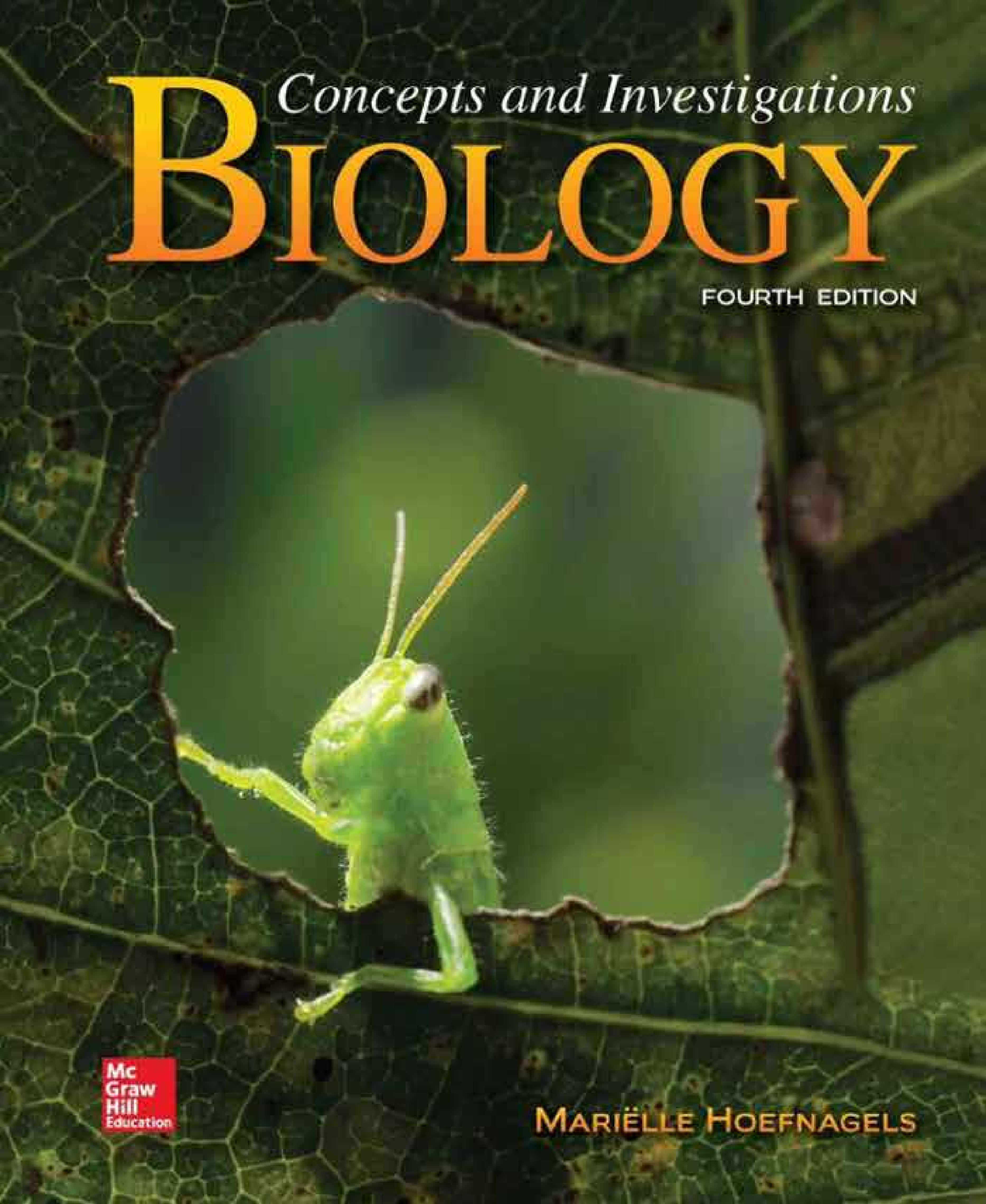
BIOLOGY
Concepts and Investigations

FOURTH EDITION



Mc Graw Hill Education

MARIËLLE HOEFNAGELS

BIOLOGY

This page intentionally left blank

BIOLOGY
Concepts and Investigations

FOURTH EDITION

MARIËLLE HOEFNAGELS
THE UNIVERSITY OF OKLAHOMA

MEDIA CONTRIBUTIONS BY
MATTHEW S. TAYLOR

Mc Graw Hill Education

BIOLOGY: CONCEPTS AND INVESTIGATIONS, FOURTH EDITION

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121.

1 2 3 4 5 6 7 8 9 0 DOW 20, 19, 18, 17

ISBN 978-0-07-802420-7
MHID 0-07-802420-X

Chief Product Officer, SVP Products & Markets: *G. Scott Virkler*
Vice President, General Manager, Products & Markets: *Marty Lange*
Vice President, Content Design & Delivery: *Betsy Whalen*
Director, Biology: *Lynn Breithaupt*
Brand Manager: *Michelle Vogler*
Director of Product Development: *Rose Koos*
Product Developer: *Anne Winch*
Marketing Manager: *Britney Ross*
Digital Product Analyst: *Christine Carlson*
Director, Content Design & Delivery: *Linda Avenarius*
Program Manager: *Angela R. FitzPatrick*
Content Project Manager (print): *Peggy Selle*
Content Project Manager (assessment): *Emily Windelborn*
Buyer: *Laura Fuller*
Designer: *Tara McDermott*
Content Licensing Specialists: *Lori Hancock/Deanna Dausener*
Cover Image: *(front) ©mustamin/Getty Images RF*
Compositor: MPS Limited
Typeface: *10/12 STIX MathJax Main*
Printer: *R. R. Donnelley*

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.
Leaf: ©*image broker/Alamy RF*
Flames: ©*Don Farrall/Getty Images RF*

Library of Congress Cataloging-in-Publication Data

Names: Hoefnagels, Mariëlle.
Title: Biology : concepts and investigations.
Description: Fourth edition / Mariëlle Hoefnagels, The University of Oklahoma;
media contributions, Matthew S. Taylor. | New York, NY : McGraw-Hill Education, [2018] | Includes index.
Identifiers: LCCN 2016047958 | ISBN 9780078024207 (alk. paper)
Subjects: LCSH: Biology–Textbooks.
Classification: LCC QH307.2 .H64 2018 | DDC 570–dc23 LC record available at https://lccn.loc.gov/2016047958

www.mhhe.com

Brief Contents

About the Author

©Davenport Photos

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

Dr. Hoefnagels received her 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

Vision and Change in Undergraduate Biology Education: A Call to Action encourages instructors to improve student engagement and learning in introductory biology courses. The central idea of the original *Vision and Change* report—and of the conferences and reports that followed—is 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, and tutorial animations. We also supply a variety of supplements that make teaching easier, including eye-catching PowerPoint® lectures with integrated clicker questions that assess conceptual understanding. As you examine this new edition, however, I hope you will see an even stronger emphasis on connections and the "big picture." Our most prominent new feature, Survey the Landscape, shows how each chapter's content fits into the unit's overall emphasis. Students often struggle to connect new topics to what they have learned previously; Survey the Landscape is designed to help them keep an eye on the big picture. These new figures, which appear in each chapter opener, can be integrated with the Pull It Together figure in every chapter's summary to help students see the "forest" *and* the "trees."

Many other changes to this book reflect the growing numbers of instructors and students who are embracing digital textbooks. Much of our work for the fourth edition was behind-the-scenes adjustments that make the narrative and art more digital-friendly. Moreover, SmartBook® user data from thousands of students using the third 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 and figures.

I agree with the *Vision and Change* report's call for instructors to embrace active learning techniques, but I also 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

©Davenport Photos

Author's Guide *To Using This Textbook*

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

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.

Is It Easier Being Green?

Food is expensive. It would be much cheaper and easier if we could feed ourselves using photosynthesis. Imagine the benefit of being photosynthetic: You could make your own food, free of charge, simply by sitting outside in the sun.

Of course, your body would have to have some new adaptations for photosynthesis to work. Your skin would have to be green, for starters. You might even have skin flaps that capture extra sunlight. You wouldn't eat, so you would need another way to acquire essential minerals; perhaps your feet would grow rootlike extensions that would absorb water and nutrients from soil.

Maybe photosynthetic cows, pigs, and chickens—or pets such as dogs and cats—would be a better idea. Feed-free animals would be a commercial and environmental triumph, costing less to own and generating less waste than the animals we raise now.

Fortunately or unfortunately, scientists will probably never be able to create photosynthetic people, chickens, or pooches. Mammals and birds move, breathe, pump blood, and maintain high body temperatures. All of this activity would likely require energy beyond what photosynthesis alone could supply.

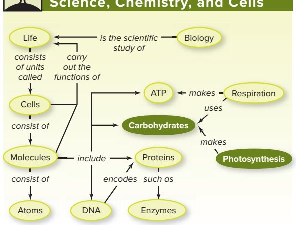
Some animals, however, have adopted the "green" lifestyle by harboring live-in photosynthetic partners (see section 5.7). The closest to a true plant–animal hybrid is probably the sea slug *Elysia chlorotica,* a solar-powered mollusk with chloroplasts (photosynthetic organelles) in the cells lining its digestive tract. The chloroplasts come from algae in the slug's diet. As the animal grazes, it punctures the algal cells and discards everything but the chloroplasts, which migrate into the animal's cells. Light passes through the slug's skin and strikes the food-producing chloroplasts. Once its "solar panels" are in place, the animal may not eat again for months!

Perhaps the most famous animals to "farm" photosynthetic partners are corals. Inside the coral are single-celled protists called dinoflagellates, which use the sun's energy to feed the coral. In exchange, the animals provide a home for the protists. Sometimes, however, the partners break up. Corals under stress sometimes expel their dinoflagellates, or the protists may leave on their own. The reef then turns white. The coral animals eventually die, endangering the entire reef ecosystem. Pollution, disease, shading, excessively warm water, and ultraviolet radiation all trigger coral bleaching. Biologists predict that global climate change will only make this problem worse.

Corals and sea slugs are not the only animals whose lives depend on photosynthesis. Yours does, too, as you will learn in the next two chapters.

LEARNING OUTLINE

SURVEY THE LANDSCAPE Science, Chemistry, and Cells



Photosynthetic cells use carbon dioxide, water, and sunlight to build carbohydrates. These molecules, which make up much of a plant's body, can also be used to store energy and generate ATP.

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

Concept maps help students see the big picture.

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

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

PULL IT TOGETHER

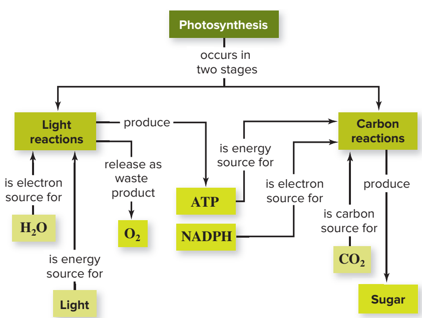


Figure 5.15 **Pull It Together: Photosynthesis.**

Refer to figure 5.15 and the chapter content to answer the following questions.

1. Review the Survey the Landscape figure in the chapter introduction, and then add *enzymes, cells, molecules,* and *respiration* to the Pull It Together concept map.
2. How would you incorporate the Calvin cycle, rubisco, C_3 plants, C_4 plants, and CAM plants into this concept map?
3. One possible connecting phrase in the concept map is "*Chlorophyll* reflects ________ wavelengths of *light*." Fill in the blank and explain your answer.
4. Build another small concept map showing the relationships among the terms *chloroplast, stroma, grana, thylakoid, photosystem,* and *chlorophyll.*
5. Besides respiration, what happens to the sugar produced in photosynthesis?

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
See What's Coming
Start by reviewing the Survey the Landscape figure at the start of each chapter to see how the material fits with the rest of the unit. Then check out the Learning Outline. Each heading is a complete sentence that summarizes the most important idea of the section. Read through these statements before you start each chapter. You can also flip to the end of the chapter before you start to read; the chapter summary and Pull It Together concept map can provide a preview of what's to come.

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

Each case 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 case as a basis for discussion of the nature of science.

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

INVESTIGATING LIFE

5.7 Solar-Powered Salamanders

This chapter's opening essay described two examples of solar-powered animals that live in the ocean: sea slugs and corals. But marine invertebrates are not the only animals with this unusual lifestyle. The eggs of spotted salamanders have live-in algae of their own.

Spotted salamanders are amphibians that live throughout the forests of North America. On rainy evenings in the spring, these animals mate in temporary ponds, where the females lay masses of fertilized eggs (figure 5.12). Each egg contains a tiny embryo and is surrounded by a thick jelly layer. Then, something unusual happens: Microscopic green algae somehow find each egg and enter the jelly layer. The algae reproduce and carry out photosynthesis in the protective confines of their new homes.

Biologists have known since 1986 that the green algae boost the O_2 concentration inside the salamander eggs, a real benefit to embryos that cannot yet breathe on their own. But do algae also feed the embryos a steady diet of sugars? Erin Graham, Robert Sanders, and two other researchers at Temple University wanted to learn more.

The team gathered algae-infected eggs from the wild and incubated them for nearly 2 hours in a solution containing CO_2 that was "tagged" with a radioactive isotope of carbon. They knew that only algae—not salamander eggs or embryos—would be able to use CO_2 directly in photosynthesis. After the incubation period, they rinsed off the excess solution and measured the amount of radioactive carbon in each egg and embryo. ⓘ *radioactive isotopes,* section 2.1C

The researchers reasoned that any radioactive carbon in a salamander embryo could come from one of two sources. The carbon might simply diffuse in from the solution, without any help from the algae. Alternatively, the algae might use the tagged carbon to produce sugars in photosynthesis, then transfer some of the radioactive sugar to the embryos. ⓘ *diffusion*, section 4.5A

To differentiate between these two possibilities, the team incubated some eggs in the light, allowing both diffusion and photosynthesis to occur. A second set of eggs was incubated in total darkness. Photosynthesis is not possible in the dark, but diffusion continues. Subtracting the amount of radioactive carbon in dark-treated embryos from the amount in light-treated embryos should therefore reveal the effect of photosynthesis.

After the experiment was complete, radioactivity measurements revealed that eggs and embryos incubated in the light incorporated more radioactive carbon than did their dark-treated counterparts, a sure sign that the algae were sharing their carbon with their tiny hosts (figure 5.13). This sugar supplement can help a developing embryo survive.

It is not surprising that animals would take on photosynthetic partners, but what's in it for the algae? They probably benefit from the partnership as well. A developing embryo releases CO_2 in respiration (see chapter 6). Perhaps this extra shot of CO_2 makes photosynthesis more efficient for the algae, completing the exchange of materials between two allies from different kingdoms of life.

Source: Graham, Erin R., Scott A. Fay, Adam Davey, and Robert W. Sanders. 2013. Intracapsular algae provide fixed carbon to developing embryos of the salamander *Ambystoma maculatum*. *Journal of Experimental Biology*, vol. 216, pages 452–459.

Figure 5.12 **Spawning.** A spotted salamander lays eggs in a pool of water.
©George Grall/National Geographic Creative

Sample	Average Net Radioactivity Difference (Light Minus Dark)	Average Hourly Change in Carbon	Source of Carbon Increase
Whole egg (Embryo)	12,041 dpm*	294.5 ng	Carbon fixation by algae in egg
Embryo alone	627 dpm*	15.4 ng	Transfer of sugars from algae to embryo

*dpm = disintegrations per minute, a measure of radioactivity

Figure 5.13 **Thanks for the Snack.** Using a radioactive isotope of carbon, researchers measured the amount of carbon transferred from egg-dwelling green algae to salamander embryos.

5.7 MASTERING CONCEPTS

1. On average, what percentage of the 294.5 ng of carbon that the algae fix each hour is transferred to the embryo? Refer to figure 5.13.
2. Identify a standardized variable, an independent variable, and a dependent variable in the experiment.

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

CHAPTER SUMMARY

5.1 Life Depends on Photosynthesis

- **Autotrophs** produce their own organic compounds from inorganic starting materials such as CO_2 and water. **Heterotrophs** rely on organic molecules produced by other organisms.

A. Photosynthesis Builds Carbohydrates Out of Carbon Dioxide and Water

- **Photosynthesis** converts kinetic energy in light to potential energy in the covalent bonds of carbohydrates, according to the following chemical equation:

$$6CO_2 + 6H_2O \xrightarrow{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

B. Plants Use Carbohydrates in Many Ways

- Plants use glucose and other sugars to grow, generate **ATP,** nourish nonphotosynthetic plant parts, and produce cellulose and many other biochemicals. Most store excess carbohydrates as starch or sucrose.

C. The Evolution of Photosynthesis Changed Planet Earth

- Before photosynthesis evolved, organisms were heterotrophs. The first autotrophs made new food sources available.
- Over billions of years, oxygen produced in photosynthesis changed Earth's climate and the history of life.

5.2 Sunlight Is the Energy Source for Photosynthesis

A. What Is Light?

- Visible light is a small part of the **electromagnetic spectrum.**
- **Photons** move in waves. The shorter the **wavelength,** the more kinetic energy per photon. Visible light occurs in a spectrum of colors representing different wavelengths.

B. Photosynthetic Pigments Capture Light Energy

- **Chlorophyll *a*** is the primary photosynthetic pigment in plants. **Accessory pigments** absorb wavelengths of light that chlorophyll *a* cannot absorb.

C. Chloroplasts Are the Sites of Photosynthesis

- Plants exchange gases with the environment through pores called **stomata.**
- Leaf **mesophyll** cells contain abundant **chloroplasts.**
- A chloroplast contains a gelatinous fluid called the **stroma.** The fluid surrounds the **grana,** which are stacks of pancake-shaped **thylakoid** membranes. Photosynthetic pigments are embedded in the thylakoid membranes, which enclose the **thylakoid space.**
- A **photosystem** consists of proteins, **antenna pigments,** and a **reaction center.**

5.3 Photosynthesis Occurs in Two Stages

- The **light reactions** of photosynthesis produce ATP and **NADPH;** these molecules provide energy and electrons for the sugar-producing **carbon reactions** (figure 5.14).

5.4 The Light Reactions Begin Photosynthesis

A. Light Striking Photosystem II Provides the Energy to Produce ATP

- Photosystem II captures light energy and sends electrons from reactive chlorophyll *a* along the **electron transport chain.**
- Electrons from chlorophyll are replaced with electrons from water. O_2 is the waste product.
- The energy released in the electron transport chain drives the active transport of protons (H^+) into the thylakoid space. The protons diffuse out through channels in **ATP synthase.** This movement powers the phosphorylation of ADP to ATP.
- The coupling of the proton gradient and ATP formation is called **chemiosmotic phosphorylation.**

B. Electrons from Photosystem I Reduce $NADP^+$ to NADPH

- Light striking photosystem I re-energizes the electrons, which pass to an enzyme that uses them to reduce $NADP^+$. The product of this reaction is NADPH.

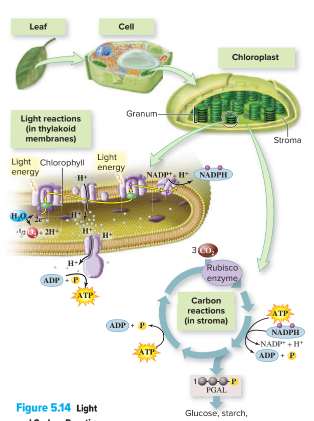


Figure 5.14 **Light and Carbon Reactions.**

5.5 The Carbon Reactions Produce Carbohydrates

- The carbon reactions use energy from ATP and electrons from NADPH in **carbon fixation** reactions that add CO_2 to organic compounds.
- In the **Calvin cycle, rubisco** catalyzes the reaction of CO_2 with **ribulose bisphosphate (RuBP)** to yield two molecules of PGA. These are converted to PGAL, the immediate product of photosynthesis. PGAL later becomes glucose and other carbohydrates.

5.6 C_3, C_4, and CAM Plants Use Different Carbon Fixation Pathways

- The Calvin cycle is also called the **C_3 pathway.** Most plant species are C_3 plants, which use only this pathway to fix carbon.
- **Photorespiration** wastes carbon and energy when rubisco reacts with O_2 instead of CO_2.
- The **C_4 pathway** reduces photorespiration by separating two carbon fixation reactions into different cells. In mesophyll cells, CO_2 is fixed as a four-carbon molecule, which moves to a **bundle-sheath cell** and liberates CO_2 to be fixed again in the Calvin cycle.
- In the **CAM pathway,** desert plants such as cacti open their stomata and take in CO_2 at night, storing the fixed carbon in vacuoles. During the day, they split off CO_2 and fix it in chloroplasts in the same cells.

5.7 Investigating Life: Solar-Powered Salamanders

- The eggs of spotted salamanders contain cells of green algae, which provide O_2 and carbon to the animal's embryo.

5.3 Photosynthesis Occurs in Two Stages

Inside a chloroplast, photosynthesis occurs in two stages: the light reactions and the carbon reactions. Figure 5.7 summarizes the entire process, and sections 5.4 and 5.5 describe each part in greater detail.

The **light reactions** convert solar energy to chemical energy. (You can think of the light reactions as the "photo-" part of photosynthesis.) In the chloroplast's thylakoid membranes, pigment molecules in two linked photosystems capture kinetic energy from photons and store it as potential energy in the chemical bonds of two molecules: ATP and NADPH.

Recall from chapter 4 that **ATP** is a nucleotide that stores potential energy in the covalent bonds between its phosphate groups. ATP forms when a phosphate group is added to ADP (see figure 4.9). The other energy-rich product of the light reactions, **NADPH,** is a coenzyme that carries pairs of energized electrons. In photosynthesis, these electrons come from one of the two reaction center chlorophyll molecules. Once the light reactions are under way, chlorophyll, in turn, replaces its "lost" electrons by splitting water molecules, yielding O_2 as a waste product. ⓘ *coenzymes,* section 4.4B

These two resources (energy and "loaded" electron carriers) set the stage for the second part of photosynthesis: the carbon reactions. In the carbon reactions, the chloroplast uses ATP, the high-energy electrons in NADPH, and CO_2 to produce sugar molecules. (These reactions are the "-synthesis" part of photosynthesis.) The ATP and NADPH come from the light reactions, and the CO_2 comes from the atmosphere. Once inside the leaf, CO_2 diffuses into a mesophyll cell and across the chloroplast membrane into the stroma, where the carbon reactions occur.

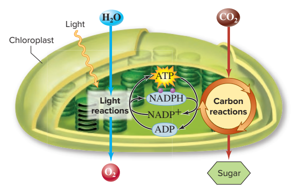


Figure 5.7 Overview of Photosynthesis. In the light reactions, pigment molecules capture light energy and transfer it to molecules of ATP and NADPH. The carbon reactions use this energy to build sugar molecules out of carbon dioxide.

Because the carbon reactions do not directly require light, they are sometimes called the "dark reactions" of photosynthesis. This term is misleading, however, because the carbon reactions occur mostly during the day, when the light reactions are producing ATP and NADPH. A more accurate alternative would be the "light-independent reactions."

5.3 MASTERING CONCEPTS

1. What happens in each of the two main stages of photosynthesis?
2. Explain the role of each of the products of the light reactions and the carbon reactions.

Burning Question

Why do leaves change colors in the fall?

Most leaves are green throughout a plant's growing season, although there are exceptions; some ornamental plants, for example, have yellow or purple foliage. The familiar green color comes from chlorophyll *a,* the most abundant pigment in photosynthetic plant parts. But the leaf also has other photosynthetic pigments. Carotenoids contribute brilliant yellow, orange, and red hues. Purple pigments, such as anthocyanins, are not photosynthetically active, but they do protect leaves from damage by ultraviolet radiation.

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

©Corbis RF

These carefully timed events help the plant conserve resources. After all, about 75% of a leaf's proteins occur in its chloroplasts. Rather than simply letting the first frost kill the leaves, the plant dismantles these proteins *before* the leaves die. The plant stores the valuable nitrogen and other nutrients from these molecules in living tissues that will survive the winter.

Spring brings a flush of fresh, green leaves. The energy to produce the foliage comes from glucose the plant produced during the last growing season and stored as starch. The new leaves make food throughout the spring and summer, so the tree can grow—both above the ground and below—and produce fruits and seeds. As the days grow shorter and cooler in autumn, the cycle will continue, and the colorful pigments will again participate in one of nature's great disappearing acts.

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

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

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

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.

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.

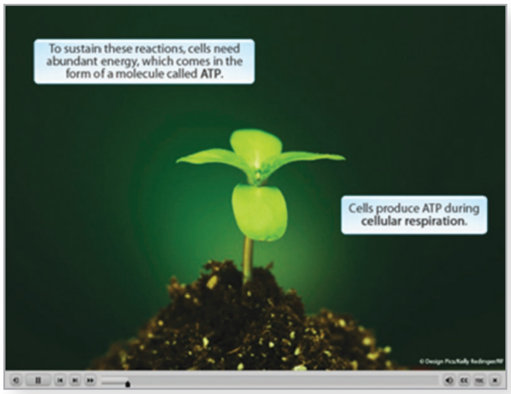
Figure It Out

If you could expose plants to just one wavelength of light at a time, would a wavelength of 300 nm, 450 nm, or 600 nm produce the highest photosynthetic rate?

Answer: 450 nm

Animated Tutorials *Explain Complicated Topics*

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



We created these tutorials to walk students through the most difficult material, step by step. Each tutorial places the topic in context, explains one or more concepts and related figures taken directly from the Hoefnagels text, and returns to the big picture at the end. You can assign the tutorials with accompanying critical thinking questions from the interactive question banks, or you can use the tutorials embedded in PowerPoint® slides in your presentations.

Your students can review the tutorials through SmartBook. Topics are listed below.

Organization of Life
Scientific Method and Interpreting a Graph
Chemical Bonding
Dehydration Synthesis and Hydrolysis
Protein Structure
Anatomy of a Cell Membrane
ATP
Enzymes
Reaction Energetics
Osmosis
Cell Structure
Overview of Photosynthesis
Light Reactions
The Calvin Cycle
Overview of Respiration
Mitochondrial Electron Transport Chain
Fermentation
Protein Synthesis
Overview of DNA Replication
Stages of Mitosis
Stages of Meiosis
Comparison of Mitosis and Meiosis
Crossing Over
Nondisjunction
Homologous Chromosomes
Constructing and Interpreting a Punnett Square
DNA Profiling
Mechanisms of Evolution
Genetic Variation: The Basis of Natural Selection
Understanding the Hardy–Weinberg Equation
Evidence for Evolution
Evidence for Human Evolution
Radiometric Dating
Reading an Evolutionary Tree
Origin of Life
Endosymbiont Theory
Viral Replication
Lytic and Lysogenic Cycles
Replication of HIV
Prokaryote Diversity
Protist Diversity
Plant Diversity
Moss Reproductive Cycle
Fern Reproductive Cycle
Conifer Reproductive Cycle
Sexual Reproduction in Angiosperms
Basidiomycete Reproductive Cycle
Diversity of Fungi
Animal Diversity
Overview of Plant Tissues
Phloem Sap Transport
Water Movement Through the Xylem
Alternation of Generations
Fruit Development
Auxin and Phototropism
Overview of Animal Tissues
Organ System Interactions
Example of Negative Feedback
Action Potential
The Synapse
Overview of the Senses
Sense of Vision
Sense of Hearing
Cell Responses to Hormones
Role of ATP in Muscle Contraction
The Heartbeat
Respiratory Surfaces
Digestion and Food Molecules
Nephron Function
Adaptive Immunity
Allergies
Oogenesis
Human Male Reproductive System
Human Female Reproductive System
Ovarian and Menstrual Cycles
Proximate and Ultimate Behaviors
Population Growth Models
Biomagnification
Water Cycle
Nitrogen Cycle
Phosphorus Cycle
Carbon Cycle
Earth's Climate and Biomes
CO_2 and Earth's Average Temperature
Threats to Biodiversity

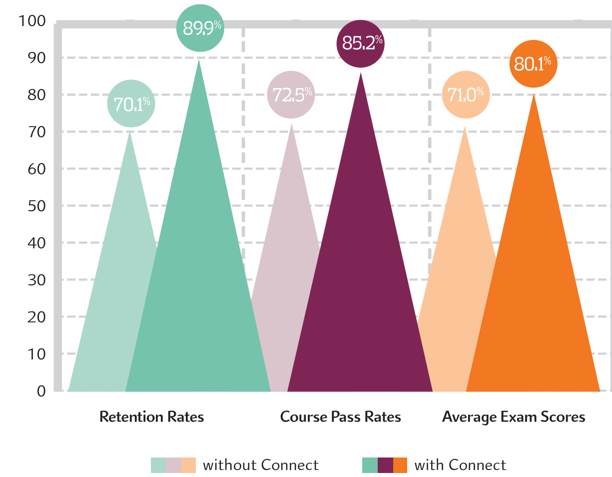
Connect
Required=Results

McGraw-Hill Connect®
Learn Without Limits

Connect is a teaching and learning platform that is proven to deliver better results for students and instructors.

Connect empowers students by continually adapting to deliver precisely what they need, when they need it, and how they need it, so your class time is more engaging and effective.

Connect's Impact on Retention Rates, Pass Rates, and Average Exam Scores

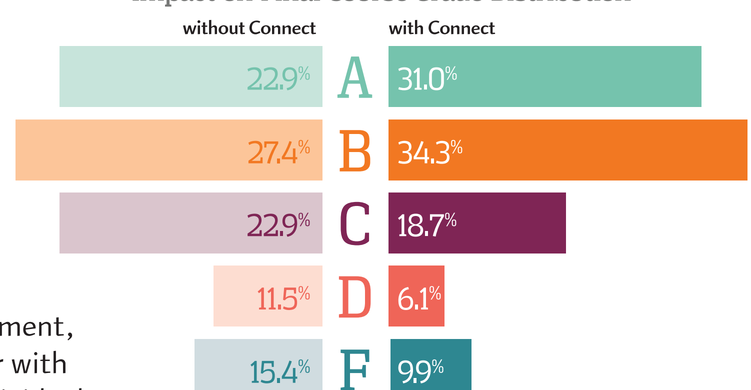


Using **Connect** improves retention rates by **19.8%**, passing rates by **12.7%**, and exam scores by **9.1%**.

> 73% of instructors who use **Connect** require it; instructor satisfaction **increases** by 28% when **Connect** is required.

Analytics

Impact on Final Course Grade Distribution

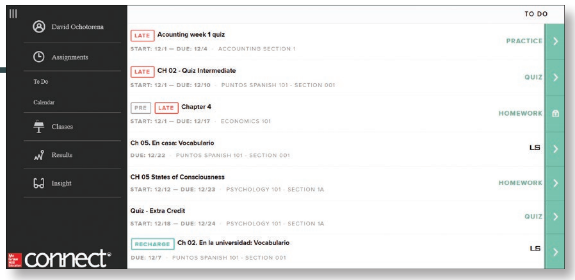


Connect Insight®

Connect Insight is Connect's new one-of-a-kind visual analytics dashboard—now available for both instructors and students—that provides at-a-glance information regarding student performance, which is immediately actionable. By presenting assignment, assessment, and topical performance results together with a time metric that is easily visible for aggregate or individual results, Connect Insight gives the user the ability to take a just-in-time approach to teaching and learning, which was never before available. Connect Insight presents data that empowers students and helps instructors improve class performance in a way that is efficient and effective.

> Students can view their results for any **Connect** course.

Mobile



Connect's new, intuitive mobile interface gives students and instructors flexible and convenient, anytime–anywhere access to all components of the Connect platform.

Adaptive

THE **ADAPTIVE READING EXPERIENCE** DESIGNED TO TRANSFORM THE WAY STUDENTS READ

More students earn **A's** and **B's** when they use McGraw-Hill Education **Adaptive** products.

SmartBook®

Proven to help students improve grades and study more efficiently, SmartBook contains the same content within the print book, but actively tailors that content to the needs of the individual. SmartBook's adaptive technology provides precise, personalized instruction on what the student should do next, guiding the student to master and remember key concepts, targeting gaps in knowledge and offering customized feedback, and driving the student toward comprehension and retention of the subject matter. Available on tablets, SmartBook puts learning at the student's fingertips—anywhere, anytime.

Over **8 billion questions** have been answered, making McGraw-Hill Education products more intelligent, reliable, and precise.

www.mheducation.com

STUDENTS WANT

SMARTBOOK®

95% of students reported **SmartBook** to be a more effective way of reading material.

100% of students want to use the Practice Quiz feature available within **SmartBook** to help them study.

100% of students reported having reliable access to off-campus wifi.

90% of students say they would purchase **SmartBook** over print alone.

95% of students reported that **SmartBook** would impact their study skills in a positive way.

McGraw Hill Education

*Findings based on 2015 focus group results administered by McGraw-Hill Education

Acknowledgments

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

Matt Taylor has worked alongside me at every stage, from first draft to finished product; in addition, he has seamlessly integrated the book's approach into our digital assets. His careful work and insights are invaluable.

I appreciate the help of my colleagues at The University of Oklahoma, including Doug Gaffin, Ben Holt, Michael Markham, and J. P. Masly. Helpful colleagues from other institutions include Marjorie Weber.

I am grateful to former OU student Emily North, who spent many hours scrutinizing art and page layouts. In addition, conversations with students in my classes spark many good ideas.

My team at McGraw-Hill is wonderful. Thank you to Managing Director Lynn Breithaupt and Executive Brand Manager Michelle Vogler, who help us create the best book and digital resources possible. Product Developer Anne Winch retains her amazing ability to juggle an ever-increasing slate of tasks, all while remaining both responsive and funny. Chris Loewenberg, Britney Ross, and Jenna Paleski contribute energy and great ideas to the marketing side. Emily Tietz continues to provide outstanding service in photo selections. I also appreciate Angie Fitzpatrick, April Southwood, and Peggy Selle for their impressive skills at the interface between us and the production team. Also among the talented folks at McGraw-Hill are Emily Windelborn, Tara McDermott, Lori Hancock, Lorraine Buczek, and Jane Peden, who has made life easier in countless ways. Thanks to all of you for all you do.

My family and friends continue to encourage me. Thank you to my parents and sister for their pride and support. I also thank my friends Kelly Damphousse, Ben and Angie Holt, Michael Markham and Kristi Isacksen, Karen and Bruce Renfroe, Ingo and Andrea Schlupp, Clarke and Robin Stroud, Matt Taylor and Elise Knowlton, and Mark Walvoord. Cats Sidecar, Smudge, and Snorkels were worthy companions in my office as well. Finally, my husband, Doug Gaffin, is always there for me, helping in countless large and small ways. I could not do this work without him.

Changes by Chapter

UNIT 1 Science, Chemistry, and Cells

- **Chapter 1 (The Scientific Study of Life):** Updated figure 1.3 to use memories as examples of emergent properties; improved figure 1.12 to more clearly define independent and dependent variables; within table 1.2, clarified definitions of *independent variable, dependent variable,* and *standardized variable.* Added several learning tools to SmartBook®: a figure depicting a simple evolutionary tree in section 1.2; a figure showing the taxonomic hierarchy in section 1.2; a miniglossary of scientific knowledge in section 1.3; a figure describing how to interpret graphs in the chapter summary.
- **Chapter 2 (The Chemistry of Life):** In table 2.1, clarified that the mass of an electron is not exactly zero; added figure 2.3, which compares a neutral hydrogen atom with H^+; improved description of electron orbitals and energy shells; improved explanation of polar covalent bonds in water molecules in narrative and in figure 2.10; clarified definition of *hydrophobic*; updated illustration of cellulose in figure 2.18 and illustration of triglycerides in figure 2.25; added figure 2.26, which shows the difference between solid and liquid lipids; wrote new Investigating Life about chemical defenses in tawny crazy ants.
- **Chapter 3 (Cells):** Based on SmartBook user data, clarified that high surface area to volume improves cell transport efficiency; improved Apply It Now box to teach students that most of their cells are not their own; replaced Burning Question with a new box on artificial cells; clarified distinction between *cytoplasm* and *cytosol* in narrative and several figures; in figure 3.10, improved accuracy of double bond in unsaturated fatty acid; adjusted figures 3.15 and 3.18 for accuracy; clarified the function of plasmodesmata. Added a new learning tool to SmartBook: a table comparing mitochondria and chloroplasts in section 3.4.
- **Chapter 4 (The Energy of Life):** In chapter opening essay, added how human evolutionary history affects our food cravings; improved illustration of potential and kinetic energy in figure 4.1; based on SmartBook user data, clarified definition of heat; updated figure 4.10 to clearly show uses of ATP; improved explanations of

negative and positive feedback; in figure 4.18, corrected position of cell membranes in plant cells in hypertonic surroundings; wrote new Apply It Now box on boosting metabolism; added aquaporins to Burning Question on headaches, to improve the connection to the chapter; wrote new Investigating Life on membrane proteins in electric fish; improved clarity of summary figure 4.24. Added a new learning tool to SmartBook: in the chapter summary, a miniglossary defining metabolism terms.

- **Chapter 5 (Photosynthesis):** Based on SmartBook user data, changed "oxidized" to "consumed" in section 5.1C to emphasize that the first organisms obtained C from their surroundings; in narrative and figure 5.8, clarified that the photosynthetic electron transport chain includes the entire pathway from photosystem II to the formation of NADPH; improved figure 5.9 to show the fates of the carbohydrates produced in the carbon reactions; clarified that rubisco is not involved in the C_4 pathway; based on SmartBook user data, explained why C_4 plants have greater water use efficiency than C_3 plants; clarified the distinction between C_4 and CAM plants; wrote new Investigating Life on carbon translocation from algae to salamander embryos. Added new learning tools to SmartBook: a miniglossary of leaf anatomy in section 5.2; a miniglossary of light reactions in section 5.4.
- **Chapter 6 (Respiration and Fermentation):** Changed chapter title to "Respiration and Fermentation" to better match the title of chapter 5; improved consistency of use of the terms *hydrogen ion gradient, H^+ gradient,* and *proton gradient*; updated Burning Question on diet pills. Made several changes based on SmartBook user data: clarified the paragraph debunking the myth that lactic acid causes muscle soreness after intense exercise; modified figure 6.9 to show how glycerol and some amino acids enter metabolism and to show that nitrogen is stripped from amino acids and eliminated as waste; improved explanation of why aerobic respiration must have evolved after O_2-generating photosynthesis. Added several learning tools to SmartBook: a table in section 6.3 showing where the reactions of respiration occur; a miniglossary of mitochondrion anatomy in section 6.3; a miniglossary of aerobic respiration in section 6.5.

UNIT 2 DNA, Inheritance, and Biotechnology

- **Chapter 7 (DNA Structure and Gene Function):** Clarified in section 7.3 that DNA must be "unpacked" for the cell to use its genetic information; based on SmartBook user data, explained that terminator sequence is part of DNA, not RNA; improved definition of promoter in narrative and position of promoter in figure 7.10; extended "cookbook" analogy to the participants in translation; improved description of the *lac* operon; added information about epigenetics; made an explicit connection between transcription factors and signal transduction; clarified bold-faced terms related to mutations; reworked figure 7.24 (Investigating Life) to show an evolutionary tree of FOXP2 protein changes; added summary figure 7.26 to show three types of RNA. Added a new learning tool to SmartBook: a miniglossary of protein synthesis in the chapter summary.
- **Chapter 8 (DNA Replication, Binary Fission, and Mitosis):** Made many small clarifications to the narrative describing chromosome structure and the events of cell division; improved figure 8.8 to include a yarn analogy of DNA compaction; based on SmartBook user data, clarified that a compacted chromosome is unavailable for transcription and improved the definition of semiconservative replication; added information about epigenetics in relation to cancer; improved the list of ways that cancer cells differ from normal cells; updated figure showing ways to reduce cancer risk. Added new learning tools to SmartBook: miniglossary of cell division in section 8.1; table comparing binary fission and mitotic cell division in chapter summary.
- **Chapter 9 (Sexual Reproduction and Meiosis):** In chapter opening essay, added possible implications of fetal screening on human evolution; increased relevance of box on mules by explaining why mules are desirable; clarified the use of the word *align* in talking about the events of meiosis and the origin of genetic variation; revised box on multiple births to focus on their rising incidence; improved connection between problems during meiosis and abnormalities in chromosome number and structure; added *aneuploid cell* as a contrast to *polyploid cell*. Added several learning tools to SmartBook: a miniglossary of variability in meiosis in section 9.5; a table comparing asexual and sexual reproduction in section 9.6; a miniglossary of chromosome abnormalities in section 9.7.
- **Chapter 10 (Patterns of Inheritance):** Reworked allele designations for all figures and narrative relevant to yellow and green peas; improved connection between proteins and traits; replaced figure 10.14 to show how genotypic ratios differ in crosses between linked and unlinked genes; based on SmartBook user data, clarified explanation of product rule; related epigenetics to environmental effects on gene expression; based on SmartBook user data, explained why males cannot be symptomless carriers of X-linked traits; revised Investigating Life to incorporate information about next-generation Bt cotton; improved lightbulb analogy of dominance relationships in figure 10.34. Added several new learning tools to SmartBook: a miniglossary of tracking inheritance in section 10.3; a miniglossary of gene linkage in section 10.5; a miniglossary of dominance relationships in section 10.6; a miniglossary of modes of inheritance in section 10.8.
- **Chapter 11 (DNA Technology):** Added CRISPR as an example of a new DNA technology to chapter opening essay; based on SmartBook user data, clarified that scientists use DNA to reveal species relationships; updated figure 11.5 to show modern DNA sequencing; added figure 11.6, which shows similarity between a gene of humans and a homologous gene in other species; improved application of DNA profiling in figure 11.9; revised description of somatic cell nuclear transfer; based on SmartBook user data, clarified that pseudogenes are noncoding DNA and that gene therapy provides supplemental DNA (not replacement DNA); wrote new Investigative Life on gene transfer between GMOs and their wild relatives. Added a new learning tool to SmartBook: a table listing some additional uses of DNA analysis in section 11.2.

UNIT 3 The Evolution of Life

- **Chapter 12 (The Forces of Evolutionary Change):** Updated chapter opening essay to mention CDIFF and CRE, two of the three most dangerous antibiotic-resistant bacteria; improved figure 12.8 to connect natural selection with mutations in DNA; reworked Burning Question to explain why there is no such thing as a "pinnacle of evolution"; improved narrative and figure explaining Hardy–Weinberg equilibrium; clarified descriptions of genetic drift and nonrandom mating; based on SmartBook user data, clarified the effect of gene flow on genetic diversity; reworked Pull It Together (figure 12.24) to explain how each mechanism of evolution affects allele frequencies. Added new learning tools to SmartBook: a miniglossary of populations and evolution in section 12.1; a miniglossary of evolutionary mechanisms in section 12.7.
- **Chapter 13 (Evidence of Evolution):** In figure 13.2, replaced *Tertiary Period* with *Paleogene* and *Neogene*; added mole eyes as an example of a vestigial structure in figure 13.11; expanded the list of vestigial structures in the narrative; based on SmartBook user data, improved figure 13.17 to better show how mutations in enhancers affect gene expression; in Investigating Life, clarified evidence that *Najash* was terrestrial. Added several learning tools to SmartBook: a miniglossary of fossil aging terms in section 13.2; a miniglossary of comparative anatomy terms in section 13.4; a figure showing all five lines of evidence for evolution in the chapter summary.
- **Chapter 14 (Speciation and Extinction):** Reorganized section on gradualism and punctuated equilibrium for clarity; added figure 14.17, which distinguishes ancestral and derived features; improved figure 14.18 to more clearly explain the anatomy of a phylogenetic tree; revised Burning Question to explain how each condition boosts the evolution rate; wrote new Investigating Life on ecological interactions that boost speciation rates. Added several learning tools to SmartBook: a miniglossary of macroevolution in section 14.1; a miniglossary of reproductive barriers in section 14.2; a miniglossary of speciation patterns in section 14.3.
- **Chapter 15 (The Origin and History of Life):** Improved illustrations of primary and secondary endosymbiosis in figure 15.9; rearranged section on human evolution for clarity; based on SmartBook user data, clarified distinction between "early" and "recent" *Homo;* replaced Investigating Life with an essay about the human and chimpanzee genome sequencing projects. Added a new learning tool to SmartBook: a table summarizing biodiversity changes over time in section 15.3.

UNIT 4 The Diversity of Life

- **Chapter 16 (Viruses):** Revised chapter opening essay to include the most recent Ebola outbreak; reworked several headings to improve clarity; reorganized paragraphs on viral envelope for clarity; rewrote the passage on latent animal viruses; based on SmartBook user data, explained which cells are infected by herpes simplex virus type I (cold sores); improved figure 16.5, which shows HIV replication; updated Investigating Life to include newer data. Added a new learning tool to SmartBook: a miniglossary of viral infections in section 16.3.
- **Chapter 17 (Bacteria and Archaea):** Based on SmartBook user data, improved figure 17.5 and clarified description of Gram-positive and Gram-negative cells; differentiated between exotoxins and endotoxins; wrote new Investigating Life on antibiotic-resistant bacteria in pig farms. Added several learning tools to section 17.2 of SmartBook: a miniglossary of prokaryote anatomy; a miniglossary of prokaryote classification; a miniglossary of gene transfer.
- **Chapter 18 (Protists):** Based on SmartBook user data, clarified differences between feeding and reproductive stages for plasmodial slime molds; corrected figure showing overall tree of life. Added new learning tools to SmartBook: a miniglossary of types of algae in section 18.2; a table summarizing the life cycles of plasmodial and cellular slime molds in section 18.3.
- **Chapter 19 (Plants):** Improved organization of introduction to section 19.1; clarified description of alternation of generations; reworked description of double fertilization; improved description of ovules; added paragraph about gluten sensitivity. Added a new learning tool to SmartBook: a miniglossary of plant reproduction in section 19.1.
- **Chapter 20 (Fungi):** Based on SmartBook user data, clarified description of figure 20.2; revised Apply It Now: Fungi and Human Health to focus on infection prevention; improved distinction between endophytes and mycorrhizal fungi. Added new learning tools to SmartBook: a miniglossary of fungal anatomy in section 20.1; a miniglossary of fungal interactions in section 20.7.
- **Chapter 21 (Animals):** Wrote new chapter opening essay to emphasize the uses of animal products in everyday objects; reorganized section 21.1 for clarity; improved definitions of *ectoderm* and *endoderm*; based on SmartBook user data, clarified that both indirect and direct development may occur in mollusks; also based on SmartBook user data, rearranged section on echinoderm defenses to put related content together; clarified description of amniotic eggs and the term *amniote*; reworked and simplified the Investigating Life section. Added new learning tools to SmartBook: a miniglossary of animal clades in section 21.1; a miniglossary of arthropod diversity in section 21.8.

UNIT 5 Plant Life

- **Chapter 22 (Plant Form and Function):** Added art of ground tissue cell types in figure 22.4; clarified the description of cells in phloem tissue; defined primary and secondary growth earlier in the chapter; improved illustrations of stem and root cross sections in figures 22.9 and 22.13; based on SmartBook user data, clarified distinction between monocots and eudicots in leaf cross sections; wrote new Apply It Now box on the topic of fire-resistant trees and shrubs; based on SmartBook user data, reworked figure 22.17 to better illustrate the definition of *bark*. Added a new learning tool to SmartBook: a miniglossary of plant anatomy in section 22.3.

- **Chapter 23 (Plant Nutrition and Transport):** Revised Apply It Now box on fertilizers; reworked some titles so the words *xylem* and *phloem* are more prominent in the chapter's main headers; clarified explanation of *sink* in description of pressure flow theory. Added a new learning tool to SmartBook: a miniglossary of plant transport in the chapter summary.
- **Chapter 24 (Reproduction and Development of Flowering Plants):** Clarified relationship between *carpel* and *ovary*; improved illustration of mature monocot and eudicot seeds in figure 24.9; based on SmartBook user data, adjusted labeling on figure depicting corn and bean seed germination; wrote new Apply It Now box on plants that attack caterpillars; improved figures 24.22 and 24.23, which illustrate photoperiod's role in flowering. Added new learning tools to SmartBook: a miniglossary of angiosperm reproduction in section 24.2; a miniglossary of plant tropisms in the chapter summary.

UNIT 6 Animal Life

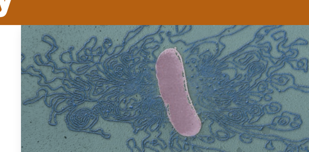
- **Chapter 25 (Animal Tissues and Organ Systems):** Wrote new chapter opener on physiological changes that happen as a person runs a marathon; revised box on organ donation to focus on artificial organs; revised many glossary terms for consistency; developed new figure 25.14, which summarizes organ system interactions. Added a new learning tool to SmartBook: a miniglossary of animal anatomy and physiology in section 25.1.
- **Chapter 26 (The Nervous System):** Added narrative and glossary definitions for *membrane potential*; clarified the significance of the "all-or-none" nature of an action potential; reworked the explanation of graded potentials and action potentials; distinguished between *action potential* and *neural impulse*; added figure 26.7, which illustrates how a neural impulse is similar to a line of firecrackers exploding; improved explanation of how the sympathetic nervous system can have both instantaneous effects and prolonged effects (via adrenal hormones); wrote new Burning Question on whether neurons communicate at the speed of light; replaced Investigating Life with an essay on a grasshopper mouse's reaction to a scorpion sting. Based on SmartBook user data, added new learning tools to SmartBook: a table of action potential events in section 26.3; a miniglossary of nervous system communication in section 26.3.
- **Chapter 27 (The Senses):** Wrote new Investigating Life on taste detection in whales. Based on SmartBook user data, added new learning tools to SmartBook: a miniglossary of the visual information pathway in section 27.4; a miniglossary of the auditory information pathway in section 27.5.
- **Chapter 28 (The Endocrine System):** Based on SmartBook user data, clarified in the introduction to section 28.2 that hormone receptors may be on the cell surface, in the cytoplasm, or in the nucleus; improved the explanation of the overall role of the hypothalamus and pituitary; reworked section on adrenal hormones and their regulation. Added new learning tools to SmartBook: a miniglossary of hormones and responses in section 28.2; a chapter summary table comparing the origins and functions of many hormones.
- **Chapter 29 (The Skeletal and Muscular Systems):** Added micrograph to illustration of skeletal muscle organization; improved figure 29.23, which summarizes the relationship between muscles and bones. Added several new learning tools to SmartBook: a miniglossary of the skeletal system in section 29.3; a table summarizing the steps of muscle contraction in section 29.4; a miniglossary of the muscular system in the chapter summary.
- **Chapter 30 (The Circulatory System):** Reworked introduction to section 30.1 for clarity; improved passage describing red blood cells; clarified description of blood clotting; added information on the possible effects of overexercising. Added new learning tools to SmartBook: a miniglossary of the heartbeat in section 30.4; a miniglossary of blood vessels in section 30.5.
- **Chapter 31 (The Respiratory System):** Wrote new chapter opener on competitive breath-holding; based on SmartBook user data, clarified the features that all respiratory surfaces have in common; revised the description of red blood cells' role in carrying O_2 and CO_2; improved section on the functions of CO_2 and blood pH in regulating the breathing rate; updated figure 31.17 to compare and contrast external and internal respiration. Added a new learning tool to SmartBook: a miniglossary of breathing in the chapter summary.
- **Chapter 32 (Digestion and Nutrition):** Reworked figure 32.9 to emphasize the types of teeth; added information on essential amino acids and essential fatty acids; wrote new Burning Question on maximizing the nutrient content of food; added new table on the calorie content of various beverages; replaced Investigating Life essay with one about the evolutionary cost of a sweet tooth; reworked Pull It Together (figure 32.22) to better cover the chapter's content. Added a new learning tool to SmartBook: a miniglossary of digestive fluids in section 32.3.
- **Chapter 33 (Regulation of Temperature and Body Fluids):** Clarified the process of urination in the human urinary system. Added a new learning tool to SmartBook: a miniglossary of temperature homeostasis in section 33.1.
- **Chapter 34 (The Immune System):** Reworked figure 34.4, which provides an overview of innate defenses; clarified the roles of white blood cells in innate defenses; improved the passage about cytotoxic T cells; made many small improvements to the narrative about adaptive immunity; based on SmartBook user data, clarified the role of MHC proteins; updated information about SCID. Added a new learning tool to SmartBook: a miniglossary of adaptive immunity in section 34.3.
- **Chapter 35 (Animal Reproduction and Development):** Wrote new chapter opener about intersex conditions; combined contraception and sexually transmitted diseases in a new section on reproductive health; clarified the events of fertilization and prenatal development; improved explanation of the placenta's structure and function; wrote a new box on male pregnancy; made a new summary figure showing the stages of human development. Added a new learning tool to SmartBook: a miniglossary on embryonic support structures in section 35.5.

UNIT 7 The Ecology of Life

- **Chapter 36 (Animal Behavior):** Based on SmartBook user data, improved figure 36.1 to differentiate between proximate and ultimate causes of behavior; clarified the definition of *search image*; combined multiple figures to make figure 36.11, which shows many types of defenses against predation. Added a new learning tool to SmartBook: a miniglossary of innate and learned behaviors in section 36.2.
- **Chapter 37 (Populations):** Revised population numbers and graphs in figures 37.6 and 37.8 for accuracy and clarity; updated information about China's former one-child policy. Added a new learning tool to SmartBook: a miniglossary of population growth in section 37.3.
- **Chapter 38 (Communities and Ecosystems):** Wrote new chapter opening essay about sustainable meat production and home gardening; improved explanation of coevolution in crossbills; updated information about mercury in tuna in figure 38.17. Added new learning tool to SmartBook: a miniglossary of diversity and succession in section 38.2.
- **Chapter 39 (Biomes):** Based on SmartBook user data, revised figure 39.4 to show a convection cell from the perspective of Earth's surface; improved explanation and illustration of El Niño in the Apply It Now box; updated Investigating Life text and figure 39.26 for clarity. Added new learning tools to SmartBook: a miniglossary of lake zones in section 39.4; a miniglossary of ocean zones in section 39.5.
- **Chapter 40 (Preserving Biodiversity):** Updated data on endangered species; added inset map to figure 40.8 showing the location of the Great Pacific Garbage Patch; revised section on global climate change to include information from the recent Paris conference; mentioned the sources of methane and N_2O in the atmosphere; corrected the amount of CO_2 released by human activities; updated photo and information about the ozone hole in figure 40.12; improved figure 40.15 to show how the Arctic sea ice minimum has changed over time; updated Pull It Together (figure 40.27) to better illustrate connections between the topics. Added a new learning tool to SmartBook: a miniglossary of pollution in section 40.3.

Contents

UNIT 1 Science, Chemistry, and Cells



©Dr. Gopal Murti/Science Source

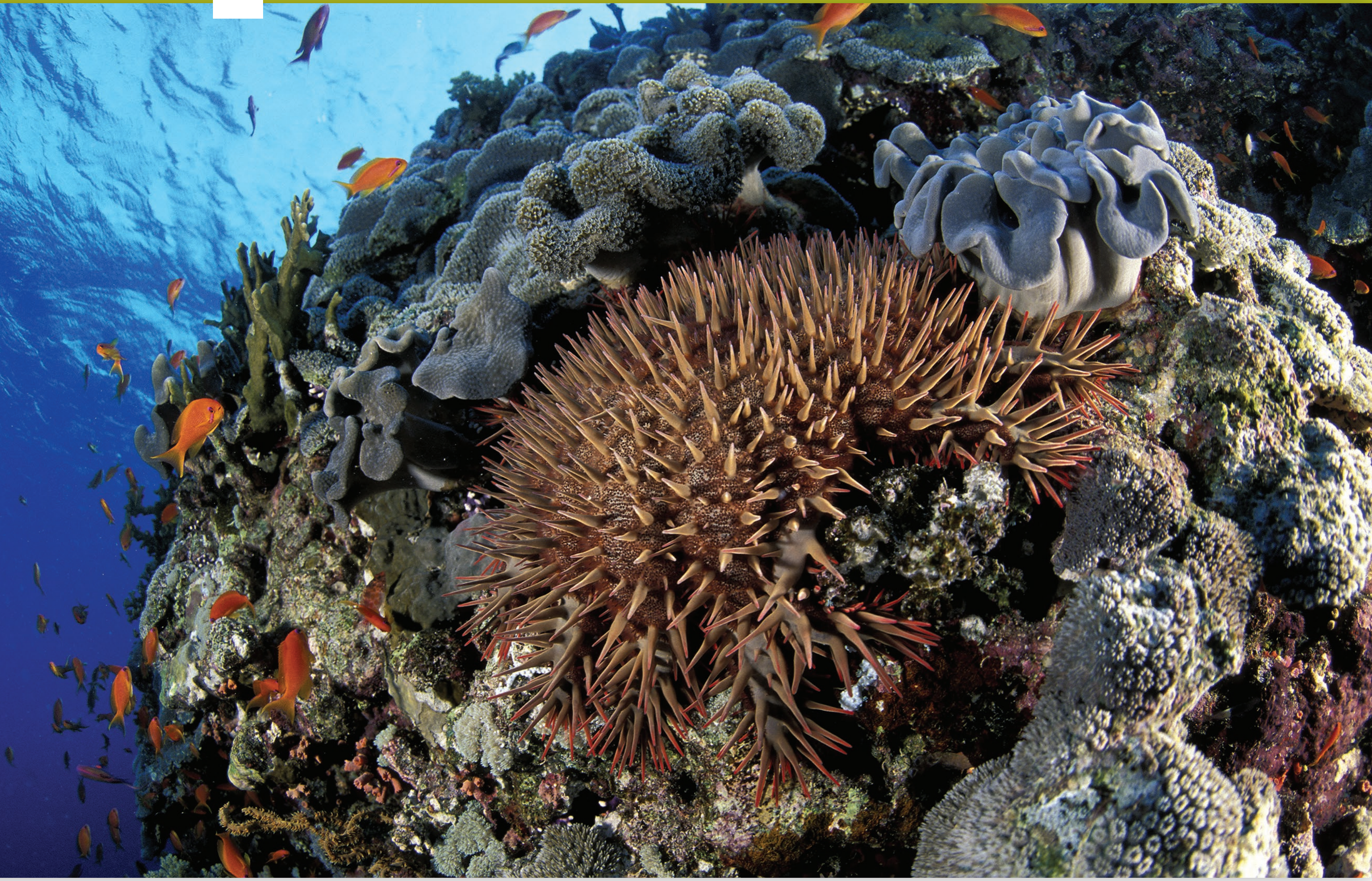
©Chris Ryan/Getty Images RF

©Gustavo Gilabert/Corbis SABA

BIOLOGY

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.

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 replacing faulty DNA with a functional "patch."

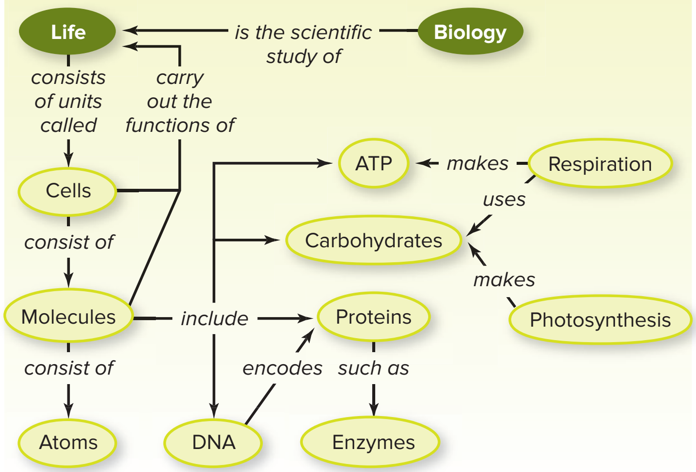
Biology also includes the study of nonhuman life. We exist only because of our interactions with other species, which provide food, oxygen, clean water, clothing, shelter, and other necessities. Even species that do not directly "serve" us are essential to the ecosystems that sustain all life. Human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

SURVEY THE LANDSCAPE
Science, Chemistry, and Cells



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

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

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 very rapidly, 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 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.**

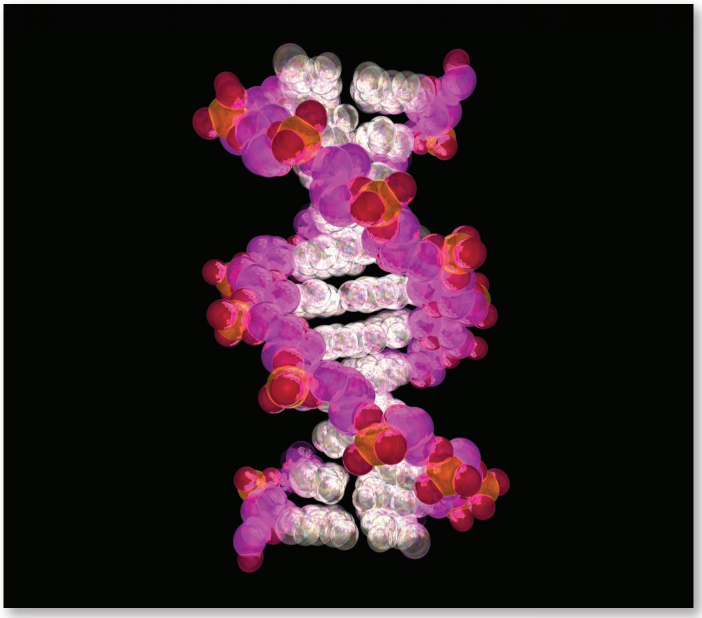


Figure 1.1 Informational Molecule of Life. All cells contain DNA, a series of "recipes" for proteins that each cell can make.
©Scott Camazine/123RF

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.

TABLE 1.1 Characteristics of Life: A Summary

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

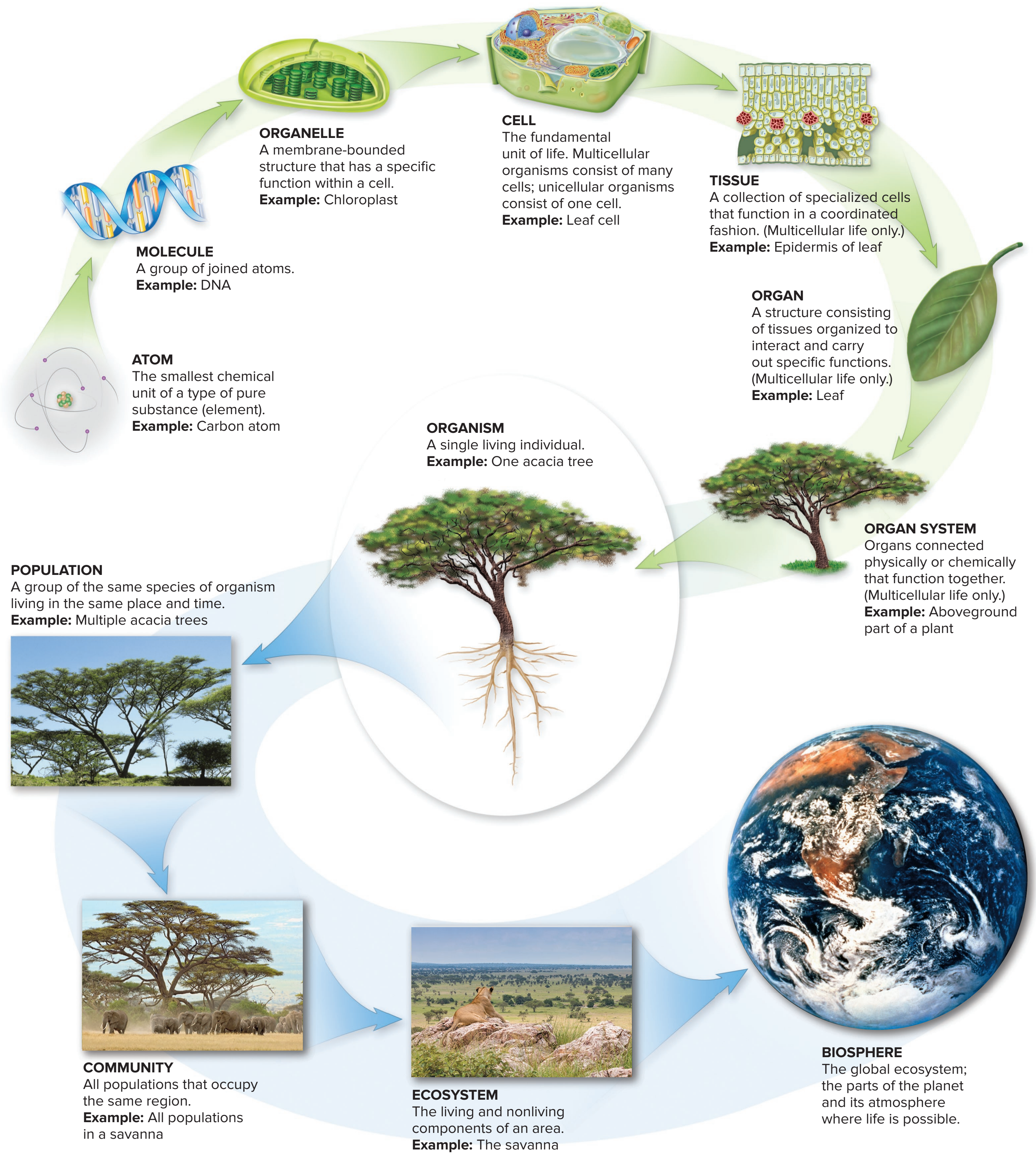


Figure 1.2 Life's Organizational Hierarchy. This diagram applies life's organizational hierarchy to a multicellular organism (an acacia tree). Green arrows represent the organizational hierarchy up to the level of the organism; blue arrows represent levels that include multiple organisms.

Photos: (population): ©Gregory G. Dimijian, M.D./Science Source; (community): ©Daryl Balfour/Gallo Images/Getty Images; (ecosystem): ©Bas Vermolen/Getty Images; (biosphere): ©Corbis RF

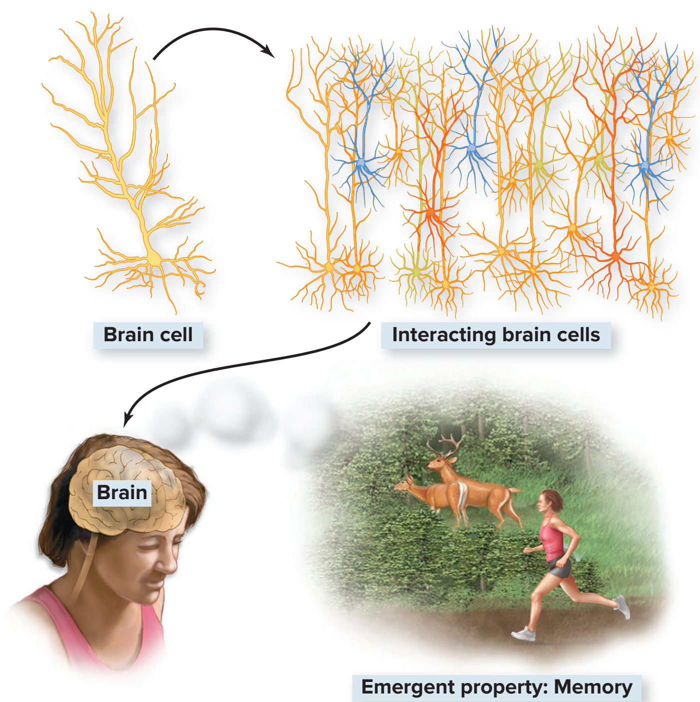


Figure 1.3 An Emergent Property—from Cells to Memories. Highly branched cells interact to form a complex network in the brain. Memories, consciousness, and other qualities of the mind emerge only when these cells interact in a certain way.

Single-celled bacteria, although less complex than animals or plants, still contain DNA, proteins, and other molecules that interact in highly organized ways.

An organism, however, is more than a collection of successively smaller parts. **Emergent properties** are new functions that arise from 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). **Producers,** also called autotrophs, make their own food by extracting energy and nutrients from nonliving sources. The most familiar 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 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

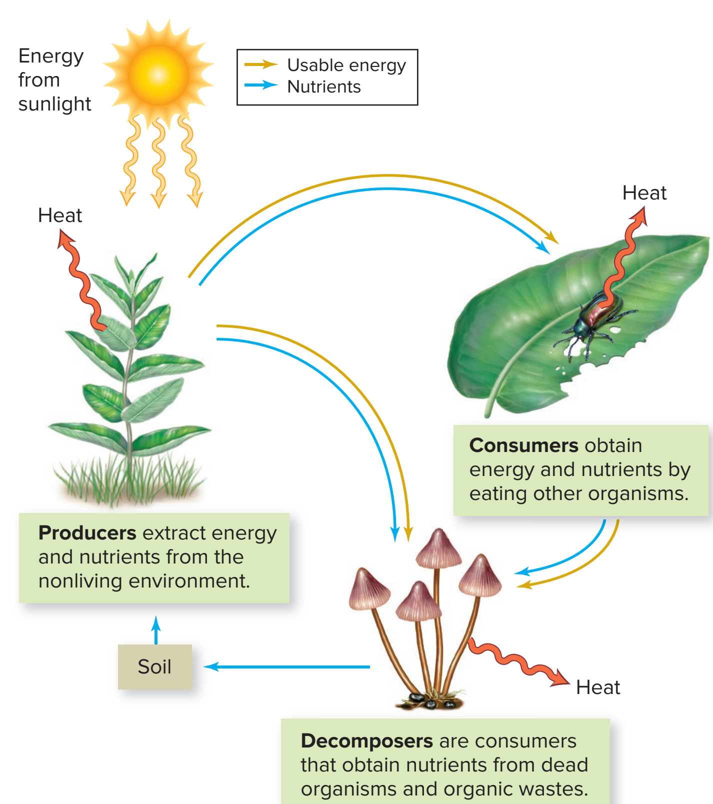


Figure 1.4 Life Is Connected. All organisms extract energy and nutrients from the nonliving environment or from other organisms. Decomposers recycle nutrients back to the nonliving environment. At every stage along the way, heat is lost to the surroundings.

a. b.

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

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 Markoc/flickr/Getty Images RF

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.

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

E. Life Evolves

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

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

Where do these adaptive traits come from? The answer lies in natural selection. The simplest way to think of natural selection is

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

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). 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.

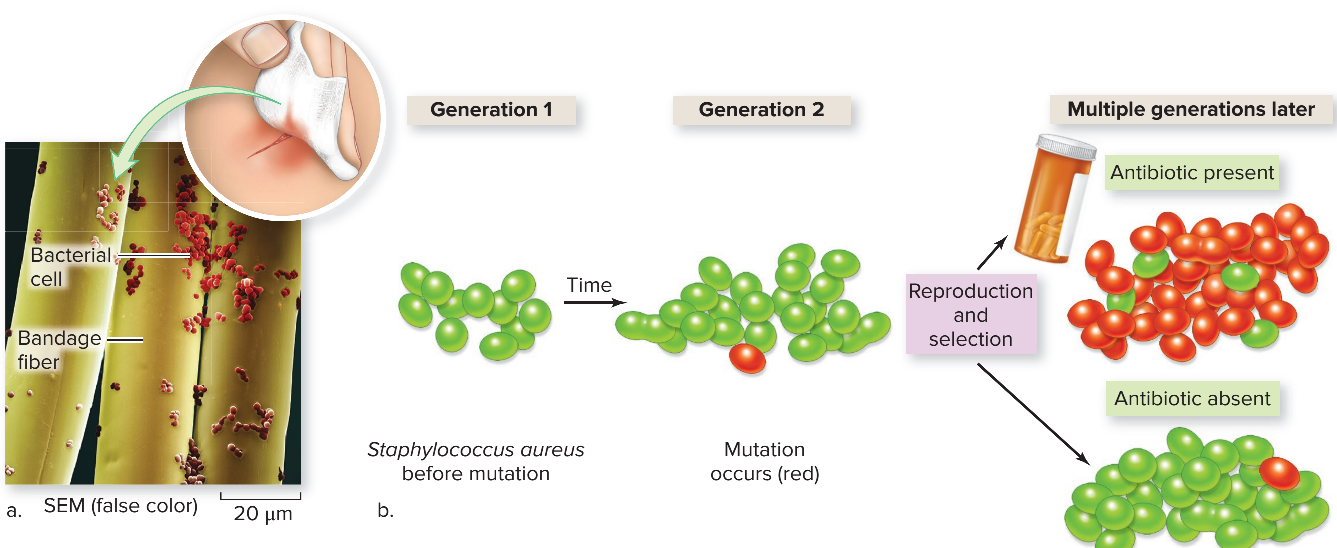


Figure 1.8 Natural Selection. (a) *Staphylococcus aureus* (commonly called "staph") is a bacterium that causes skin infections. (b) A bacterium undergoes a random genetic mutation that (by chance) makes the cell resistant to an antibiotic. The presence of the antibiotic increases the reproductive success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

Photo: (a): © Paul Gunning/Science Source

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

But taxonomy involves more than simply naming species. Taxonomists also strive to classify organisms according to what we know about evolutionary relationships; that is, how recently one type of organism shared an ancestor with another type. The more recently they diverged from a shared ancestor, the more closely related we presume the two types of organisms to be. 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.

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.

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): ©Heather Davies/Getty Images RF; (Archaea): ©Eye of Science/Science Source; (Protista): ©Melba Photo Agency/PunchStock RF; (Animalia): USDA/ARS/Scott Bauer; (Fungi): ©Corbis RF; (Plantae) USDA/Keith Weller