequent study revealed that Neandertal DNA contains the same two changes as those observed in modern humans. The mutations therefore must have occurred before modern humans and Neandertals split from their last common ancestor, some 300,000 to 400,000 years ago. The presence of the human-specific FOXP2 protein in Neandertals, however, does not tell the whole story. Researchers have found an additional mutation in a noncoding region (intron) of *FOXP2* that is unique to present-day humans. The absence of this mutation in Neandertal DNA may explain differences in human and Neandertal ability to communicate.

The study of *FOXP2* is important because it helps us understand a critical period in human history. The gene changed after humans diverged from chimpanzees, and then individuals with the new, advantageous allele had higher reproductive fitness than those with any other version. The new allele therefore quickly became fixed in the human population. Without those events, human communication and culture (including everything you chat about with your friends) might never have happened.

Figure 7.24 **FOXP2 Protein Compared.** This evolutionary tree shows how the 715 amino acids of the FOXP2 protein differ in mice and various primates. Each blue box represents a difference of one amino acid.

Photos: (human): Arthur Tilley/Stockbyte/Getty Images; (chimp): Darryl Estrine/Getty Images; (gorilla): Erni/Shutterstock; (orangutan): Getty Images; (macaque): Judi Mowlem/Flickr/Getty Images; (mouse): imageBROKER/SuperStock

Sources: Enard, Wolfgang, Molly Przeworski, Simon E. Fisher, and five coauthors, including Svante Pääbo. August 22, 2002. Molecular evolution of *FOXP2*, a gene involved in speech and language. *Nature*, vol. 418, pages 869–872.

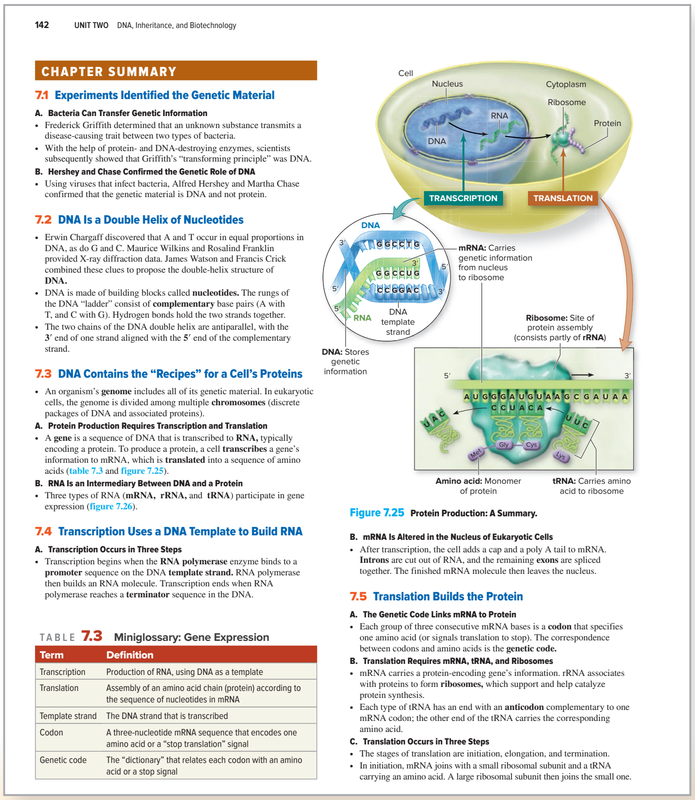
Krause, Johannes, Carles Lalueza-Fox, Ludovic Orlando, and 10 coauthors, including Svante Pääbo. November 6, 2007. The derived *FOXP2* variant of modern humans was shared with Neandertals. *Current Biology*, vol. 17, pages 1908–1912.

Maricic, Tomislav, Günther Oleg Georgiev, and 14 coauthors, including Svante Pääbo. April 1, 2013. A recent evolutionary change affects a regulatory element in the human *FOXP2* gene. *Molecular Biology and Evolution*, vol. 30, pages 844–852.

7.8 MASTERING CONCEPTS

1. What question about the *FOXP2* gene were the researchers trying to answer?
2. What could scientists learn by mutating the *FOXP2* gene in a developing human? Would such an experiment be ethical?

The Chapter Summary highlights key points and terminology from the chapter.



142 UNIT TWO DNA, Inheritance, and Biotechnology

CHAPTER SUMMARY

7.1 Experiments Identified the Genetic Material

A. Bacteria Can Transfer Genetic Information
- Frederick Griffith determined that an unknown substance transmits a disease-causing trait between two types of bacteria.
- With the help of protein- and DNA-destroying enzymes, scientists subsequently showed that Griffith's "transforming principle" was DNA.

B. Hershey and Chase Confirmed the Genetic Role of DNA
- Using viruses that infect bacteria, Alfred Hershey and Martha Chase confirmed that the genetic material is DNA and not protein.

7.2 DNA Is a Double Helix of Nucleotides

- Erwin Chargaff discovered that A and T occur in equal proportions in DNA, as do G and C. Maurice Wilkins and Rosalind Franklin provided X-ray diffraction data. James Watson and Francis Crick combined these clues to propose the double-helix structure of **DNA.**
- DNA is made of building blocks called **nucleotides.** The rungs of the DNA "ladder" consist of **complementary** base pairs (A with T, and C with G). Hydrogen bonds hold the two strands together.
- The two chains of the DNA double helix are antiparallel, with the **3′** end of one strand aligned with the **5′** end of the complementary strand.

7.3 DNA Contains the "Recipes" for a Cell's Proteins

- An organism's **genome** includes all of its genetic material. In eukaryotic cells, the genome is divided among multiple **chromosomes** (discrete packages of DNA and associated proteins).

A. Protein Production Requires Transcription and Translation
- A **gene** is a sequence of DNA that is transcribed to **RNA,** typically encoding a protein. To produce a protein, a cell **transcribes** a gene's information to mRNA, which is **translated** into a sequence of amino acids (table 7.3 and figure 7.25).

B. RNA Is an Intermediary Between DNA and a Protein
- Three types of RNA (**mRNA, rRNA,** and **tRNA**) participate in gene expression (figure 7.26).

7.4 Transcription Uses a DNA Template to Build RNA

A. Transcription Occurs in Three Steps
- Transcription begins when the **RNA polymerase** enzyme binds to a **promoter** sequence on the DNA **template strand.** RNA polymerase then builds an RNA molecule. Transcription ends when RNA polymerase reaches a **terminator** sequence in the DNA.

TABLE 7.3 Miniglossary: Gene Expression

Term	Definition
Transcription	Production of RNA, using DNA as a template
Translation	Assembly of an amino acid chain (protein) according to the sequence of nucleotides in mRNA
Template strand	The DNA strand that is transcribed
Codon	A three-nucleotide mRNA sequence that encodes one amino acid or a "stop translation" signal
Genetic code	The "dictionary" that relates each codon with an amino acid or a stop signal

Figure 7.25 **Protein Production: A Summary.**

B. mRNA Is Altered in the Nucleus of Eukaryotic Cells
- After transcription, the cell adds a cap and a poly A tail to mRNA. **Introns** are cut out of RNA, and the remaining **exons** are spliced together. The finished mRNA molecule then leaves the nucleus.

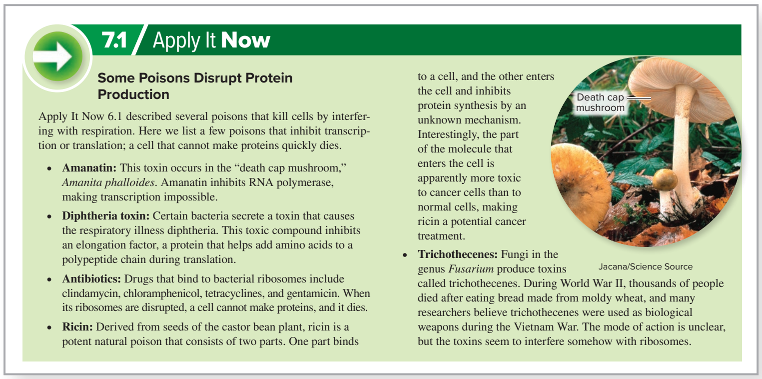
7.5 Translation Builds the Protein

A. The Genetic Code Links mRNA to Protein
- Each group of three consecutive mRNA bases is a **codon** that specifies one amino acid (or signals translation to stop). The correspondence between codons and amino acids is the **genetic code.**

B. Translation Requires mRNA, tRNA, and Ribosomes
- mRNA carries a protein-encoding gene's information. rRNA associates with proteins to form **ribosomes,** which support and help catalyze protein synthesis.
- Each type of tRNA has an end with an **anticodon** complementary to one mRNA codon; the other end of the tRNA carries the corresponding amino acid.

C. Translation Occurs in Three Steps
- The stages of translation are initiation, elongation, and termination.
- In initiation, mRNA joins with a small ribosomal subunit and a tRNA carrying an amino acid. A large ribosomal subunit then joins the small one.

Apply It Now boxes reinforce the applications of specific topics to the real world.



7.1 Apply It Now

Some Poisons Disrupt Protein Production

Apply It Now 6.1 described several poisons that kill cells by interfering with respiration. Here we list a few poisons that inhibit transcription or translation; a cell that cannot make proteins quickly dies.

- **Amanatin:** This toxin occurs in the "death cap mushroom," *Amanita phalloides*. Amanatin inhibits RNA polymerase, making transcription impossible.
- **Diphtheria toxin:** Certain bacteria secrete a toxin that causes the respiratory illness diphtheria. This toxic compound inhibits an elongation factor, a protein that helps add amino acids to a polypeptide chain during translation.
- **Antibiotics:** Drugs that bind to bacterial ribosomes include clindamycin, chloramphenicol, tetracyclines, and gentamicin. When its ribosomes are disrupted, a cell cannot make proteins, and it dies.
- **Ricin:** Derived from seeds of the castor bean plant, ricin is a potent natural poison that consists of two parts. One part binds to a cell, and the other enters the cell and inhibits protein synthesis by an unknown mechanism. Interestingly, the part of the molecule that enters the cell is apparently more toxic to cancer cells than to normal cells, making ricin a potential cancer treatment.
- **Trichothecenes:** Fungi in the genus *Fusarium* produce toxins called trichothecenes. During World War II, thousands of people died after eating bread made from moldy wheat, and many researchers believe trichothecenes were used as biological weapons during the Vietnam War. The mode of action is unclear, but the toxins seem to interfere somehow with ribosomes.

Jacana/Science Source

7.1 Burning Question

Do genes determine sexual orientation?

MOLEKUUL/SPL/age fotostock

Despite periodic headlines about newly discovered "gay genes," scientists have not discovered a simple relationship between DNA and sexual orientation.

Research linking human behavior to individual genes is extremely difficult for several reasons. First, to establish a clear link to DNA, a researcher must be able to define and measure a behavior. This in itself is difficult because the spectrum of human sexual behavior does not necessarily conform to tidy boundaries. Second, multiple genes are likely to be involved. Third, epigenetic factors may affect gene expression: An individual who inherits a gene version associated with a trait will not necessarily express the gene if it remains "off." To complicate matters, combinations of environmental cues that are unique to each individual may also influence gene expression.

Nevertheless, research has yielded some evidence of a role for genes in determining sexual orientation, at least in males. For example, an identical twin of a gay male is much more likely to also be gay than is a nonidentical twin, indicating a strong genetic contribution. In addition, some experiments have uncovered tantalizing genetic correlations: Researchers have found that some gene versions that are often present in gay males may also increase fertility in their mothers, and other studies have revealed distinctive patterns of gene activation in some gay males (see DNA availability in section 7.6B). Overall, however, clear cause-and-effect relationships remain elusive.

In addition to genes, the womb environment may also be associated with a male's sexual orientation. The more older brothers a male has, the more likely he is to be gay. This "birth order" effect occurs only for siblings with the same biological mother; having older stepbrothers does not increase the chance that a male is gay. That means that events before birth (such as changes in the womb during previous pregnancies) are responsible for the effect.

While understanding the influences on sexual orientation may be interesting, its broader relevance to society remains controversial. Does this research simply further support the well-established conclusion that sexual orientation is not a choice, leading to broader acceptance of all people? Or does it unintentionally reinforce bigotry by casting less-common sexual orientations as "disorders"?

To summarize the answer to this Burning Question, research does suggest a genetic contribution to sexual orientation. Sorting out the complex interactions between multiple genes and the environment, however, remains a formidable challenge.

Submit your burning question to
Marielle.Hoefnagels@mheducation.com

mRNA Exit from Nucleus For a protein to be produced, mRNA must leave the nucleus and attach to a ribosome (figure 7.18, part 4). If the mRNA fails to leave, the gene is silenced.

mRNA Degradation Not all mRNA molecules are equally stable. Some are rapidly destroyed, perhaps before they can be translated, whereas others persist long enough to be translated many times (figure 7.18, part 5).

Moreover, tiny RNA sequences called microRNAs can play a role in regulating gene expression. Each microRNA is only about 21 to 23 nucleotides long, and it does not encode a protein. Instead, a cell may produce a microRNA that is complementary to a coding mRNA. If the microRNA attaches to the mRNA, the resulting double-stranded RNA cannot be translated at a ribosome and is likely to be destroyed. Medical researchers are actively studying microRNAs; the ability to silence harmful genes may help treat illnesses ranging from cancer to influenza and HIV.

Protein Processing and Degradation Some proteins must be altered before they become functional (figure 7.18, part 6). Dozens of modifications are possible, including the addition of sugars or an alteration in the protein's structure. Producing insulin, for example, requires a precursor protein to be cut in two places. If these modifications fail to occur, the insulin protein cannot function.

In addition, to do its job, a protein must move from the ribosome to where the cell needs it. For example, a protein secreted in milk must be escorted to the Golgi apparatus and be packaged for export (see figure 3.13). A gene is effectively silenced if its product never moves to the correct destination.

Finally, like RNA, not all proteins are equally stable. Some are degraded shortly after they form, whereas others persist longer.

A human cell may express hundreds to thousands of genes at once. Unraveling the complex regulatory mechanisms that control the expression of each gene is an enormous challenge. Biologists now have the technology to begin navigating this regulatory maze. The work has just begun, but the payoff will be a much better understanding of cell biology, along with many new medical applications. The same research may also help scientists understand how external influences on gene expression contribute to complex traits, such as the one described in Burning Question 7.1.

7.6 MASTERING CONCEPTS

1. What are some reasons that cells regulate gene expression?
2. How does a repressor protein help regulate the expression of a bacterial operon?
3. Explain how epigenetic modifications change the likelihood of transcription.
4. How do enhancers and transcription factors interact to regulate gene expression?

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 *Practice 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.

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 Center. Most could easily be used as clicker questions as well.

7.4 Figure It Out

Suppose that a substitution mutation replaces the first A in the following mRNA sequence with a U:
5′-AAAGCAGUACUA-3′.
How many amino acids will be in the polypeptide chain?

Answer: Zero

Burning Questions cover topics that students wonder about.

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.

Scientific Literacy questions reveal why biology matters to everyone.

These new thought questions at the end of each chapter encourage students to integrate biology with social, political, and ethical issues. They make great discussion and homework questions.

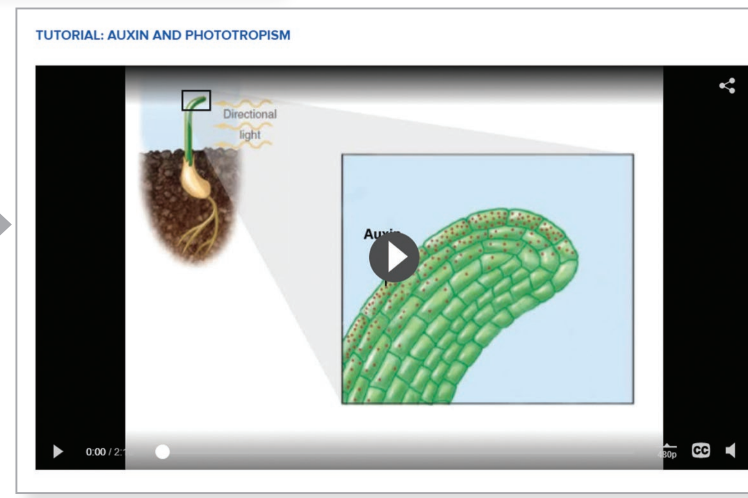
SCIENTIFIC LITERACY

Since 2018, the DNA-testing company 23andMe has allowed the drug company GlaxoSmithKline to access the vast amounts of genetic information in 23andMe's databases. Use the Internet to learn more about the partnership between these companies. How might their arrangement benefit human health? What are some potential ethical concerns?

Author's Guide *to Digital-Only Content*

Videos embedded in the ebook narrative bring relevance, clarity, and motion to difficult concepts.

Live-action and time-lapse videos integrated within the narrative show textbook concepts at work in the real world.



Animated tutorials guide students through complicated topics, using illustrations and examples from the book.

Answers to all chapter questions are found at the end of the question stem within the ebook.

24.6 MASTERING CONCEPTS

1. How do statoliths and auxins participate in gravitropism? A:
2. How does thigmotropism help some plants climb? A:

Answer Mastering Concepts 24.6:
Thigmotropism is a response to touch in a specialized structure such as a tendril. Hormones cause differential growth in the tendril, allowing it to encircle physical supports such as a trellis or the branches of another plant.

Digital-only tables, miniglossaries, and figures expand on content from the print textbook.

Digital-only tables and miniglossaries help students organize new information and serve as helpful study tools.

New digital-only figures focus extra attention on topics not illustrated in the print text. In addition, some print figures have been reformatted for better display on mobile devices.

DIGITAL EDITION PLANT TROPISMS: A SUMMARY

Type	Stimulus	Response	Example
Phototropism	Light	Photoreceptors absorb light energy; auxins move to shaded side of stem and stimulate cell elongation.	Stem bends toward window.
Gravitropism	Gravity	Starch-rich statoliths "sink" within root cap cells; auxins cause root to bend downward (hypothesized mechanism).	Roots grow downward into soil.
Thigmotropism	Touch	Unknown	Tendril coils around trellis.

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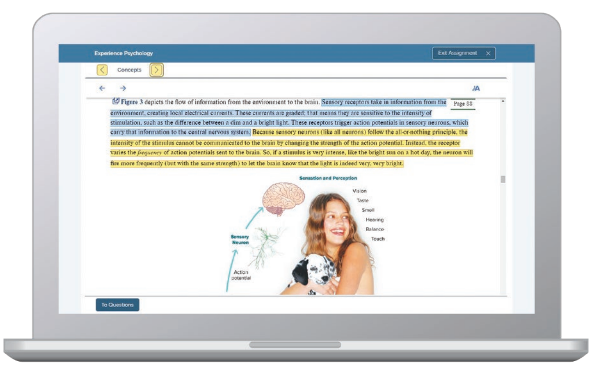

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Changes by Chapter

UNIT 1 Science, Chemistry, and Cells

- **Chapter 1 (The Scientific Study of Life):** Added connections between *enzymes, respiration,* and *photosynthesis* to all Survey the Landscape illustrations in unit 1; changed *producers* to *primary producers* throughout narrative and art to improve consistency with other chapters; added a paragraph explaining figure 1.8; clarified common ancestry of animals and fungi in figure 1.9 and derivative figures throughout the book; introduced the idea of eukaryotic "supergroups" in section 1.2; revised paragraph in section 1.3 describing topics that are off-limits for science; added *Design experiment* to figure 1.10. Based on SmartBook user data, improved the explanation of the relationship between growth and development in section 1.1. Added a new learning tool to ebook: a miniglossary of reproduction and development in section 1.1.
- **Chapter 2 (The Chemistry of Life):** Added an explanation of electron cloud in section 2.1; revised section 2.3's introductory paragraph to make it more relatable to readers; improved figure 2.15 to better highlight the positions of neutrality, acidity, and alkalinity; added brackets and reworked labels in figure 2.20 to clarify primary and secondary structures; added cell for context in figure 2.24; deleted information about trans fats in section 2.5 and Burning Question 2.2, as they are no longer allowed in processed foods; added to Burning Question 2.2 an explanation of why highly digestible junk foods contribute more calories than raw fruits and vegetables; in section 2.5, clarified that the animal body produces the cholesterol it needs; added to section 2.5 a passage about the functions of waxes in animals and plants; reworked Pull It Together to add hydrogen bonds and increase the number of connections. Added new learning tools to ebook: a table summarizing the characteristics of water and a video showing oil and water separation in section 2.3.
- **Chapter 3 (Cells):** Wrote a new chapter opener exploring the link between medical specimens and patient privacy; modified figure 3.6 to clarify the relationship between cytoplasm and its components; modified figures 3.8 and 3.9 to better depict ribosomes; rearranged figure 3.28 for more efficient arrangement and enhanced labeling; in section 3.6, added a paragraph about components of the cell wall that interfere with biofuels production; expanded figure 3.31 to include more information about prokaryotic and eukaryotic cells. Based on SmartBook user data, clarified in section 3.4 that some plastids store starch. Added a new learning tool to ebook: a miniglossary of features common to all cells in section 3.1.
- **Chapter 4 (The Energy of Life):** In chapter introduction, added specific suggestions for relating the parts to the whole in Learn How to Learn; reworked chapter opening essay to focus on hummingbirds, sloths, and ways we can to boost our own metabolic rate; in section 4.1, explained how light and sound have kinetic energy; reworked figure 4.9 to clarify the concept of coupled reactions and reworked the passage describing figure 4.9 to clarify that energy from the ATP hydrolysis reaction drives the endergonic reaction; reworked figure 4.10b to better integrate with other content from the chapter; added new Burning Question 4.1 on hibernation; added new figure 4.19 to illustrate how ATP synthase enzyme uses facilitated diffusion; added new Apply It Now 4.1 on hand sanitizers; clarified figure 4.24 to better illustrate vesicle recycling in electric fish. Based on SmartBook user data, clarified figure 4.7 to show that the endmost high-energy covalent bond breaks in ATP hydrolysis. Added a new learning tool to ebook: a video of a hummingbird in flight in the chapter opening essay.
- **Chapter 5 (Photosynthesis):** Wrote a new chapter opening essay about the mass of air; added details about previewing a chapter in Learn How to Learn; changed leaf photo in figure 5.5; in section 5.5, simplified the definition of carbon fixation and added information about the importance of the Calvin cycle; standardized depictions of the Calvin cycle throughout figure 5.11; reworked figure 5.13 and the Investigating Life essay for clarity; added *chlorophyll* and *other organic molecules* to figure 5.14. Based on SmartBook user data, clarified that the cellulose built with the products of photosynthesis is part of plant cell walls. Added new learning tools to ebook: a miniglossary of oxidation and reduction in photosynthesis in section 5.1; a miniglossary of leaf anatomy in section 5.2.
- **Chapter 6 (Respiration and Fermentation):** Wrote a new chapter opening essay about the controversy over high fructose corn syrup; clarified labels and caption in figure 6.1;

revised figure 6.10 for clarity; revised figure 6.11 to add inputs to and outputs of fermentation; updated Burning Question 6.1 to reflect changes in diet pill availability; replaced Figure It Out 6.2; revised figure 6.12 for clarity. Added new learning tools to ebook: a miniglossary of oxidation and reduction in cellular respiration in section 6.1; a table summarizing high-energy products of cellular respiration in section 6.6 (based on SmartBook user data).

UNIT 2 DNA, Inheritance, and Biotechnology

- **Chapter 7 (DNA Structure and Gene Function):** Throughout the chapter, replaced *protein synthesis* with *gene expression* as appropriate; wrote new chapter opening essay on the first use of DNA to solve a crime; in section 7.4, clarified that RNA polymerase both unzips and copies the DNA in transcription; in figure 7.10, clarified the position of RNA polymerase relative to the transcription bubble; added the untranslated region at the 5´ end to figure 7.11 for consistency with figure 7.15; modified figure 7.15 to improve consistency with figure 7.11 and to clarify the relationship between the codon and the anticodon; in section 7.5, clarified how translation is initiated; updated Burning Question 7.1 to reflect current research; clarified wording in table 7.2 and added a row for deletion mutations that cause frameshifts; updated research in Investigating Life section. Based on SmartBook user data, clarified that eukaryotic chromosomes are linear; simplified the description of the roles of the cap and poly A tail. Added new learning tools to ebook: a table summarizing the stages of transcription; a table summarizing the stages of translation; a figure illustrating the DNA scale from nucleotide to chromosome.
- **Chapter 8 (DNA Replication, Binary Fission, and Mitosis):** Reworked figure 8.2 to include more cell division functions; revised figure 8.4 for clarity; in section 8.4, reinforced that each replicated chromosome consists of two sister chromatids; revised Figure It Out 8.2 to reinforce that replication does not double the chromosome number; revised Burning Question 8.1 to answer whether plants get cancer; in section 8.6, added information about immunotherapy as a cancer treatment and connected the passage on cancer risk to Burning Question 16.1 (human papillomavirus); wrote new Investigating Life on adaptive cancer therapies. Based on SmartBook user data, added bold type and glossary definition for *RNA primer;* clarified that eukaryotic chromosomes are linear. Added a new learning tool to ebook: a figure illustrating the DNA scale from nucleotide to chromosome.
- **Chapter 9 (Sexual Reproduction and Meiosis):** In section 9.2, clarified that sex chromosomes XX are *typical* of females and XY are *typical* of males; added that chromosomes have been replicated to figure 9.3's caption; made several changes to clarify the difference between homologous and replicated chromosomes; stated explicitly that DNA replication does not make a cell diploid; emphasized that alleles typically differ only slightly, so homologous chromosome pairs likewise differ only slightly; clarified figure 9.4 to avoid the implication that offspring inherit chromosomes that are already replicated; added Mastering Concepts question to reinforce the changes to section 9.2; added two chromosomes to figure 9.6; revised Figure It Out 9.2 to include not only DNA content but also chromosome number; revised arrow colors in figure 9.11; in section 9.6, reminded readers that variation arising from meiosis and mutations is the foundation of evolutionary change; in section 9.7, explained the connection between misalignment in crossing over and errors in chromosome structure; reworked Apply It Now 9.1 to include conjoined twins and parasitic twins and to update information on incidence of multiple births; incorporated crossing over into figure 9.23; added questions at end of chapter to reinforce the difference between homologous and replicated chromosomes. Based on SmartBook user data, bold-faced *parental chromatid* and *recombinant chromatid* in section 9.5 and added both terms to figure 9.8 and to the digital-only miniglossary of variability in meiosis. Added new learning tools to ebook: a figure showing an analogy between homologous chromosomes and book editions; a figure illustrating the DNA scale from nucleotide to chromosome.
- **Chapter 10 (Patterns of Inheritance):** In sections 10.1 and 10.7, clarified that sex chromosomes XX are *typical* of females and XY are *typical* of males; in the figure 10.1 caption, added a reminder of the relationship between homologous and replicated chromosomes; in section 10.2, clarified that mutations can be harmful, neutral, or beneficial; in section 10.4, modified the narrative and added to figure 10.12's caption to propose alternative hypotheses for the results of a dihybrid cross before revealing that Mendel observed independent assortment; labeled parental and recombinant chromatids in figure 10.15; in section 10.8, added achondroplasia as an example of a disorder caused by a mutation for which the encoded protein is overly active; in table 10.3, added rows for cancer-related autosomal dominant and autosomal recessive genes; in section 10.9, briefly described epigenetics and explained why identical twins become more different as they age; reworked figure 10.29 to incorporate a histogram showing the frequencies of each allele combination; connected dominant and recessive alleles to functional and nonfunctional proteins in Pull It Together; added a pedigree problem to the How to Solve a Genetics Problem section. Added new learning tools to ebook: a figure summarizing the names of the generations in genetics; a figure listing milestones in the history of genetics; a figure illustrating the DNA scale from nucleotide to chromosome.
- **Chapter 11 (DNA Technology):** Wrote new chapter opening essay on the use of CRISPR-Cas9 in citrus trees; added photo to figure 11.1 to show the amount of DNA in a bacterial cell; reworked figure 11.2 to show the production

of insulin; in section 11.2, noted that plasmids occur naturally in bacteria and yeasts, added golden rice as an example of a transgenic plant, noted that transgenic farm animals can secrete human proteins in their milk, clarified that genetically modified foods have not been linked to health problems in humans, added information about high-throughput DNA technologies, added that transposons can cause problems in genes where they land, and clarified that trained technicians rarely contaminate PCR reaction tubes; clarified figure 11.8; updated data in figure 11.9; added CRISPR-Cas9 to Burning Question 11.1; reworked figure 11.13 for clarity and improved layout; in section 11.3, added monkeys to the list of cloned mammals; added subheading and new figure 11.17 to explain CRISPR-Cas9; in Apply It Now 11.1, added CRISPR-Cas9 as a new way of doping. Added a new learning tool to ebook: a figure illustrating the DNA scale from nucleotide to chromosome.

UNIT 3 The Evolution of Life

- **Chapter 12 (The Forces of Evolutionary Change):** Added *genetic variation* to all Survey the Landscape illustrations in unit 3; in the chapter opening essay, added information about preventing the spread of antibiotic-resistant bacteria; reworked figure 12.5 to add artificial selection for dog breeds; revised Apply It Now 12.1 to focus on dog evolutionary history and to clarify why purebred dogs have health problems; in section 12.2C, added a paragraph explaining the connection between natural selection and long-term evolutionary processes; added description and photo of porcupinefish to illustrate adaptations; in section 12.3, added table with selected misconceptions about evolution; added illustration to Burning Question 12.1 to compare inaccurate and accurate depictions of human evolution; added an intermediate habitat to figure 12.14a. Based on SmartBook user data, clarified in section 12.7 that migration tends to reduce genetic differences between populations.
- **Chapter 13 (Evidence of Evolution):** Clarified figure 13.2 for consistency with chapter 15 and to add a footnote about the Anthropocene; in section 13.2B, added a paragraph connecting the word *Phanerozoic* and the abundance of fossil evidence from that time; clarified Figure It Out 13.1; in section 13.6, added a sentence to emphasize the advantage of molecular data over other forms of evidence for evolution; in section 13.6, connected the passage on gene duplication to section 9.7B. Based on SmartBook user data, revised passage on marsupials in section 13.3.
- **Chapter 14 (Speciation and Extinction):** Reworked parts of the chapter opening essay to focus on Socotra (to match the accompanying photo) and to better foreshadow the contents of the chapter; clarified that the ladybugs in figure 14.4 are herbivorous; added labels to figure 14.8 and clarified the description of the little greenbuls from the forest and ecotone; reworked figure 14.9 and the accompanying narrative to better show the difference between the cichlids; in section 14.4, described bryozoans to clarify why they have an extensive fossil record; added a description of the adaptive radiation of mammals illustrated in figure 14.13; in section 14.5, added a new subheading explaining why today's biodiversity crisis matters; reworked figure 14.15 to better show the nested taxonomic hierarchy; added Figure It Out 14.2 to help readers articulate common ancestry.
- **Chapter 15 (The Origin and History of Life):** Wrote new chapter opening essay about the biological meaning of *race;* revised section 15.1 to accommodate the possibility of dozens of types of amino acids; in section 15.2, revised passage and illustration on endosymbiosis to include proteobacteria; in section 15.3, added brief descriptions of some unfamiliar groups of organisms, including bryozoans; in section 15.3, replaced the outdated Tertiary Period with the Paleogene and Neogene Periods and corrected the start of the Quaternary Period; added *hominoid* to table 15.1; in section 15.4, added *Homo naledi* to the list of *Homo* species, mentioned the Denisovans, clarified the passage on interbreeding with Neandertals, clarified the passage on the emergence of bipedalism, added folate to the passage on skin pigment, offered a more explicit link to Investigating Life 25.6, and added an explanation of the proposed Anthropocene epoch. Added new learning tools to ebook: three videos depicting primates in section 15.4A.

UNIT 4 The Diversity of Life

- **Chapter 16 (Viruses):** Added receptors to entire cell surface in figure 16.3; in section 16.4, added *virulence* as a bold-faced term and explained that high virulence does not always mean high fitness; in section 16.4, improved explanation of HIV attachment to T cell; updated Burning Question 16.1 on cancer-causing human papillomavirus; added new figure to Apply It Now 16.1 to illustrate how anti-HIV drugs work. Added a new learning tool to ebook: a table listing viruses that infect humans.
- **Chapter 17 (Bacteria and Archaea):** In chapter opening essay, noted that biofilms can degrade diesel fuel; in section 17.2, added information about the composition of the archaean cell wall to narrative and figure 17.2; added inset for ribosomes to figure 17.3; in section 17.2, explained why gram-positive cells retain violet dye; added mechanisms of antibiotic resistance to Apply It Now 17.1; rearranged figure 17.8 and added icons for aerobic and anaerobic environments; added *Helicobacter pylori* to table 17.1; in section 17.3, improved consistency between bacterial descriptions and section 15.2; in section 17.3, explained why producing antibiotics is adaptive for soil bacteria and updated information on archaean superphyla; updated information about gene function in Focus on Model Organisms 17.1; in section 17.4, added the term *microbiome* to connect microbiology with current news, bold-faced the term

virulence, and clarified the difference between exotoxins and endotoxins; in section 17.5, added a sentence about low-tech solutions to the spread of antibiotic-resistance genes. Based on SmartBook user data, clarified that chemotrophs derive energy from oxidizing chemicals in section 17.2. Added a new learning tool to ebook: a miniglossary of prokaryote diversity in section 17.2.

- **Chapter 18 (Protists):** Updated chapter opening essay to reflect recent research on *Pfiesteria*; revised section 18.1 to consider updated information about eukaryotic supergroups; in section 18.2, emphasized the enormous scale of the aquatic habitats occupied by algae; added information about toxins to Burning Question 18.1; in section 18.2, connected *Chlamydomonas* and *Volvox* to the evolution of multicellularity in section 15.2; updated information about eukaryotic supergroups in section 18.5 and table 18.1. Added new learning tools to ebook: videos showing *Euglena* and *Volvox* in section 18.2; a video showing *Paramecium* and a miniglossary of protozoa in section 18.4.
- **Chapter 19 (Plants):** In section 19.1, emphasized that cyanobacteria and algae were the first to release O_2; reworked figure 19.11 to show that fern gametophytes typically cross-fertilize; updated Focus on Model Organisms 19.1. Added new learning tools to ebook: a table summarizing bryophyte characteristics in section 19.2; a table summarizing seedless vascular plant characteristics in section 19.3; a table summarizing gymnosperm characteristics in section 19.4; a table summarizing angiosperm characteristics in section 19.5; in the chapter summary, a figure showing highlights in the history of plants and a table summarizing plant adaptations.
- **Chapter 20 (Fungi):** Updated the chapter opening essay with additional uses for fungi; modified figure 20.3 to show feeding at hyphal tips; connected step numbers in figure 20.16 to the narrative and modified the caption to highlight the roles of mitotic division and meiosis; in section 20.7, improved explanation of materials exchange in a mycorrhiza; improved figure 20.20 to show exchange of materials between a lichen's partners; added a miniglossary of fungal anatomy and reproduction (previously a digital-only feature) to the print edition. Added new learning tools to ebook: a time-lapse video showing mushroom growth in the chapter opening essay; a table summarizing chytrid characteristics in section 20.2; a table summarizing zygomycete characteristics in section 20.3; a table summarizing glomeromycete characteristics in section 20.4; a table summarizing ascomycete characteristics in section 20.5; a time-lapse video of moldy food with Burning Question 20.1; a table summarizing basidiomycete characteristics in section 20.6; a video showing leaf-cutter ants and a figure comparing the anatomy of arbuscular mycorrhizae and ectomycorrhizae in section 20.7.
- **Chapter 21 (Animals):** Improved the layout of figure 21.8; in section 21.2, added information about commercial sponges harvesting; in section 21.8, added information about insect abundance and diversity; in section 21.9, clarified that echinoderms have a type of radial symmetry called *pentamerism*; in section 21.11, clarified information about tunicates; added tuataras to figure 21.38; updated information in Apply It Now 21.3. Added new learning tools to ebook: 13 videos to help students visualize the diversity in the animal kingdom; a table summarizing sponge characteristics in section 21.2; a table summarizing cnidarian characteristics in section 21.3; a table summarizing flatworm characteristics in section 21.4; a table summarizing mollusk characteristics in section 21.5; a table summarizing annelid characteristics in section 21.6; a table summarizing roundworm characteristics in section 21.7; a figure showing monarch butterfly metamorphosis and a table summarizing arthropod characteristics in section 21.8; a table summarizing echinoderm characteristics in section 21.9; a table summarizing chordate characteristics in section 21.10; a table summarizing tunicate and lancelet characteristics in section 21.11; tables summarizing hagfish and lamprey characteristics in section 21.12; a table summarizing fish characteristics in section 21.13; a table summarizing amphibian characteristics in section 21.14; a table summarizing reptile characteristics in section 21.15; a table summarizing mammal characteristics in section 21.16; a figure showing highlights in the history of animals in the chapter summary.

UNIT 5 Plant Life

- **Chapter 22 (Plant Form and Function):** In the chapter opening essay, mentioned that coca leaf chewing is part of everyday life in the Andes; in section 22.1, added introductory paragraph explaining why this unit focuses on angiosperms, noted that some tendrils are derived from leaves, and improved the descriptions of the photos in figure 22.3; in section 22.2, added hormones to the list of substances carried in xylem and phloem; rearranged section 22.2 and improved table 22.2 to reduce confusion between cell types and tissue systems; in section 22.3, added stipules to narrative and figure 22.10, along with an inset to show the axillary bud and stipules; added labels for upper and lower cuticles in figure 22.12; clarified labels in figure 22.17; in section 22.5, added information about potential benefits of domatia; in chapter summary, clarified description of collenchyma.
- **Chapter 23 (Plant Nutrition and Transport):** Updated Apply It Now 23.1 to expand on the pros and cons of different forms of fertilizer; in section 23.2, added hormones to contents of xylem sap, added mycorrhizae to the passage on root hairs in the description of figure 23.7, and added adhesion to passage on cohesion–tension theory; in section 23.3, noted that the cells that make up sieve tubes are alive; in section 23.4, reworked and clarified the passage on parasitic plants. Added a new learning tool to ebook: a video of a Venus flytrap in the chapter opening essay.

- **Chapter 24 (Reproduction and Development of Flowering Plants):** Reworked the chapter opening essay to focus more on wild bees; in section 24.1, set the context for the chapter's focus on angiosperms by reminding readers of other plant groups; added a picture of a rooted cutting to figure 24.1; in section 24.2, improved the description of coevolution, added descriptive part labels to figure 24.7, and improved the explanation of the cotyledons' role in monocot and eudicot seeds; in section 24.3, clarified the descriptions of seed germination and early seedling growth; in section 24.4, clarified the descriptions of some hormones; in Apply It Now 24.1, explained why knowing about plant defenses could be useful; in section 24.5, added that cryptochrome is sensitive to blue light and clarified the adaptive value of phytochrome's role in seed germination. Added new learning tools to ebook: a time-lapse video of germinating wheat seeds in section 24.3; a time-lapse video of phototropism in section 24.5; time-lapse videos of gravitropism and thigmotropism in section 24.6; a time-lapse video of growth from buds in section 24.7.

UNIT 6 Animal Life

- **Chapter 25 (Animal Tissues and Organ Systems):** Added *survival* and *reproductive success* to all Survey the Landscape illustrations in unit 6; in section 25.2, explained the role of stem cells in generating animal tissues; in section 25.2, introduced and explained the term *interstitial fluid* with the extracellular matrix; omitted the term *ground substance* from all references to the extracellular matrix; referred to anchoring junctions in passage about the extracellular matrix; clarified the difference between the basement membrane and a cell's plasma membrane; wrote new Apply It Now 25.1 on organ system interactions in food poisoning; added *sensors, control center,* and *effector* to figure 25.10 and its caption and added *control center* to corresponding narrative. Added new learning tools to ebook: a video of an athlete with a prosthetic limb in the chapter opening essay; a miniglossary of animal tissues in section 25.2; a miniglossary of negative feedback in section 25.4.
- **Chapter 26 (The Nervous System):** Improved depiction of planarian brain in figure 26.2; in section 26.3, clarified that the resting potential reflects a balance of forces on multiple ions, including K^+; in section 26.3, refined the distinction between graded potentials and action potentials and clarified that the passage connecting the two refers only to stimuli that provoke action potentials (not inhibitory stimuli); expanded figure 26.7 to better depict the analogy between action potential propagation and a chain of firecrackers; in section 26.3, clarified that the voltage-gated sodium channels at each node of Ranvier respond to depolarization at the previous node; improved depiction of saltatory conduction in figure 26.8; modified figure 26.14 to clarify the relationship between the brain's main areas and the brainstem; in section 26.6, combined two figures to show the cerebral cortex photo in the context of the corresponding art; expanded Apply It Now 26.1 to include GABA and additional information about serotonin. Added a new learning tool to ebook: a miniglossary of neuron anatomy in section 26.2.
- **Chapter 27 (The Senses):** Wrote new chapter opening essay on distraction blindness; wrote new Burning Question 27.1 on scratching bug bites; corrected appearance of tectorial membrane in figure 27.13 and figure 27.18; in section 27.5, clarified that the semicircular canals detect rotation but not tilt; added paragraph on retinal implants in Apply It Now 27.1; added paragraph describing new technologies in hearing aids and cochlear implants in Apply it Now 27.2; in chapter ending, added a Write It Out question about why capsaicin feels hot. Added new learning tools to ebook: a miniglossary of smell and taste in section 27.3; expanded the miniglossary of the pathway of auditory information in section 27.5.
- **Chapter 28 (The Endocrine System):** In the chapter opening essay, distinguished between an immediate fear response and a sustained hormonal response to stress; in section 28.2, clarified that steroid hormones may inhibit or stimulate gene expression; reworked Burning Question 28.1 to focus on BPA; modified figure 28.7 to include the role of the hypothalamus as a sensor; modified figure 28.10 to include the pancreas as a sensor; reworked graph in figure 28.12 to illustrate the association between obesity and type 2 diabetes. Added a new learning tool to ebook: a miniglossary of hormones and responses in section 28.2.
- **Chapter 29 (The Skeletal and Muscular Systems):** Updated the chapter opening essay to incorporate new technologies in prosthetics; in section 29.3, clarified that bone marrow consists of tissue; added sensors to figure 29.9; replaced one micrograph in figure 29.15 with a more informative one; in section 29.4, clarified the paragraph describing the role of ATP in muscle contraction; in section 29.5, improved consistency between passage on fermentation and chapter 6; in Burning Question 29.2, added a paragraph about sports balm.
- **Chapter 30 (The Circulatory System):** Wrote new chapter opening essay about childhood leukemia; in Burning Question 30.1, added information about treatment for bruises; in section 30.2, clarified the functions of blood plasma and explained its relationship with interstitial fluid, clarified the passage about leukemia, and clarified the description of platelet origin; in Burning Question 30.2, clarified that plasma is purified before use by pharmaceutical companies; in section 30.4, added a brief description of gap junctions and defined stroke volume; added sensors to figure 30.15; in section 30.6, clarified the relationship between lymph vessels and lymph capillaries; in section 30.7, added icefish circulatory system adaptations to strengthen the connection with chapter content. Added a new learning tool to ebook: a miniglossary of circulation in section 30.5.

- **Chapter 31 (The Respiratory System):** In section 31.2, removed the word *tubules* from the description of the respiratory system; in section 31.2, added a sentence explaining the role of surfactants in alveoli and clarified that the inner surface of each alveolus is coated with a thin film of water; in section 31.3, clarified that forceful exhalation requires muscle contraction; in Apply It Now 31.1, added e-cigarettes and nicotine gum/patches as potential aids to help stop smoking; in section 31.4, clarified paragraph explaining the interaction between iron, hemoglobin, red blood cells, and O_2; in section 31.4, clarified the roles of CO_2 and blood pH in regulating the breathing rate; added hypoxic chambers and Diamox to Burning Question 31.1. Based on SmartBook user data, clarified what it means for the bicarbonate reactions to reverse at the lungs in section 31.4. Added a new learning tool to ebook: a miniglossary of the pathway of respiration in section 31.2.
- **Chapter 32 (Digestion and Nutrition):** Revised the chapter opening essay to include more information about probiotics; in section 32.2, explained intracellular digestion in a sponge collar cell and added a corresponding inset to figure 32.4a; clarified that the cecum is part of the large intestine in figure 32.6a; in section 32.3, clarified the role of peristalsis in mixing food with enzymes to form a liquid; in section 32.3, explained the role of the sphincter at the lower end of the esophagus and connected its function to heartburn; in section 32.3, defined *bowels* and added “producing cholesterol” to the list of liver functions; wrote new Burning Question 32.1 about vegan diets; added celiac disease, Crohn disease, and irritable bowel syndrome to Apply It Now 32.1; in section 32.4, updated illustration of nutrition label and clarified the distinction between calories and food Calories.
- **Chapter 33 (Regulation of Temperature and Body Fluids):** In section 33.1, clarified the distinction between ectothermy, endothermy, and heterothermy; added hibernation to the paragraph on heterothermy; in section 33.5, improved consistency of use of *salts* and *ions*; in section 33.5, added a sentence to explain aldosterone’s effects on the kidneys; added a paragraph about urine color as an indication of dehydration to Burning Question 33.1; in section 33.6, added a second, contrasting study and two new illustrations. Based on SmartBook user data, added a new learning tool to ebook: a table of thermoregulatory adaptations in section 33.1. Added two new videos to ebook: marine iguanas feeding underwater and basking in the chapter opening essay.
- **Chapter 34 (The Immune System):** In section 34.1, added *leukocytes* as an alternative name for white blood cells; in section 34.2A, clarified that inflammation can be a response to infection or allergy, not just minor injury; clarified innate defenses in figure 34.4; in section 34.3, defined clonal selection in the passage on T cell proliferation; wrote new Apply It Now 34.1 on medical applications of antibodies; in section 34.4, emphasized that most vaccines cannot cause disease and referred back to Burning Question 16.1; added a row for celiac disease to table 34.4; in section 34.5, mentioned the role of basophils in allergic reactions, reinforced the role of histamine in allergies, and added information about “retraining” the immune system to accept allergens such as peanuts. Based on SmartBook user data, added information about why an Rh^+ woman’s immune system does not attack an Rh^+ fetus in section 34.5. Added a new learning tool to ebook: a miniglossary of adaptive immunity in section 34.3.
- **Chapter 35 (Animal Reproduction and Development):** Revised and updated the chapter opening essay; in section 35.1, explained the difference in size and motility between sperm and eggs; in section 35.2, reminded students that spermatogonia have 46 chromosomes and clarified why abuse of synthetic steroids reduces sperm counts; in section 35.3, clarified how an egg cell moves into and within the uterine tube and reminded readers that the secondary oocyte contains 23 chromosomes; revised Burning Question 35.1 and figure 35.A for clarity; in section 35.4, changed *STD* to *STI* to conform with modern terminology, noted the pregnancy rate for women who use no contraception, updated information on the HPV vaccine, and referred to Burning Question 16.1; in section 35.5, clarified the structure and function of the placenta and clarified some of the events of embryonic and fetal development; improved Apply It Now 35.1 to define infertility and mention that either males or females can be infertile; clarified the difference between miscarriage and stillbirth in Apply It Now 35.2; wrote new Investigating Life section 35.7 about sexual cannibalism in nursery web spiders. Based on SmartBook user data, referred readers in section 35.3 to the chapter summary to compare the timing of spermatogenesis and oogenesis. Added a new learning tool to ebook: a timeline of human development in section 35.5.

UNIT 7 The Ecology of Life

- **Chapter 36 (Animal Behavior):** In section 36.1, added examples of everyday applications of animal behavior; in section 36.2, updated information about birds with human vocabularies; in section 36.4, added polyandry to the section describing polygamy and revised the passage on mate guarding; in section 36.5, clarified the distinction between *direct fitness* and *indirect fitness* and expanded the passage on altruism in humans. Added new learning tools to ebook: a video of a dung beetle in section 36.1; a video of blue-footed boobies courting in section 36.4; a video of a cuttlefish changing color in section 36.6.
- **Chapter 37 (Populations):** In section 37.1 and throughout the chapter, added conservation biology examples where space and flow permitted; in Apply It Now 37.1, added information on counting animals in the open ocean; in section 37.2, added examples of ways that conservation biologists can boost birth rates and reduce death rates, updated information about immigration in the United States and worldwide birth and death rates, added a paragraph explaining how human activities

promote the migration of invasive species to new areas, and added the designators “late loss,” “constant loss,” and “early loss” to type I, type II, and type III species in narrative and figure 37.5; in section 37.3, clarified why *r* is constant in exponential and logistic growth equations; updated information about the human population in section 37.5’s narrative, figure 37.12, figure 37.15, table 37.2, and Burning Question 37.1; in section 37.5, clarified the passage describing the demographic transition; in section 37.6, clarified how microbes form the base of the food web in a toxic stream; in the chapter ending, added new figure summarizing population growth rates. Based on SmartBook user data, modified figures 37.6 and 37.8 to better show how the tabulated numbers relate to one another. Added a new learning tool to ebook: a figure comparing opportunistic to equilibrium life histories.

- **Chapter 38 (Communities and Ecosystems):** In section 38.1, added the definition of *carnivore,* rearranged the section on prey defenses to start with the most familiar examples, and referred back to section 22.5 as another example of coevolution; in section 38.2, added that it took decades of scientific debate to determine that few communities reach climax conditions; modified figure 38.14 to point out that phytoplankton are primary producers and that krill eat detritus; in section 38.3, clarified explanation of keystone species and reminded readers that heat is exchanged with the environment and leaves the food web; in section 38.4, modified the illustrations of the carbon, nitrogen, and phosphorus cycles to indicate processes that are heavily influenced by human activities; added labels for denitrification to figure 38.21; in section 38.4, clarified the explanation of eutrophication; wrote new Investigating Life section on monarch butterfly migration; in chapter ending, added a new Scientific Literacy question asking students to explore how policy makers weigh both science and economics to make decisions. Added a new learning tool to ebook: a video of a chameleon catching a spider in section 38.1; a figure depicting otters as keystone species in section 38.3.
- **Chapter 39 (Biomes):** Wrote new chapter opening essay on life in caves; added a paragraph on oxygen isotopes in foram shells to Burning Question 39.1; added inset to figure 39.2 to explain the uneven distribution of sunlight over Earth’s surface; added lines for 60 N and 60 S to figure 39.7; in section 39.3, stated that the main selective forces in the rain forest are competition for light and nutrients and added information about soils in deciduous forests and tropical savannas; added descriptive labels to figure 39.23; wrote new Investigating Life about the economic impacts of climate change, especially on the timber industry. Based on SmartBook user data, clarified in section 39.3 that most temperate forests are in the northern hemisphere. Added new learning tools to ebook: a video of bats emerging from a cave in the chapter opening essay; a time-lapse video of a deciduous tree in section 39.3; a video of coral reef biodiversity in section 39.5.
- **Chapter 40 (Preserving Biodiversity):** Wrote new chapter opening essay on invasive lionfish; added new figure 40.3 to show where human impacts on the environment are most intense; in section 40.1, explained the HIPPO acronym; in section 40.3, mentioned toxins from landfills as a source of water pollution, clarified the explanations of pollution from sewage and of eutrophication, and added art to figure 40.12 to explain acid deposition; in section 40.4, updated data for atmospheric CO_2, average temperature, and Arctic ice extent; added new Burning Question 40.1 comparing today’s pace of climate change to the rate of change throughout Earth’s history; in section 40.6, updated information about major habitat restoration projects, added a passage explaining the black-footed ferret recovery program, and added a passage about using CRISPR-Cas9 to add chestnut blight resistance genes to American chestnut trees; expanded the tips in Burning Question 40.2; in chapter ending, added a new Scientific Literacy question asking students to explore the science and ethics of political decisions. Added a new learning tool to ebook: a table listing selected consequences of climate change.

Contents

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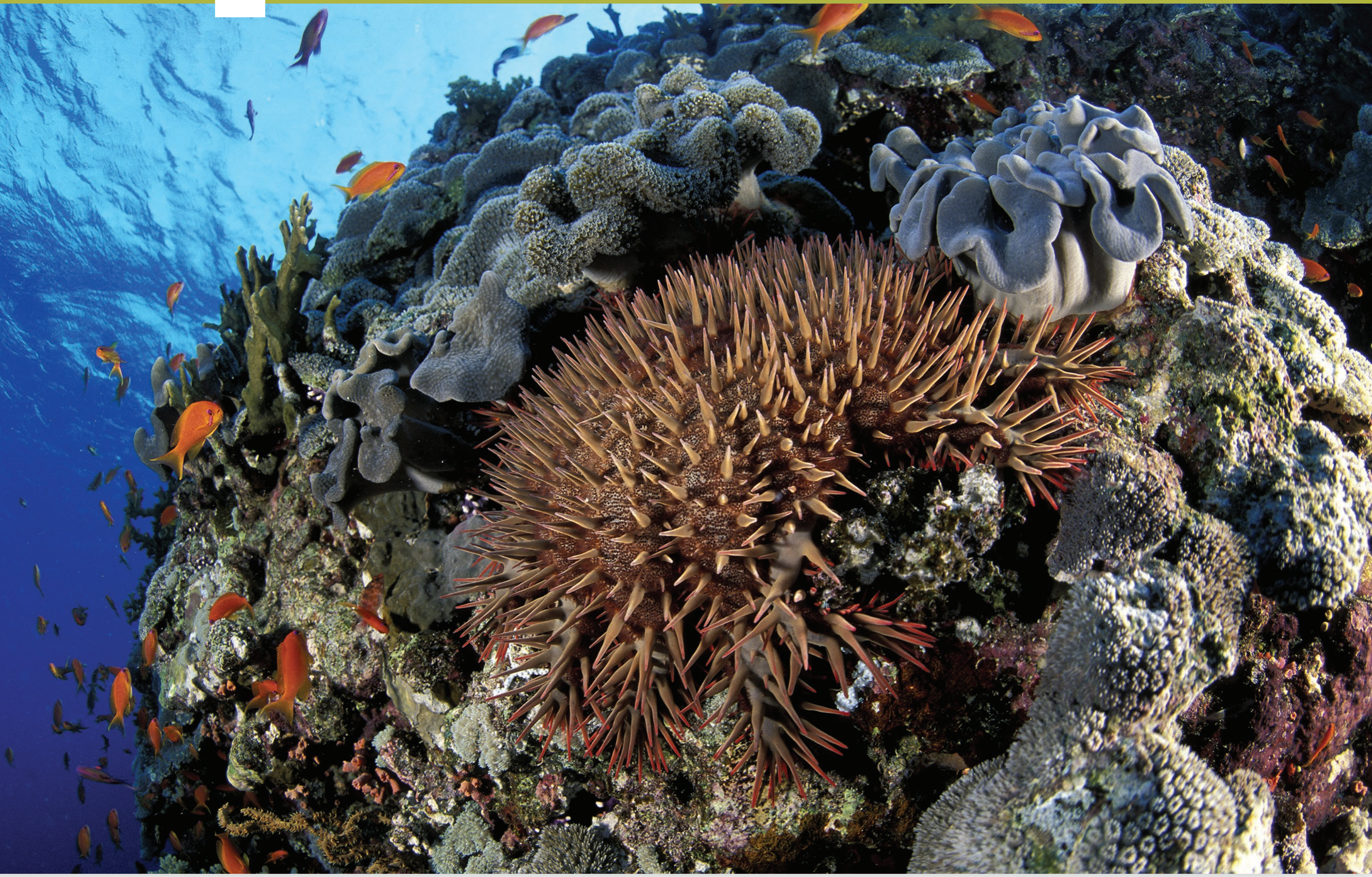
Daniel Garcia/AFP/Getty Images

CHAPTER 1

The Scientific Study of Life



Undersea World. A coral reef in the Red Sea is home to countless marine species. The prickly animal in the center is a "crown of thorns" sea star.
Franco Banfi/WaterF/age fotostock

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.

UNIT 1

Life Is Everywhere

Welcome to biology, the scientific study of life. Living organisms surround us. You are alive, and so are your friends, your pets, and the plants in your home and yard. Bacteria thrive on and in your body. Any food you ate today was (until recently, anyway) alive. And the news is full of biology-related discoveries about fossils, new cancer treatments, genetics, global climate change, and the environment.

Stories 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 life-saving drugs—and genetically engineered plants that produce their own pesticides. This same technology may one day enable physicians to routinely cure hemophilia, cystic fibrosis, and other genetic diseases by supplementing a person's faulty DNA with a functional "patch."

Biology also includes the study of nonhuman life. We exist only because of our interactions with other species, which provide food, oxygen, clean water, clothing, shelter, and other necessities. Even species that do not directly "serve" us are essential to the ecosystems that sustain all life. Human activities, however, are pushing many ecosystems dangerously out of balance.

Consider the "crown of thorns" sea star shown here. These animals are notorious for their arsenal of sharp, venomous spines, which may cause painful wounds. At low population densities, their coral-eating habits help maintain reef biodiversity. Sometimes, however, huge numbers of sea stars destroy entire patches of coral. What causes these infestations? Many researchers point to nutrient-polluted runoff from nearby farms and cities. The nutrient influx triggers a population explosion of algae, which sea star larvae eat as they develop into adults. Removing the adults from an infested reef is dangerous and labor-intensive, but help is coming from an unusual source: Underwater robots have been programmed to seek out the crown of thorns and deliver a lethal injection.

The list of biology-related topics goes on and on: global climate change, stem cell therapies, new cancer treatments, infectious disease, improved crop plants, synthetic life, infertility treatment, endangered species, DNA fingerprinting, biofuels, pollution, the history of life, and more. 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.

LEARNING OUTLINE

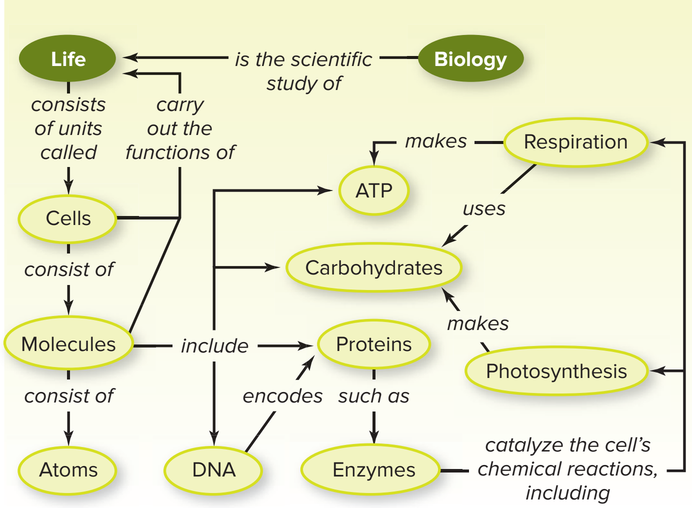
1.1 What Is Life?

1.2 The Tree of Life Includes Three Main Branches

1.3 Scientists Study the Natural World

1.4 Investigating Life: The Orchid and the Moth

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 at the end of the chapter.

1.1 What Is Life?

Biology is 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.

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. 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.

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

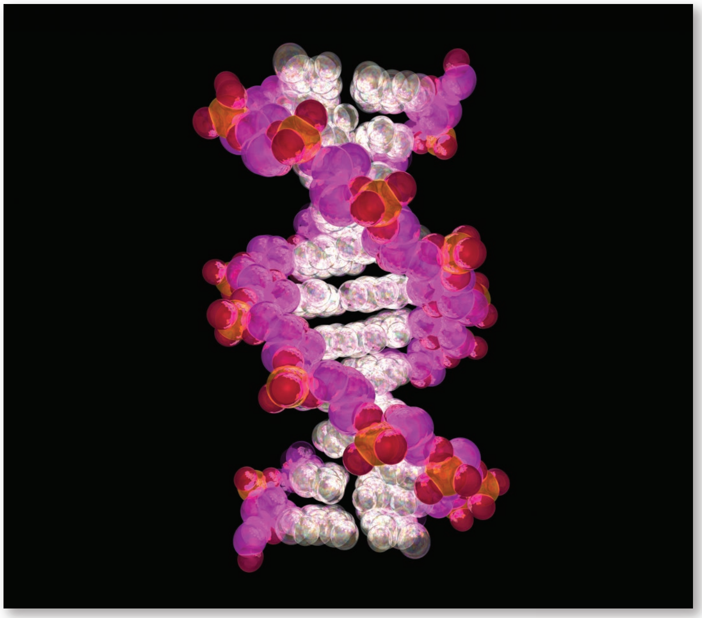


Figure 1.1 Informational Molecule of Life. All cells contain DNA, a series of "recipes" for proteins that each cell can make.
Scott Camazine/123RF

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

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 that increases in size, and, at maturity, reproduces sexually to produce its own acorns.
Evolution	Increasing numbers of bacteria survive treatment with antibiotic drugs.

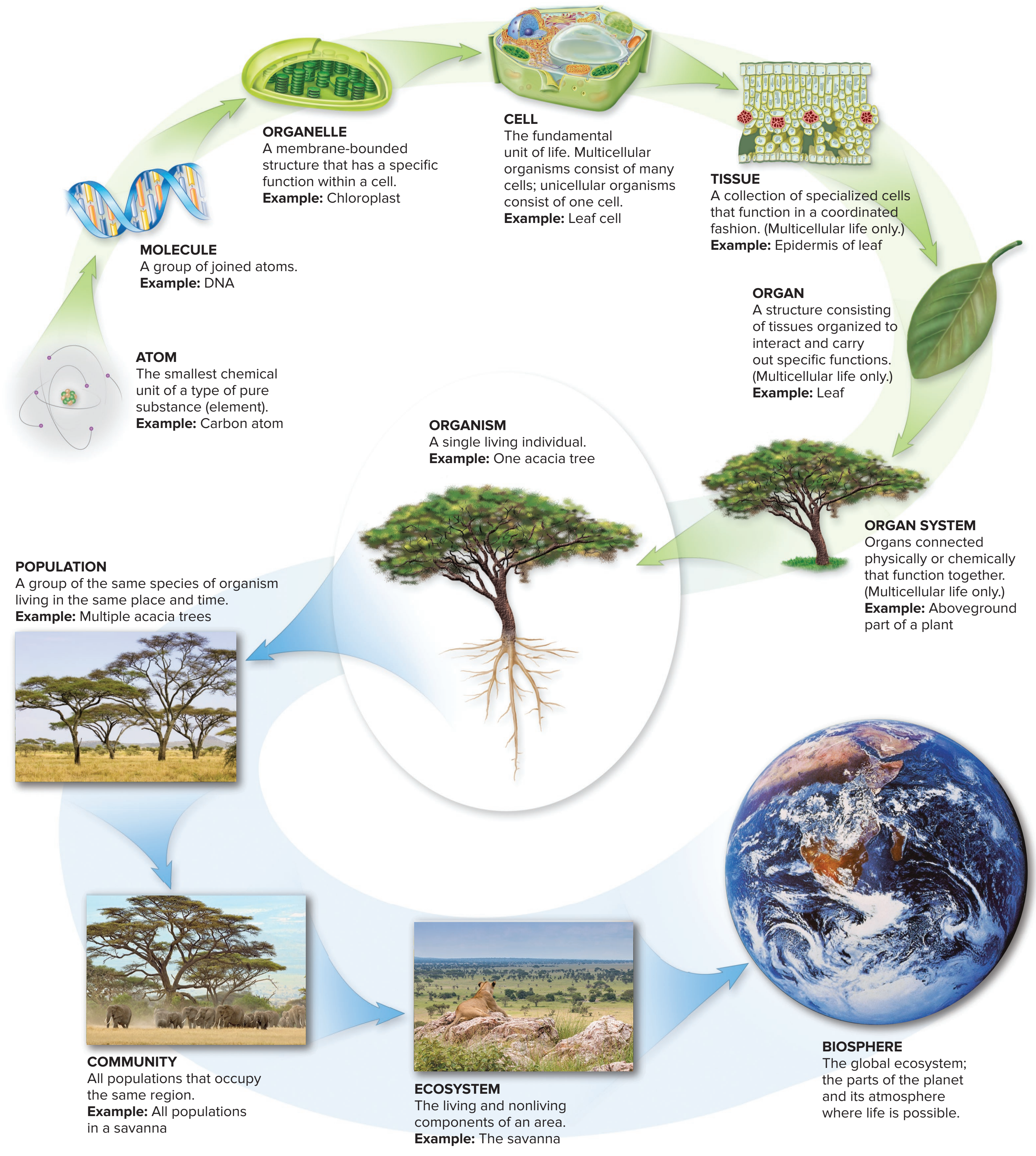


Figure 1.2 **Life's Organizational Hierarchy.** This diagram applies life's organizational hierarchy to a multicellular organism (an acacia tree). Green arrows represent the organizational hierarchy up to the level of the organism; blue arrows represent levels that include multiple organisms.

Photos: (population): ChrisCrafter/E+/Getty Images; (community): Daryl Balfour/Gallo Images/Getty Images; (ecosystem): Bas Vermolen/Getty Images; (biosphere): StockTrek/Getty Images

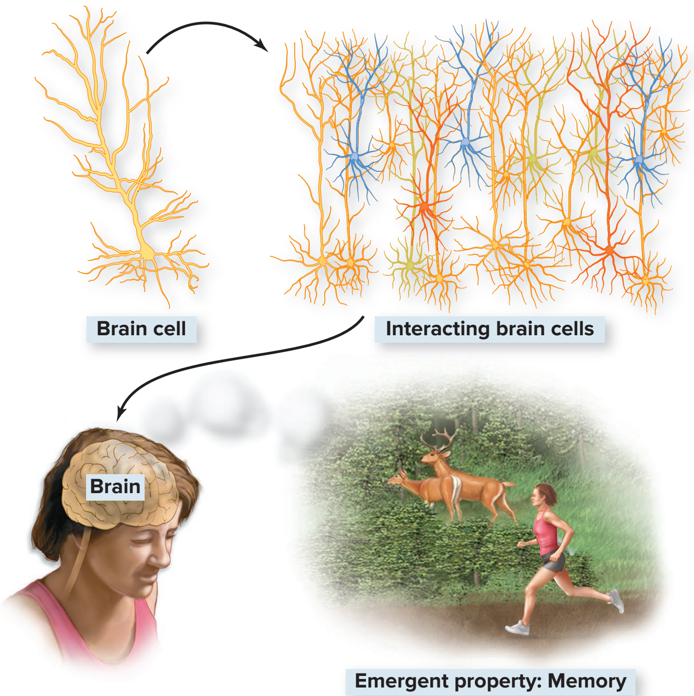


Figure 1.3 An Emergent Property—from Cells to Memories. Highly branched cells interact to form a complex network in the brain. Memories, consciousness, and other qualities of the mind emerge only when these cells interact in a certain way.

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 physical and chemical 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.

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.

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. 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 38.3A

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

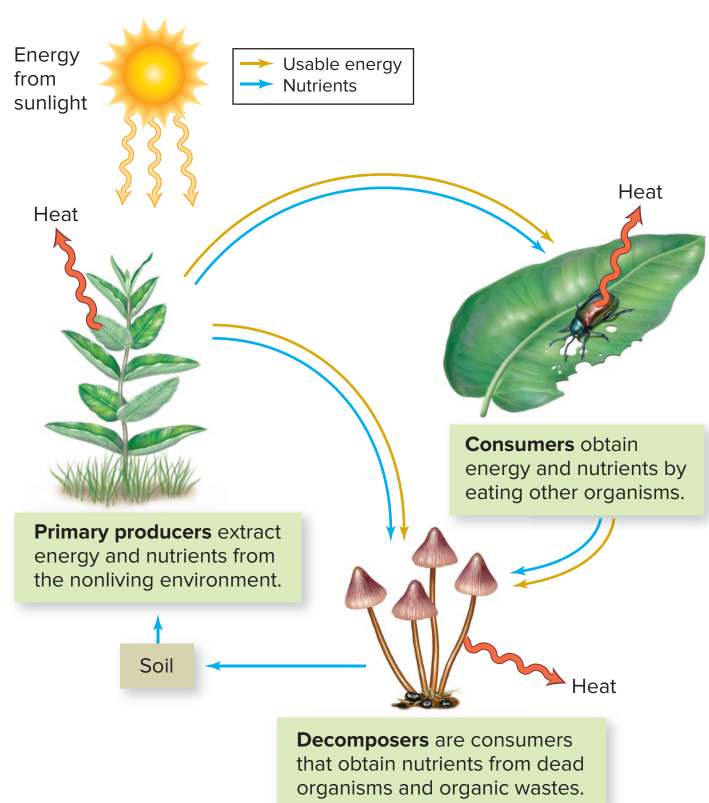


Figure 1.4 Life Is Connected. All organisms extract energy and nutrients from the nonliving environment or from other organisms. Decomposers recycle nutrients back to the nonliving environment. At every stage along the way, heat is lost to the surroundings.

a. b.

Figure 1.5 Temperature Homeostasis. (a) Shivering and (b) sweating are responses that maintain body temperature within an optimal range.
(a): Kristy-Anne Glubish/Design Pics; (b): John Rowley/Getty Images

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.

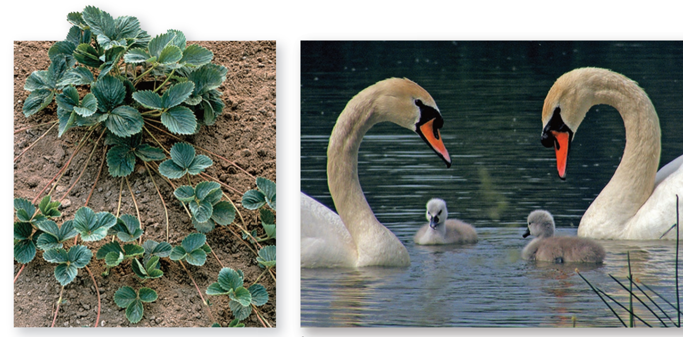
Because cells maintain homeostasis by counteracting changes as they occur, organisms must be able to sense and react to stimuli. To illustrate this idea, consider the mechanisms that help maintain your internal temperature at about 37°C (figure 1.5). When you go outside on a cold day, you may begin to 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.

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 (figure 1.6a). 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 (figure 1.6b). By mixing genes at each generation, sexual reproduction results in tremendous diversity in a 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.



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.
(a): Dorling Kindersley/Getty Images; (b): jadranko/Moment/Getty Images

Before each offspring can reproduce, it must develop into an adult. The term *development* describes not only growth but also the many other changes that occur as an organism matures. Each young swan in figure 1.6b, for example, started as a single fertilized egg cell. That cell divided over and over, forming an embryo. Continued cell division and specialization into tissues, organs, and organ systems yielded the newly hatched swans. The youngsters will continue to grow as they develop 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.

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.
Mark Webster/Getty Images

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 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 1.8 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 the publication of his book *On the Origin of Species by Means of Natural Selection,* which introduced 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, evolution has been operating since life began, and it explains the current diversity of life. In fact, 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. Does any nonliving object possess all of the characteristics of life? Explain your answer.
2. List the levels of life's organizational hierarchy from smallest to largest, starting with atoms and ending with the biosphere.
3. The bacteria in figure 1.8 reproduce asexually, yet they are evolving. What is their source of genetic variation?

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

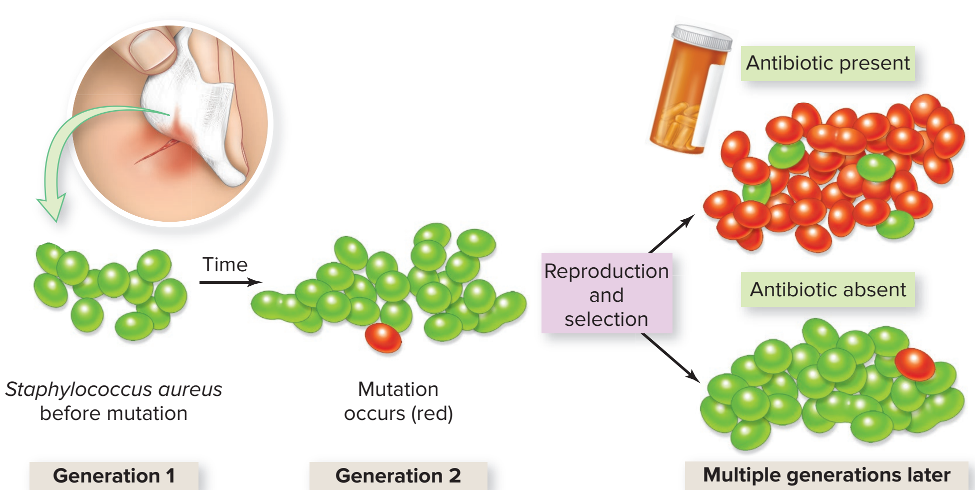


Figure 1.8 Natural Selection. *Staphylococcus aureus* (commonly called "staph") is a bacterium that causes skin infections. A bacterium undergoes a random genetic mutation that (by chance) makes the cell resistant to an antibiotic. The presence of the antibiotic increases the reproductive success of 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.

species. A human, for example, is *Homo sapiens*. (Note that scientific names are always italicized and that only the genus 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. Researchers infer these relationships by comparing anatomical, behavioral, cellular, genetic, and biochemical characteristics.

Section 14.6 describes the taxonomic hierarchy in more detail. For now, it is enough to know that genetic evidence suggests that all species fall into one of three **domains,** the broadest (most inclusive) taxonomic category. Figure 1.9 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.

The species in each domain are further subdivided into **kingdoms;** figure 1.9 shows the kingdoms within domain Eukarya. Three of these kingdoms—Animalia, Fungi, and Plantae—are familiar to most people. Within each one, organisms share the same general strategy for acquiring energy. The plant kingdom contains autotrophs, whereas fungi and animals are consumers that differ in the details of how they obtain food. But the fourth group of eukaryotes, the Protista, contains a huge collection of unrelated species. Protista is a convenient but artificial "none of the above" category for the many species of eukaryotes that are not plants, fungi, or animals.

New research based on genetic sequences is helping to organize the eukaryotes into several "supergroups." The aim is to place each species with its relatives, regardless of its historical classification as an animal, a fungus, a plant, or a protist. Section 18.5 describes the supergroups in more detail.

1.2 MASTERING CONCEPTS

1. What are the goals of taxonomy?
2. How are domains related to kingdoms?
3. List and describe the four main groups of eukaryotes. How is the organization of eukaryotes changing?

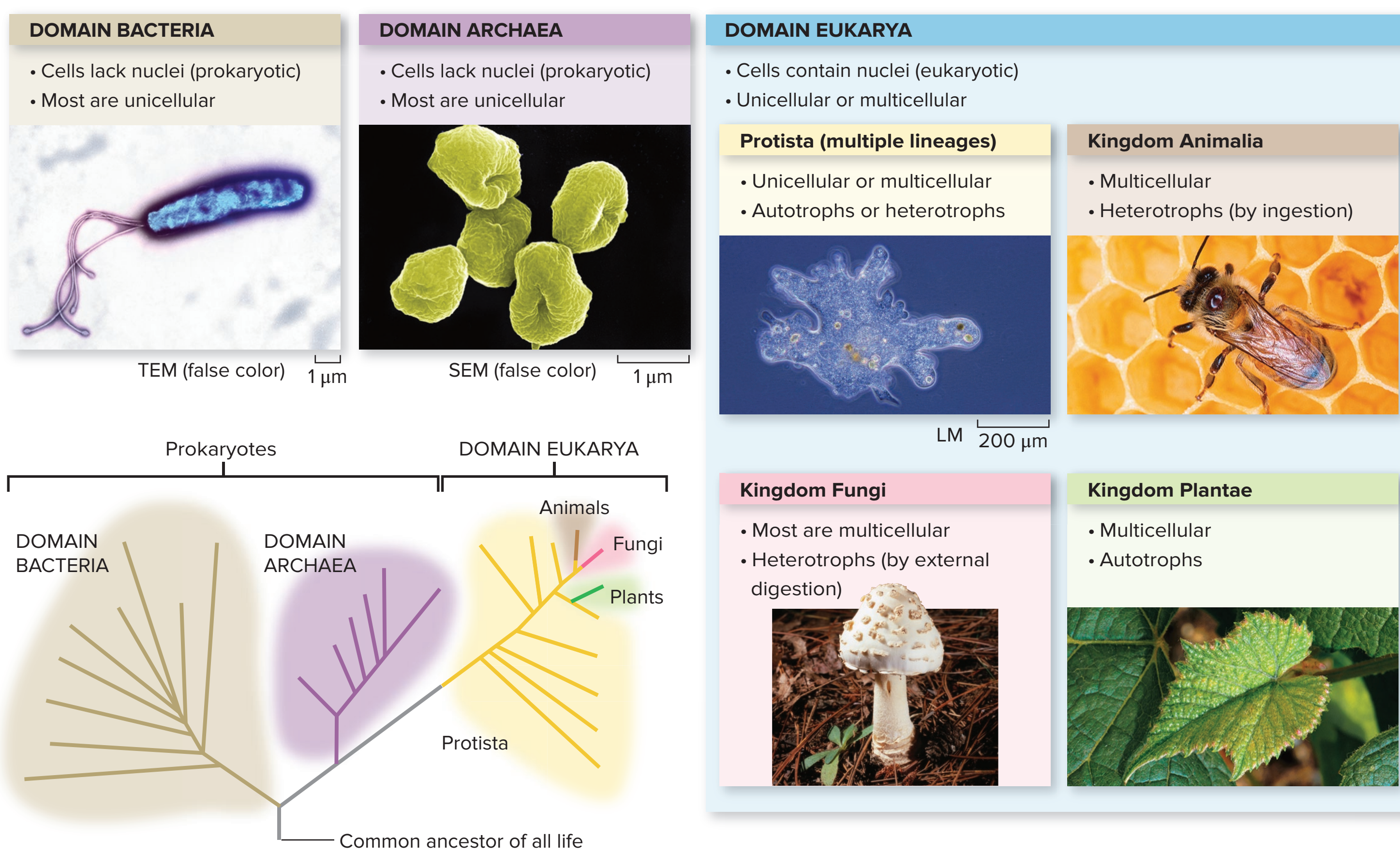


Figure 1.9 Life's Diversity. The three domains of life arose from a hypothetical common ancestor, shown at the base of the evolutionary tree.

Photos: (Bacteria): Science Photo Library/Getty Images; (Archaea): Eye of Science/Science Source; (Protista): Melba Photo Agency/Alamy Stock Photo; (Animalia): Source: Scott Bauer/USDA/ARS; (Fungi): Ro-ma Stock Photography/Getty Images; (Plantae): Source: Keith Weller/USDA