

CAMPBELL

# BIOLOGY

CONCEPTS & CONNECTIONS

EIGHTH EDITION



REECE • TAYLOR • SIMON • DICKEY • HOGAN

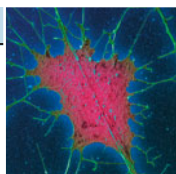
# Brief Contents

## 1 Biology: *Exploring Life* 1

### UNIT I

#### The Life of the Cell

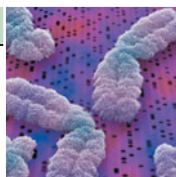
- 2 The Chemical Basis of Life 16
- 3 The Molecules of Cells 32
- 4 A Tour of the Cell 50
- 5 The Working Cell 72
- 6 How Cells Harvest Chemical Energy 88
- 7 Photosynthesis: *Using Light to Make Food* 106



### UNIT II

#### Cellular Reproduction and Genetics

- 8 The Cellular Basis of Reproduction and Inheritance 124
- 9 Patterns of Inheritance 152
- 10 Molecular Biology of the Gene 180
- 11 How Genes Are Controlled 208
- 12 DNA Technology and Genomics 230



### UNIT III

#### Concepts of Evolution

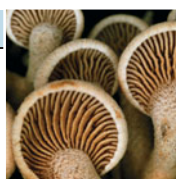
- 13 How Populations Evolve 254
- 14 The Origin of Species 276
- 15 Tracing Evolutionary History 292



### UNIT IV

#### The Evolution of Biological Diversity

- 16 Microbial Life: *Prokaryotes and Protists* 318
- 17 The Evolution of Plant and Fungal Diversity 340
- 18 The Evolution of Invertebrate Diversity 364
- 19 The Evolution of Vertebrate Diversity 388



### UNIT V

#### Animals: Form and Function

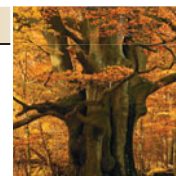
- 20 Unifying Concepts of Animal Structure and Function 412
- 21 Nutrition and Digestion 428
- 22 Gas Exchange 452
- 23 Circulation 466
- 24 The Immune System 484
- 25 Control of Body Temperature and Water Balance 504
- 26 Hormones and the Endocrine System 516
- 27 Reproduction and Embryonic Development 532
- 28 Nervous Systems 562
- 29 The Senses 586
- 30 How Animals Move 602



### UNIT VI

#### Plants: Form and Function

- 31 Plant Structure, Growth, and Reproduction 620
- 32 Plant Nutrition and Transport 642
- 33 Control Systems in Plants 660



### UNIT VII

#### Ecology

- 34 The Biosphere: *An Introduction to Earth's Diverse Environments* 678
- 35 Behavioral Adaptations to the Environment 698
- 36 Population Ecology 722
- 37 Communities and Ecosystems 738
- 38 Conservation Biology 760





CAMPBELL  
**BIOLOGY**  
CONCEPTS & CONNECTIONS  
EIGHTH EDITION



JANE B. REECE *Berkeley, California*

ERIC J. SIMON *New England College*

MARTHA R. TAYLOR *Ithaca, New York*

JEAN L. DICKEY *Clemson University*

KELLY HOGAN *University of North Carolina, Chapel Hill*

**PEARSON**

Boston Columbus Indianapolis New York San Francisco Upper Saddle River  
Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montréal Toronto  
Delhi Mexico City São Paulo Sydney Hong Kong Seoul Singagore Taipei Tokyo

**Editor-in-Chief:***Beth Wilbur***Executive Director of Development:***Deborah Gale***Acquisitions Editor:***Alison Rodal***Executive Editorial Manager:***Ginnie Simione Jutson***Editorial Project Manager:***Debbie Hardin***Development Editors:***Debbie Hardin, Susan Teahan***Editorial Assistant:***Libby Reiser***Senior Supplements Project Editor:***Susan Berge***Supplements Production Project Manager:***Jane Brundage***Manager, Text Permissions:***Tim Nicholls***Project Manager, Text Permissions:***Alison Bruckner***Text Permissions Specialist:***James Toftness, Creative Compliance, LLC***Director of Production:***Erin Gregg***Managing Editor:***Michael Early***Production Project Manager:***Lori Newman***Production Management and Composition:***S4Carlisle Publishing Services***Design Manager:***Marilyn Perry***Cover and Interior Designer:***Hespenheide Design***Illustrations:***Precision Graphics***Development Artists:***Kelly Murphy; Andrew Recher, Precision Graphics***Senior Photo Editor:***Donna Kalal***Photo Researcher:***Kristin Piljay***Photo Permissions Management:***Bill Smith Group***Director of Editorial Content MasteringBiology®:***Tania Mlawer***Development Editor, MasteringBiology®:***Juliana Tringali***Senior Mastering® Media Producer:***Katie Foley***Associate Mastering® Media Producer:***Taylor Merck***Editorial Media Producer:***Daniel Ross***Senior Manager Web Development:***Steve Wright***Web Development Lead:***Dario Wong***Vice President of Marketing:***Christy Lesko***Executive Marketing Manager:***Lauren Harp***Senior Marketing Manager:***Amee Mosley***Manufacturing Buyer:***Jeffrey Sargent***Cover Printer:***Lehigh-Phoenix***Text Printer:***Courier/Kendallville***Cover Photo Credit:***Andy Rouse/Nature Picture Library*

Credits and acknowledgments for materials borrowed from other sources and reproduced, with permission, in this textbook appear on the appropriate page within the text or on p. A-26.

Copyright © 2015, 2012, 2009 Pearson Education, Inc. All rights reserved. Manufactured in the United States of America. This publication is protected by Copyright, and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. To obtain permission to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, One Lake Street, Upper Saddle River, NJ 07458, or you can fill out one of our forms at <http://www.pearsoned.com/permissions/>.

Readers may view, browse, and/or download material for temporary copying purposes only, provided these uses are for noncommercial personal purposes. Except as provided by law, this material may not be further reproduced, distributed, transmitted, modified, adapted, performed, displayed, published, or sold in whole or in part, without prior written permission from the publisher.

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed in initial caps or all caps.

MasteringBiology® and BioFlix® are registered trademarks, in the U.S. and/or other countries, of Pearson Education, Inc. or its affiliates.

**Library of Congress Cataloging-in-Publication Data**

Reece, Jane B.  
Campbell biology: concepts and connections / Jane B. Reece [and four others].—Eighth edition.  
pages cm  
Previous edition: Campbell biology: concepts & connections, 2012.  
ISBN 978-0-321-88532-6  
1. Biology. I. Title. II. Title: Biology.  
QH308.2.B56448 2013  
570—dc23

2013024409

ISBN 10: 0-321-88532-5; ISBN 13: 978-0-321-88532-6 (Student Edition)  
ISBN 10: 0-321-94668-5; ISBN 13: 978-0-321-94668-3 (Books a la Carte Edition)

1 2 3 4 5 6 7 8 9 10—CRK—18 17 16 15 14

[www.pearsonhighered.com](http://www.pearsonhighered.com)**PEARSON**



# About the Authors



**Jane B. Reece** has worked in biology publishing since 1978, when she joined the editorial staff of Benjamin Cummings. Her education includes an A.B. in biology from Harvard University, an M.S. in microbiology from Rutgers University, and a Ph.D. in bacteriology from the University of California, Berkeley. At UC Berkeley, and later as a postdoctoral fellow in genetics at Stan-

ford University, her research focused on genetic recombination in bacteria. Dr. Reece taught biology at Middlesex County College (New Jersey) and Queensborough Community College (New York). During her 12 years as an editor at Benjamin Cummings, she played a major role in a number of successful textbooks. She is coauthor of *Campbell Biology*, Tenth Edition, *Campbell Biology in Focus*, *Campbell Essential Biology*, and *Campbell Essential Biology with Physiology*, Fourth Edition.



**Martha R. Taylor** has been teaching biology for more than 35 years. She earned her B.A. in biology from Gettysburg College and her M.S. and Ph.D. in science education from Cornell University. At Cornell, she has served as assistant director of the Office of Instructional Support and has taught introductory biology for both majors and nonmajors. Most recently, she was a

lecturer in the Learning Strategies Center, teaching supplemental biology courses. Her experience working with students in classrooms, in laboratories, and with tutorials has increased her commitment to helping students create their own knowledge of and appreciation for biology. She has been the author of the *Student Study Guide* for all ten editions of *Campbell Biology*.



**Eric J. Simon** is a professor in the Department of Biology and Health Science at New England College (Henniker, New Hampshire). He teaches introductory biology to science majors and non-science majors, as well as upper-level courses in tropical marine biology and careers in science. Dr. Simon received a B.A. in biology and computer science and an M.A. in biology from Wesleyan

University, and a Ph.D. in biochemistry from Harvard University. His research focuses on innovative ways to use technology to improve teaching and learning in the science classroom, particularly for nonscience majors. Dr. Simon is the lead author of the introductory nonmajors biology textbooks *Campbell Essential Biology*, Fifth Edition, and *Campbell Essential Biology with Physiology*, Fourth Edition, and the author of the introductory biology textbook *Biology: The Core*.



**Jean L. Dickey** is Professor Emerita of Biological Sciences at Clemson University (Clemson, South Carolina). After receiving her B.S. in biology from Kent State University, she went on to earn a Ph.D. in ecology and evolution from Purdue University. In 1984, Dr. Dickey joined the faculty at Clemson, where she devoted her career to teaching biology to nonscience majors in a variety

of courses. In addition to creating content-based instructional materials, she developed many activities to engage lecture and laboratory students in discussion, critical thinking, and writing, and implemented an investigative laboratory curriculum in general biology. Dr. Dickey is author of *Laboratory Investigations for Biology*, Second Edition, and coauthor of *Campbell Essential Biology*, Fifth Edition, and *Campbell Essential Biology with Physiology*, Fourth Edition.



**Kelly Hogan** is a faculty member in the Department of Biology at the University of North Carolina at Chapel Hill, teaching introductory biology and introductory genetics to science majors. Dr. Hogan teaches hundreds of students at a time, using active-learning methods that incorporate technology such as cell phones as clickers, online homework, and peer evaluation tools. Dr. Hogan

received her B.S. in biology at the College of New Jersey and her Ph.D. in pathology at the University of North Carolina, Chapel Hill. Her research interests relate to how large classes can be more inclusive through evidence-based teaching methods and technology. She provides faculty development to other instructors through peer-coaching, workshops, and mentoring. Dr. Hogan is the author of *Stem Cells and Cloning*, Second Edition, and is lead moderator of the *Instructor Exchange*, a site within MasteringBiology® for instructors to exchange classroom materials and ideas.



**Neil A. Campbell** (1946–2004) combined the inquiring nature of a research scientist with the soul of a caring teacher. Over his 30 years of teaching introductory biology to both science majors and nonscience majors, many thousands of students had the opportunity to learn from him and be stimulated by his enthusiasm for the study of life. While he is greatly missed by his

many friends in the biology community, his coauthors remain inspired by his visionary dedication to education and are committed to searching for ever better ways to engage students in the wonders of biology.

Make important connections between biological concepts and your life

**NEW!** Each chapter opens with a **high-interest question** to spark your interest in the topic. Questions are revisited later in the chapter, in either a Scientific Thinking or Evolution Connection module.

## CHAPTER 12 DNA Technology and Genomics

? Are genetically modified organisms safe?

Papaya fruit, shown in the photograph below, are sweet and loaded with vitamin C. They are borne on a rapidly growing treelike plant (*Carica papaya*) that grows only in tropical climates. In Hawaii, papaya is both a dietary staple and a valuable export crop. Although thriving today, Hawaii's papaya industry seemed doomed just a few decades ago. A deadly pathogen called the papaya ringspot virus (PRV) had spread throughout the islands and appeared poised to completely eradicate the papaya plant population. But scientists from the University of Hawaii were able to rescue the industry by creating new, genetically engineered PRV-resistant strains of papaya. Today, the papaya industry is once again vibrant—and the vast majority of Hawaii's papayas are genetically modified organisms (GMOs). However, not everyone is happy about the circumstances surrounding the recovery of the Hawaiian papaya industry. Although genetically modified papayas are approved for consumption in the United States (as are many other GMO fruits and vegetables), some critics have raised safety concerns—for the people who eat them and for the environment. On three occasions over a three-year

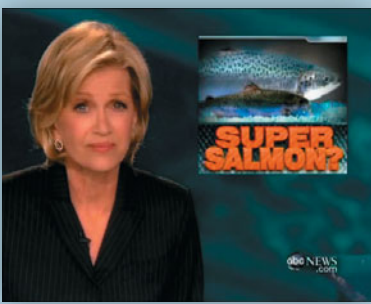
span, thousands of papaya trees on down under the cover of darkness. GMO crops. Although few would should we in fact be concerned about question continues to foster consi In addition to GMOs in our di in many other ways: Gene cloning dustrial products, DNA profiling ence, new technologies produce and DNA can even be used to in chapter, we'll discuss each of the specific techniques used, how th legal, and ethical issues that are



### The New York Times

#### May 12, 2013 Seeking Clues to Heart Disease in DNA of an Unlucky Family

By GINA KOLATA  
Early heart disease ran in Rick Del Sontro's family, and every time he went for a run, he was scared his heart would betray him. So he did all he could to improve his odds. He kept himself lean, stayed away from red meat, spurned cigarettes and exercised intensely, even completing an Ironman Triathlon.



### MasteringBiology®

◀ ABC News Videos and Current Events articles from The New York Times connect what you learn in biology class to fascinating stories in the news.



## BIG IDEAS

### Gene Cloning (12.1–12.5)

A variety of laboratory techniques can be used to copy and combine DNA molecules.



### Genetically Modified Organisms (12.6–12.10)

Transgenic cells, plants, and animals are used in agriculture and medicine.



### DNA Profiling (12.11–12.16)

Genetic markers can be used to definitively match a DNA sample to an individual.



### Genomics (12.17–12.21)

The study of complete DNA sets helps us learn about evolutionary history.



Big Ideas help you connect the overarching concepts that are explored in the chapter.

## CONNECTION

Connection modules in every chapter relate biology to your life and the world outside the classroom.

### 16.5 Biofilms are complex associations of microbes

#### CONNECTION

In many natural environments, prokaryotes attach to surfaces in highly organized colonies called **biofilms**. A biofilm may consist of one or several species of prokaryotes, and it may include protists and fungi as well. Biofilms can form on almost any support, including rocks, soil, organic material (including living tissue), metal, and plastic. You have a biofilm on your teeth—dental plaque is a biofilm that can cause tooth decay. Biofilms can even form without a solid foundation, for example, on the surface of stagnant water.

Biofilm formation begins when prokaryotes secrete signaling molecules that attract nearby cells into a cluster. Once the cluster becomes sufficiently large, the cells produce a gooey coating that glues them to the support and to each other, making the biofilm extremely difficult to dislodge. For example, if you don't scrub your shower, you could find a biofilm growing around the drain—running water alone is not strong enough to wash it away. As the biofilm gets larger and more complex, it becomes a "city" of microbes. Communicating by chemical signals, members of the community coordinate the division of labor, defense against invaders, and other activities. Channels in the biofilm allow nutrients to reach cells in the interior and allow wastes to leave, and a variety of environments develop within it.

Biofilms are common among bacteria that cause disease in humans. For instance, ear infections and urinary tract infections are often the result of biofilm-forming bacteria. Cystic fibrosis patients are vulnerable to pneumonia caused by bacteria that form biofilms in their lungs. Biofilms of harmful

bacteria can also form on implanted medical devices such as catheters, replacement joints, or pacemakers. The complexity of biofilms makes these infections especially difficult to defeat. Antibiotics may not be able to penetrate beyond the outer layer of cells, leaving much of the community intact. For example, some biofilm bacteria produce an enzyme that breaks down penicillin faster than it can diffuse inward.

Biofilms that form in the environment can be difficult to eradicate, too. A variety of industries spend billions of dollars every year trying to get rid of biofilms that clog and corrode pipes, gum up filters and drains, and coat the hulls of ships (Figure 16.5). Biofilms in water distribution pipes may survive chlorination, the most common method of ensuring that drinking water does not contain any harmful microorganisms. For example, biofilms of *Vibrio cholera*, the bacterium that causes cholera, found in water pipes were capable of withstanding levels of chlorine 10 to 20 times higher than the concentrations routinely used to chlorinate drinking water.



▲ Figure 16.5 A biofilm fouling the insides of a pipe pipes were capable of withstanding levels of chlorine 10 to 20 times higher than the concentrations routinely used to chlorinate drinking water.

#### ? Why are biofilms difficult to eradicate?

Biofilms are difficult to eradicate because substances from penetrating into the interior of the biofilm. Biofilms stick to each other; the outer layer of cells may prevent antimicrobial substances from penetrating into the interior of the biofilm.

## EVOLUTION CONNECTION

Evolution Connection modules present concrete examples of the evidence for evolution within each chapter, providing you with a coherent theme for the study of life.

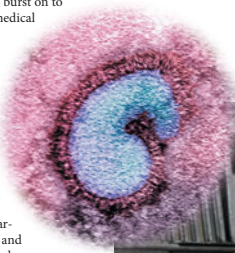
### 10.19 Emerging viruses threaten human health

#### EVOLUTION CONNECTION

**Emerging viruses** are ones that seem to burst on to the scene, becoming apparent to the medical community quite suddenly. There are many familiar examples, such as the 2009 H1N1 influenza virus (discussed in the chapter introduction). Another example is **HIV** (human immunodeficiency virus), the virus that causes **AIDS** (acquired immunodeficiency syndrome). HIV appeared in New York and California in the early 1980s, seemingly out of nowhere. Yet another example is the deadly Ebola virus, recognized initially in 1976 in central Africa; it is one of several emerging viruses that cause hemorrhagic fever, an often fatal syndrome characterized by fever, vomiting, massive bleeding, and circulatory system collapse. A number of other dangerous newly recognized viruses cause encephalitis, inflammation of the brain. One example is the

#### Why are viral diseases such a constant threat?

West Nile virus, which appeared in North America in 1999 and has since spread to all 48 contiguous U.S. states. West Nile virus is spread primarily by mosquitoes, which carry the virus in blood sucked from one victim and can transfer it to another victim. West Nile virus cases surged in 2012, especially in Texas. Severe acute respiratory syndrome (SARS) first appeared in China in 2002. Within eight months, about 8,000 people were infected, and 10% died. Researchers quickly



Courtesy: TEM 180,000x

▼ Figure 10.19 A Hong Kong health-care worker prepares to cull a chicken to help prevent the spread of the avian flu virus (shown in the inset)





## Stay focused on the key concepts

**Central concepts** summarize the key topic of each module, helping you stay focused as you study.

**Checkpoint questions** at the end of each module help you stay on track.

**NEW and revised art** provides clear visuals to help you understand key topics. Selected figures include numbered steps that are keyed to explanations in the text.

### 4.9 The Golgi apparatus modifies, sorts, and ships cell products

After leaving the ER, many transport vesicles travel to the **Golgi apparatus**. Using a light microscope and a staining technique he developed, Italian scientist Camillo Golgi discovered this membranous organelle in 1898. The electron microscope confirmed his discovery more than 50 years later, revealing a stack of flattened sacs, looking much like a pile of pita bread. A cell may contain many, even hundreds, of these stacks. The number of Golgi stacks correlates with how active the cell is in secreting proteins—a multistep process that, as you have just seen, is initiated in the rough ER.

The Golgi apparatus serves as a molecular warehouse and processing station for products manufactured by the ER. You can follow these activities in **Figure 4.9**. Note that the flattened Golgi sacs are not connected, as are ER sacs. **1** One side of a Golgi stack serves as a receiving dock for transport vesicles produced by the ER. **2** A vesicle fuses with a Golgi sac, adding its membrane and contents to the “receiving” side. **3** Products of the ER are modified as a Golgi sac progresses through the stack. **4** The “shipping” side of the Golgi

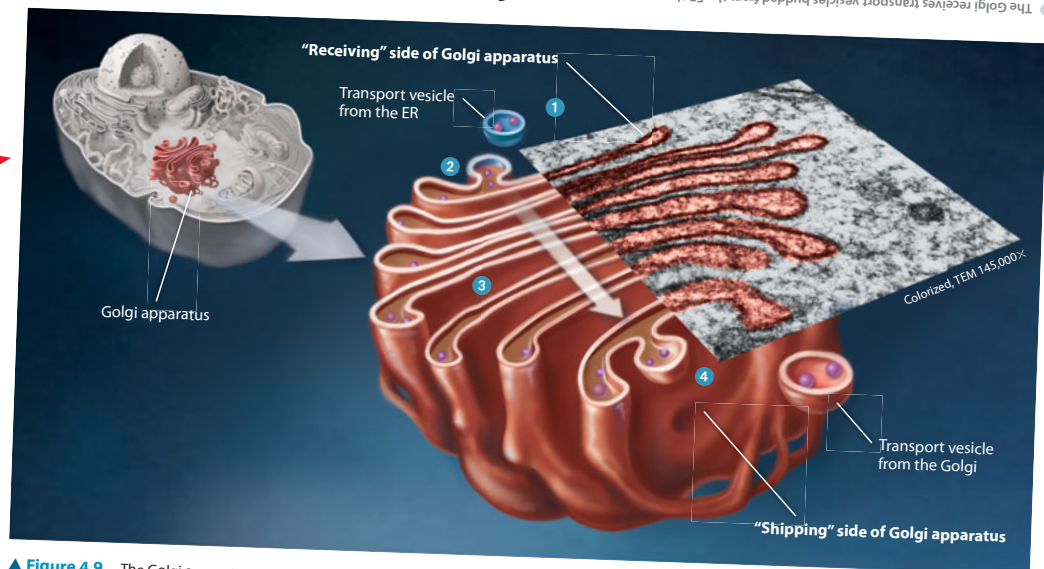
functions as a depot, dispatching its products in vesicles that bud off and travel to other sites.

How might ER products be processed during their transit through the Golgi? Various Golgi enzymes modify the carbohydrate portions of the glycoproteins made in the ER, removing some sugars and substituting others. Molecular identification tags, such as phosphate groups, may be added that help the Golgi sort molecules into different batches for different destinations.

Finished secretory products, packaged in transport vesicles, move to the plasma membrane for export from the cell. Alternatively, finished products may become part of the plasma membrane itself or part of another organelle, such as a lysosome, which we discuss next.

**? What is the relationship of the Golgi apparatus to the ER in a protein-secreting cell?**

The Golgi receives transport vesicles budded from the ER that contain proteins synthesized by bound ribosomes. The Golgi finishes processing the proteins and dispatches transport vesicles to the plasma membrane, where the proteins are secreted.



**▲ Figure 4.9** The Golgi apparatus receiving, processing, and shipping products

MasteringBIOLOGY

Logged in as Jennifer Smith, Student | Help | Log Out

### Connecting the Concepts: Cell Division

Return to CCG Prototypes

Item Type: | Difficulty: -- | Time: <1m | Contact the Publisher

Manage this Item: [Standard View]

Jon Boillard

#### Part A - Cell division concept map

Drag the terms to their correct locations in this concept map about cell division.

Submit | Try another | Show answer | Quit part

Continue | See Score and Provide Feedback

## MasteringBiology®

◀ **Connecting the Concepts** activities link one biological concept to another.

## Learn how to think like a scientist

► **New Scientific Thinking** modules explore how scientists use the processes of science for discovery. Each module concludes with a question that challenges you to think like a scientist.

► **New Scientific Thinking** topics include:

- **Module 2.15** — Scientists study the effects of rising atmospheric CO<sub>2</sub> on coral reef ecosystems
- **Module 8.10** — Tailoring treatment to each patient may improve cancer therapy
- **Module 25.3** — Coordinated waves of movement in huddles help penguins thermoregulate
- **Module 26.3** — A widely used weed killer demasculinizes male frogs
- **Module 29.2** — The model for magnetic sensory reception is incomplete

SCIENTIFIC THINKING

## 12.9 Genetically modified organisms raise health concerns

SCIENTIFIC THINKING

As soon as scientists realized the power of DNA technology, they began to worry about potential dangers. Early concerns focused on the possibility that recombinant DNA technology might create new pathogens. To guard against rogue microbes, scientists developed a set of guidelines including strict laboratory safety and containment procedures, the genetic crippling of transgenic organisms to ensure that they cannot survive outside the laboratory, and a prohibition on certain dangerous experiments. Today, most public concern centers on GMOs used for food.

**Human Safety** Genetically modified organisms are used in crop production because they are more nutritious or because they are cheaper to produce. But do these advantages come at a cost to the health of people consuming GMOs? When investigating complex questions like this one, scientists often use multiple experimental methods. A 2012 animal study involved 104 pigs that were divided into two groups: The first was fed a diet containing 39% GMO corn and the other a closely related non-GMO corn. The health of the pigs was measured over the short term (31 days), the medium term (110 days), and the normal generational life span. The researchers reported no significant differences between the two groups and no traces of foreign DNA in the slaughtered pigs.

Although pigs are a good model organism for human digestion, critics argue that human data are required to draw conclusions about the safety of dietary GMOs for people. The results of one human study, conducted jointly by Chinese and American researchers, were published in 2012. Sixty-eight children (ages 6–8) were fed Golden Rice, spinach (rich in beta-carotene), or a capsule containing 100,000 IU of vitamin A over 21 days, blood samples were drawn, and the amount of vitamin A in the body produced from the capsules was measured. The data show that the beta-carotene in the capsules was converted to vitamin A with similar efficiency, while the beta-carotene in Golden Rice was converted to vitamin A significantly less efficiently (Figure 12.9). Researchers conclude that GMO rice can be a source of preventing vitamin A deficiency. The findings, this study caused an uproar. It called the study an unethical “scandal.” The scientists had used Chinese schoolchildren. The project leaders countered that consent had been obtained in the United States. The controversy highlights the difficulty of conducting research on human beings of limited value, but human health is at stake. To date, no study has documented health problems from GMO foods, and there is genetic evidence that the GMO foods on the market are not yet possible to measure the effects of GMOs on human health.

Advocates of a cautious approach to genetic engineering argue that transgenic plants might pass

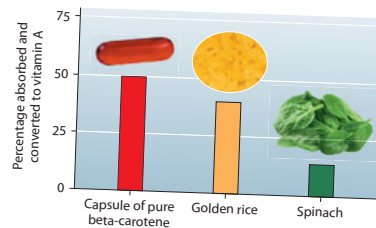
their new genes to related species in nearby wild areas, disturbing the composition of the natural ecosystem. Critics of GMO crops can point to several studies that do indeed show unintended gene transfer from engineered crops to nearby wild relatives. But GMO advocates counter that no lasting or detrimental effects from such transfers have been demonstrated, and that some GMOs (such as bacteria engineered to break down oil spills) can actively help the environment.

**Labeling** Although the majority of several staple crops grown in the United States—including corn and soybeans—are genetically modified, products made from GMOs are not required to be labeled in any way. Chances are you ate a food containing GMOs today, but the lack of labeling means you probably can't say for certain. Labeling of foods containing more than trace amounts of GMOs is required in Europe, Japan, Australia, China, Russia, and other countries. Labeling advocates point out that the information would allow consumers to decide for themselves whether they wish to be exposed to GMO foods. Some biotechnology advocates, however, respond that similar demands were not made when “transgenic” crop plants produced by traditional breeding techniques were put on the market. For example, triticale (a crop used primarily in animal feed but also in some human foods) was created decades ago by combining the genomes of wheat and rye—two plants that do not interbreed in nature. Triticale is now sold worldwide without any special labeling.

Scientists and the public need to weigh the possible benefits versus risks on a case-by-case basis. The best scenario would be to proceed with caution, basing our decisions on sound scientific information rather than on either irrational fear or blind optimism.

**?** Why might crop plants engineered to be resistant to weed killer pose a danger to the environment?

© The genes for herbicide resistance could transfer to closely related weeds, which could then become resistant.



**▲ Figure 12.9** Vitamin A production after consumption of different sources of beta-carotene

Data from G. Tang et al., Beta-carotene in Golden Rice is as good as beta-carotene in oil at providing vitamin A to children, *American Journal of Clinical Nutrition* 96(3): 658–64 (2012).

Scientific Thinking: What Roles Do Diet and the Microbial Community in the Intestines Play in Obesity?

Fast foods, cookies and ice cream, sodas and energy drinks—Americans eat a lot of processed foods high in fats and simple sugars. Not surprisingly, this type of diet can lead to weight gain and is one of the main culprits in the obesity epidemic in this country. But, is there more to this story?

The foods you eat serve as food for the community of microorganisms that inhabit your digestive tract. Those microbes have their own food “preferences,” metabolizing different types of food molecules and releasing their byproducts, which your body then absorbs.

Scientists have hypothesized that a high-fat, high sugar diet actually alters the composition of the microbial community that inhabits the beginning of the large intestine, which contributes to obesity. Because of the difficulties of carrying out experiments on humans, scientists have used mice as an animal model in which to test this hypothesis.

**Part A - Designing a controlled experiment**

In one experiment, scientists raised mice in germ-free conditions (who therefore lacked intestinal microbes). The mice were fed a low-fat diet rich in the complex plant polysaccharides often called fiber.

When the mice were 12 weeks old, the scientists transplanted the microbial community from the intestine of a single “donor” mouse into all of the germ-free mice. Then they divided the mice randomly into two groups and fed each group a different diet:

- Group 1 (the control group) continued to eat a low-fat, high-fiber diet.
- Group 2 (the experimental group) ate a high-fat, high-sugar diet.

MasteringBiology®

► **NEW! Scientific Thinking activities** teach you how to practice important scientific skills like understanding variables and making predictions. Specific wrong-answer feedback coaches you to the correct response.



## Maximize your learning and success

- ▶ **New Visualizing the Concept** modules walk you through challenging concepts and complex processes.
- ▶ The brief narrative works together with the artwork to help you visualize and understand the topic.

**Hints** embedded within the module emulate the guidance that you might receive during instructor office hours or in a tutoring session. These hints provide additional information to deepen your understanding of the topic.

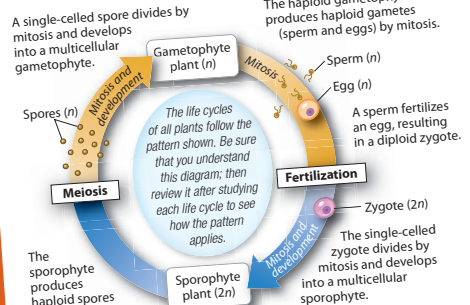
## ▶ Alternation of Generations and Plant Life Cycles

**VISUALIZING THE CONCEPT**

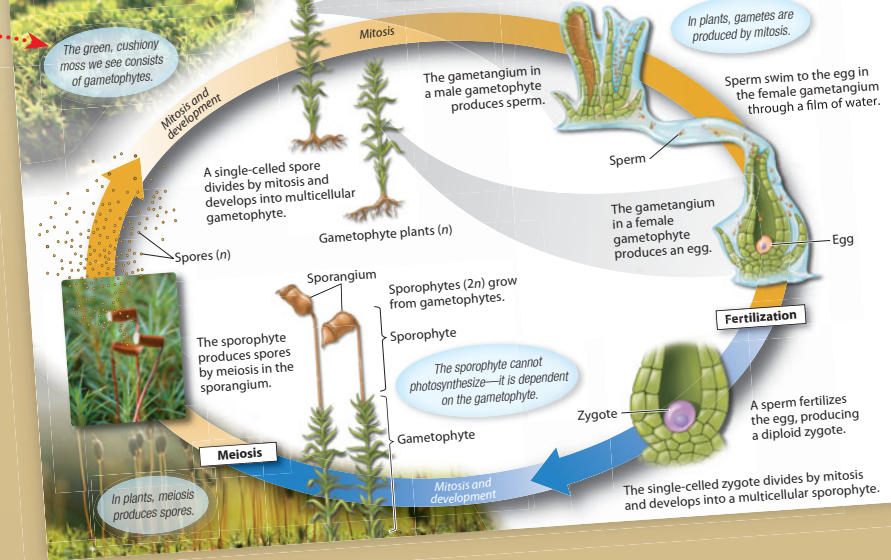
### 17.3 Haploid and diploid generations alternate in plant life cycles

Plants have life cycles that are very different from ours. Humans are diploid individuals—that is, each of us has two sets of chromosomes, one from each parent (Module 8.12). Gametes (sperm and eggs) are the only haploid stage in the human life cycle. Plants have an **alternation of generations**: The diploid and haploid stages are distinct, multicellular bodies. The haploid generation of a plant produces gametes and is called the **gametophyte**. The diploid generation produces spores and is called the **sporophyte**. In a plant's life cycle, these two generations alternate in producing each other. In mosses, as in all nonvascular plants, the gametophyte is the larger, more obvious stage of the life cycle. Ferns, like most plants, have a life cycle dominated by the sporophyte. Today, about 95% of all plants, including all seed plants, have a dominant sporophyte in their life cycle. The life cycles of all plants follow a pattern shown here.

#### THE PLANT LIFE CYCLE



#### A Moss Life Cycle



## MasteringBiology®

- ▶ **NEW! Visualizing the Concept Activities** include interactive videos that were created and narrated by the authors of the text.

**26.8 Pancreatic hormones regulate blood glucose level**

The pancreas is a gland with dual functions: it secretes digestive enzymes into the small intestine, and it secretes hormones that regulate the level of glucose in the blood and the body. Recall that glucose is an energy source for animal cells. Let's see how blood glucose level is regulated.

Scattered throughout the pancreas are clusters of endocrine cells, called **pancreatic islets**. Within each islet are beta cells, which produce insulin, and alpha cells, which produce glucagon. Insulin and glucagon are said to be **antagonistic hormones** because the effects of one oppose the effects of the other. The balance in

secretion of insulin and glucagon maintains a homeostatic "set point" of glucose. Two negative feedback systems control the amount of glucose in the blood. One feedback system involves the release of insulin, whereas the other involves the release of glucagon. When insulin is present in the blood, glucose is taken up by nearly all cells, and extra glucose is stored in the liver as a polysaccharide called glycogen. When the blood glucose level falls, glucagon stimulates the liver to release glycogen, and the blood glucose level rises, using a human example.

**REGULATION OF BLOOD GLUCOSE**

**Effects of antagonistic hormones**

**Insulin release**  
Beta cells of the pancreas release insulin into the blood. Insulin stimulates cells to take up glucose from the blood. Rising blood glucose level stimulates the pancreas to release insulin.

**Glucagon release**  
Alpha cells of the pancreas release glucagon into the blood. Glucagon stimulates the liver to release glucose from glycogen stores and return glucose to the blood. Falling blood glucose level stimulates the pancreas to release glucagon.

**Regulation of Blood Glucose** more info

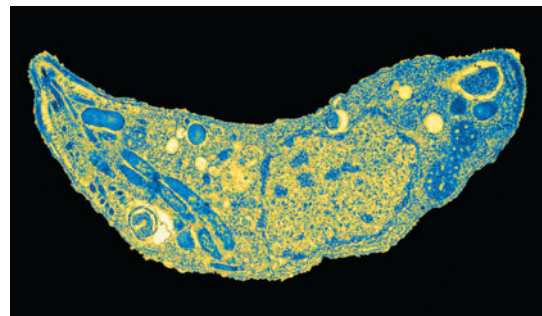
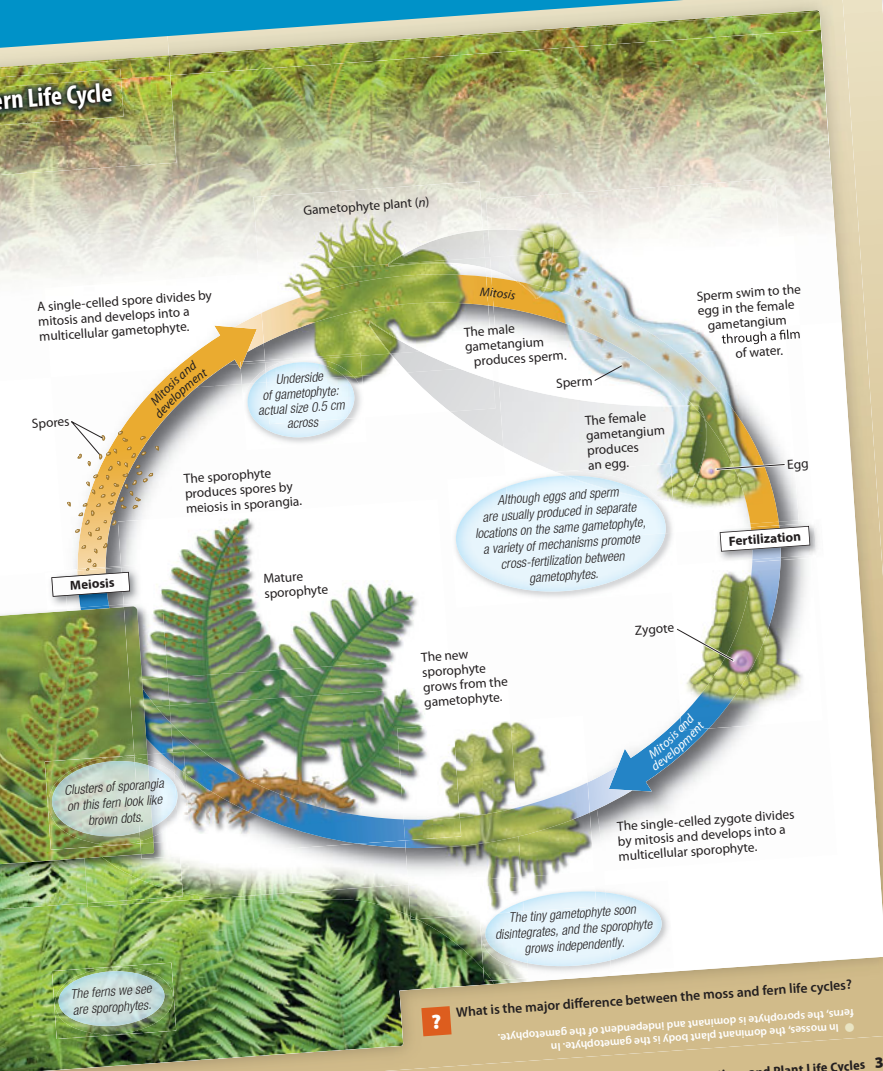
Beta cells of the pancreas release insulin into the blood

Glucose Insulin

00:00 / 01:45



Plant Life Cycle

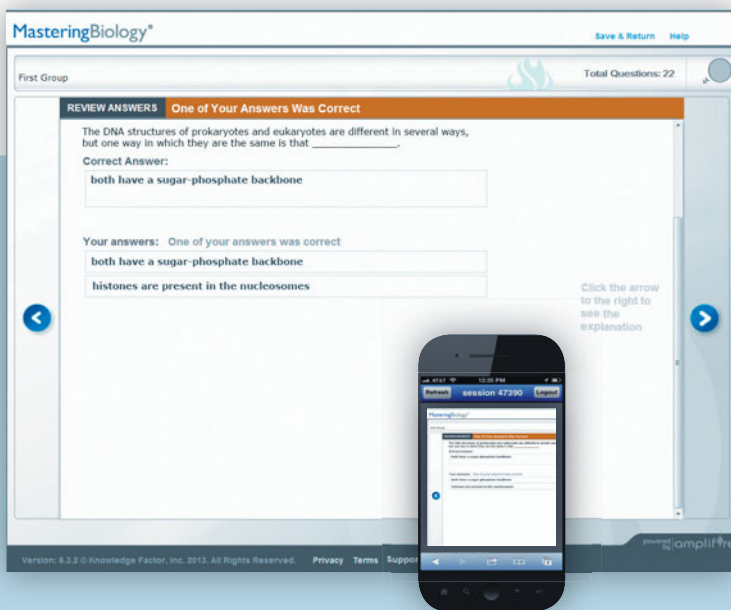


Colonized TEM 9,375X

**▲ Figure 4.1C** Transmission electron micrograph of *Toxoplasma* (This parasite of cats can be transmitted to humans, causing the disease toxoplasmosis.)

**Try This** Describe a major difference between the *Paramecium* in Figure 4.1B and the protist in this figure. (Hint: Compare the notations along the right sides of the micrographs.)

**▲ New! Try This** activities help you actively engage with the figures and develop positive study habits.



MasteringBiology®

**◀ New Dynamic Study Modules** enable you to study effectively on your own and more quickly learn the information. These modules can be accessed on smartphones, tablets, and computers.

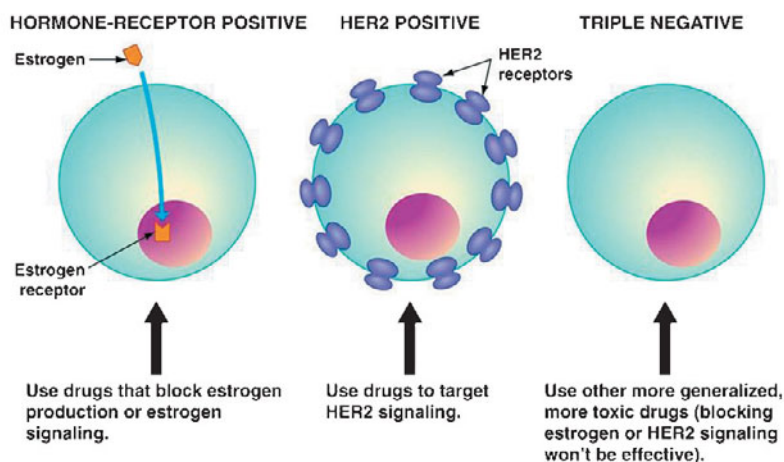
# To the Instructor: Implement active learning in your classroom

## Resources save you hours of time preparing for class

▶ **NEW! Learning Catalytics™** is a “bring your own device” student engagement, assessment, and classroom intelligence system. This technology has grown out of twenty years of cutting-edge research, innovation, and implementation of interactive teaching and peer instruction.



## Three classes of breast cancer tumors lead to more personalized therapy



## Connect your lectures to current topics

▶ **Campbell Current Topics PowerPoint** slides help you prepare a high-impact lecture developed around current issues. Topics include cancer, global climate change, athletic cheating, nutrition, and more.

## Three cancer treatments: “Slash, burn, and poison”



Surgery removes many (but often not all) cancerous cells.



Radiation therapy disrupts cell division.



Chemotherapy involves drugs that disrupt cell division.



Home About Instructor Exchange About the Board Submit Your Ideas

TAG ARCHIVES: DNA

## Demonstrating a Frame Shift Mutation

Posted on October 24, 2011 in [Instructor Exchange](#)

Written by Edward J. Zalsky, Blackburn College. Adapted by Kelly A. Hogan, University of North Carolina at Chapel Hill.

**Learning Outcomes:**

- To demonstrate the effect of a reading frame shift mutation in DNA.

**Activity Description:** Students compare three sentences and/or design their own frame shift sentences.

**Time Needed:** 5 minutes

**Materials Needed:** None

**Activity Instructions:** A simple way to demonstrate the effect of a reading frame shift is to have students compare three sentences. The first is a simple sentence. Students then compare the sentence when a letter is added (2) or deleted (3). The reading frames, or words, are returned into nonsense.

SUBSCRIBE TO RSS:

EMAIL SUBSCRIPTION:

SEARCH:

CATEGORIES: Select Category

TAGS: Select Tag

RECENT POSTS:

- [Homeostasis of a Sleepiness Factor](#)
- [Introductory Journal Club](#)
- [Speed Dating with Gene Testing](#)
- [Using Analogies in](#)

◀ **Instructor Exchange**, moderated by co-author Kelly Hogan, offers a library of active learning strategies contributed by instructors from across the country.

▶ **BioFlix activities** offer students 3-D animations to help them visualize and learn challenging topics.

## Assign tutorials to help students prepare for class

▶ **Video Tutor Sessions and MP3 Tutor Sessions**, hosted by co-author Eric Simon, provide on-the-go tutorials focused on key concepts and vocabulary.



MasteringBIOLOGY® Logged in as Jennifer Smith, Student | Help | Log Out

Chromosome duplication

Sister chromatids

Essential Bio Signed in as Libby Peiser, Instructor | Help | Close

4. A Tour of the Cell | BioFlix Activity: Tour of an Animal Cell -- Cell Structures

Item Type: Coaching Activities | Difficulty: 2 | Time: 3m | Learning Outcomes: | Contact the Publisher | Manage this Item: Standard View

**BioFlix Activity: Tour of an Animal Cell -- Cell Structures**

Can you label the structures of an animal cell?

To review the structure of an animal cell, watch this BioFlix animation: [Tour of an Animal Cell](#)

**Part A - Animal cell structure**

Drag the labels onto the diagram to identify the structures of an animal cell.

Labels: Cytosol, Cytoskeleton, Golgi Apparatus, Mitochondrion, Nucleus, Plasma Membrane, Ribosomes, Rough Endoplasmic Reticulum (ER), Smooth Endoplasmic Reticulum (ER), Centriole, Vacuole, Flagellum (Not in most plant cells)

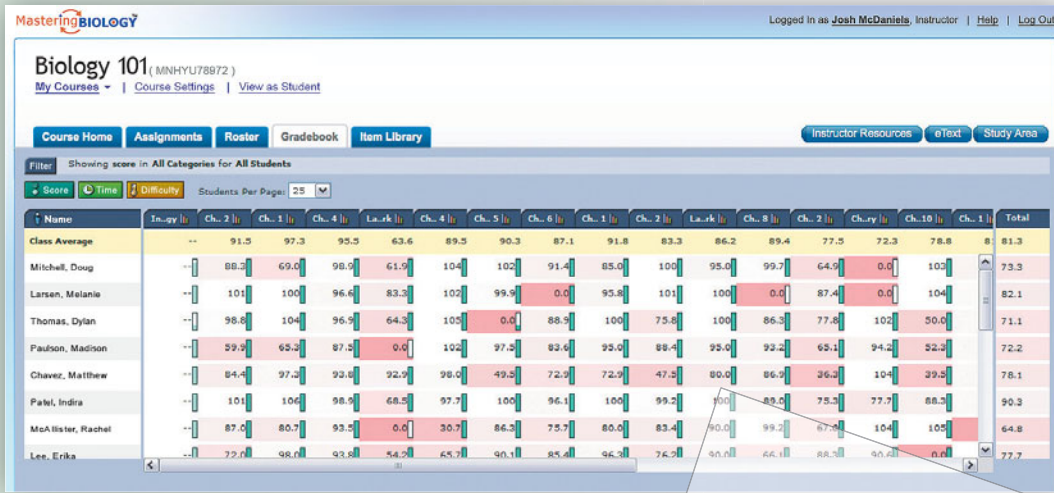
Submit My Answers Give Up



# To the Instructor: How to use MasteringBiology®

MasteringBiology® is an online assessment and tutorial system designed to help you teach more efficiently. It offers a variety of interactive activities to engage students and help them to succeed in the course.

## Access students' results with easy-to-interpret student performance data



### Gradebook

- Every assignment is **automatically graded**.
- At a glance, **shades of red** highlight vulnerable students and challenging assignments.

▶ **Student performance data** reveal how students are doing compared to a national average and which topics they're struggling with.

▶ **Wrong answer summaries** give unique insight into your students' misconceptions and support just-in-time teaching.

Part A  
In muscle cells, fermentation produces \_\_\_\_.

ANSWER

- carbon dioxide, lactate, NAD<sup>+</sup>, and ATP
- pyruvate
- carbon dioxide, lactate, NADH, and ATP
- carbon dioxide, ethanol, NAD<sup>+</sup>, and ATP
- carbon dioxide, ethanol, NADH, and ATP

Answer Stats:	Students	% Correct	% Unfinished	% Req'd Solution	Wrong/student	Hints/student
System Average	5548	98%	1.4%	0.6%	0.6	0
This Course (MBDEMOGRADES)	25	100%	0%	0%	0.5	0

**Wrong Answers for This Course (MBDEMOGRADES)**

% Wrong	Answer	Response
38.5%	carbon dioxide, lactate, NADH, and ATP	Fermentation oxidizes NADH.
23.1%	carbon dioxide, ethanol, NADH, and ATP	Fermentation oxidizes NADH
23.1%	carbon dioxide, ethanol, NAD <sup>+</sup> , and ATP	These are the products of fermentation as it occurs in yeast cells.
15.4%	pyruvate	Pyruvate is a reactant in fermentation.

These are the products of fermentation as it occurs in muscle cells.

Part B  
In fermentation \_\_\_\_ is reduced and \_\_\_\_ is oxidized.

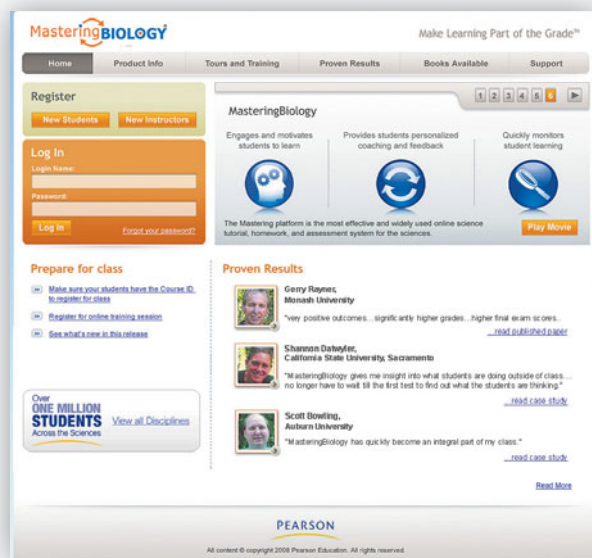
## Gain insight into student progress at a glance

▶ **Get daily diagnostics.**

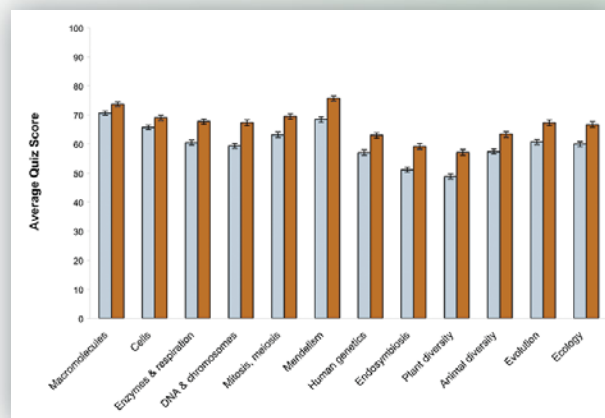
**Gradebook Diagnostics** provide unique insight into class performance. With a single click, see a summary of how your students are struggling or progressing.



## MasteringBiology® is easy for you and your students to use



◀ **The Mastering platform** is the most effective and widely used online tutorial, homework, and assessment system for the sciences.



### With MasteringBiology®, you can:

- **Assign** publisher-created pre-built assignments to get started quickly.
- **Easily edit** any of our questions or answers to match the precise language you use.
- **Import your own questions** and begin compiling meaningful data on student performance.
- **Easily export grades** to Microsoft® Excel or other course-management systems.

### △ **Efficacy studies**

Go to the **“Proven Results”** tab at [www.masteringbiology.com](http://www.masteringbiology.com) to see efficacy studies.

# Preface

Inspired by the thousands of students in our own classes over the years and by enthusiastic feedback from the many instructors who have used our book, we are delighted to present this new, Eighth Edition. We authors have worked together closely to ensure that both the book and the supplementary material online reflect the changing needs of today's courses and students, as well as current progress in biology. Titled *Campbell Biology: Concepts & Connections* to honor Neil Campbell's founding role and his many contributions to biology education, this book continues to have a dual purpose: to engage students from a wide variety of majors in the wonders of the living world and to show them how biology relates to their own existence and the world they inhabit. Most of these students will not become biologists themselves, but their lives will be touched by biology every day. Understanding the concepts of biology and their connections to our lives is more important than ever. Whether we're concerned with our own health or the health of our planet, a familiarity with biology is essential. This basic knowledge and an appreciation for how science works have become elements of good citizenship in an era when informed evaluations of health issues, environmental problems, and applications of new technology are critical.

## Concepts and Connections

**Concepts** Biology is a vast subject that gets bigger every year, but an introductory biology course is still only one or two semesters long. This book was the first introductory biology textbook to use concept modules to help students recognize and focus on the main ideas of each chapter. The heading of each module is a carefully crafted statement of a key concept. For example, "A nerve signal begins as a change in the membrane potential" announces a key concept about the generation of an action potential (Module 28.4). Such a concept heading serves as a focal point, and the module's text and illustrations converge on that concept with explanation and, often, analogies. The module text walks the student through the illustrations, just as an instructor might do in class. And in teaching a sequential process, such as the one diagrammed in Figure 28.4, we number the steps in the text to correspond to numbered steps in the figure. The synergy between a module's narrative and graphic components transforms the concept heading into an idea with meaning to the student. The checkpoint question at the end of each module encourages students to test their understanding as they proceed through a chapter. Finally, in the Chapter Review, all the key concept statements are listed and briefly summarized under the overarching section titles, explicitly reminding students of what they've learned.

**Connections** Students are more motivated to study biology when they can connect it to their own lives and interests—for example, when they are able to relate science to health

issues, economic problems, environmental quality, ethical controversies, and social responsibility. In this edition, blue Connection icons mark the numerous application modules that go beyond the core biological concepts. For example, the new Connection Module 26.12 describes the potential role oxytocin plays in human–dog bonding. In addition, our Evolution Connection modules, identified by green icons, connect the content of each chapter to the grand unifying theme of evolution, without which the study of life has no coherence. Explicit connections are also made between the chapter introduction and either the Evolution Connection module or the new Scientific Thinking module in each chapter; new high-interest questions introduce each chapter, drawing students into the topic and encouraging a curiosity to explore the question further when it appears again later in the chapter.

## New to This Edition

**New Scientific Thinking Modules** In this edition we placed greater emphasis on the process of scientific inquiry through the addition to each chapter of a new type of module called Scientific Thinking, which is called out with a purple icon. These modules cover recent scientific research as well as underscore the spirit of inquiry in historical discoveries. All Scientific Thinking modules strive to demonstrate to students what scientists do. Each of these modules identifies key attributes of scientific inquiry, from the forming and testing of hypotheses to the analysis of data to the evaluation and communication of scientific results among scientists and with society as a whole. For example, the new Module 2.15 describes how scientists use both controlled experiments and observational field studies to document the effects of rising atmospheric CO<sub>2</sub> on coral reef ecosystems. Module 13.3 describes the scientific search for the common ancestor of whales, using different lines of inquiry from early fossil clues, molecular comparisons, and a series of transitional fossils that link whales to cloven-hoofed mammals, animals that live on land. And to prepare students for the renewed focus in the book on how biological concepts emerge from the process of science, we have significantly revised the introduction in Chapter 1, Biology: Exploring Life. These changes will better equip students to think like scientists and emphasize the connections between discovery and the concepts explored throughout the course.

**New Visualizing the Concept Modules** Also new to this edition are modules that raise our hallmark art–text integration to a new level. These Visualizing the Concept modules take challenging concepts or processes and walk students through them in a highly visual manner, using engaging, attractive art; clear and concise labels; and instructor "hints" called out in light blue bubbles. These short hints emulate the one-on-one coaching an instructor might provide to a students during



office hours and help students make key connections within the figure. Examples of this new feature include Module 9.8, which demonstrates to students the process of reading and analyzing a family pedigree; Module 17.3, which introduces the concept of plant life cycles through a combination of photographs and detailed life cycle art displayed across an impressive two-page layout; and Module 26.8, which walks students through the concept of homeostatic controls in blood glucose levels.

**New “Try This” Tips** One theme of the revision for the Eighth Edition is to help all students learn positive study habits they can take with them throughout their college careers and, in particular, to encourage them to be active in their reading and studying. To foster good study habits, several figures in each chapter feature a new “Try This” study tip. These action-oriented statements or questions direct students to study a figure more closely and explain, interpret, or extend what the figure presents. For example, in Figure 3.13B, students are asked to “Point out the bonds and functional groups that make the R groups of these three amino acids either hydrophobic or hydrophilic.” Figure 6.10B is a new figure illustrating the molecular rotary motor ATP synthase, and the accompanying Try This tip asks students to “Identify the power source that runs this motor. Explain where this ‘power’ comes from.” Figure 36.7, on the effect of predation on the life history traits of guppies, offers the following Try This tip: “Use the figure to explain how the hypothesis was tested.”

**Improvements to End-of-Chapter Section** The Testing Your Knowledge questions are now arranged to reflect Bloom’s Taxonomy of cognitive domains. Questions and activities are grouped into Level 1: Knowledge/Comprehension, Level 2: Application/Analysis, and Level 3: Synthesis/Evaluation. In addition, a new Scientific Thinking question has been added to each chapter that connects to and extends the topic of the Scientific Thinking module. Throughout the Chapter Review, new questions have been added that will help students better engage with the chapter topic and practice higher-level problem solving.

**New Design and Improved Art** The fresh new design used throughout the chapters and the extensive reconceptualization of many figures make the book even more appealing and accessible to visual learners. The cellular art in Chapter 4, A Tour of the Cell, for example, has been completely reimaged for more depth perspective and richer color. The new big-picture diagrams of the animal and plant cells are vibrant and better demonstrate the spatial relationships among the cellular structures with an almost three-dimensional style. The illustrations of cellular organelles elsewhere in Chapter 4 include electron micrographs overlaid on diagrams to emphasize the connection between the realistic micrograph depiction and the artwork. Figure 4.9, for example, shows a micrograph of an actual Golgi apparatus paired with an illustration; an accompanying orientation diagram—a hallmark of *Concepts and Connections*—continues to act as a roadmap that reminds students of how an organelle fits within the overall cell structure. Finally, throughout the book we have

introduced new molecular art; for example, see Figure 10.11B for a new representation of a molecule of tRNA binding to an enzyme molecule.

**The Latest Science** Biology is a dynamic field of study, and we take pride in our book’s currency and scientific accuracy. For this edition, as in previous editions, we have integrated the results of the latest scientific research throughout the book. We have done this carefully and thoughtfully, recognizing that research advances can lead to new ways of looking at biological topics; such changes in perspective can necessitate organizational changes in our textbook to better reflect the current state of a field. You will find a unit-by-unit account of new content and organizational improvements in the “New Content” section on pp. xvii–xviii following this Preface.

**New MasteringBiology®** A specially developed version of MasteringBiology, the most widely used online tutorial and assessment program for biology, continues to accompany *Campbell Biology: Concepts & Connections*. In addition to 170 author-created activities that help students learn vocabulary, extend the book’s emphasis on visual learning, demonstrate the connections among key concepts (helping students grasp the big ideas), and coach students on how to interpret data, the Eighth Edition features two additional new activity types. New Scientific Thinking activities encourage students to practice the basic science skills explored in the in-text Scientific Thinking feature, allowing students to try out thinking like a scientist and allowing instructors to assess this understanding; new Visualizing the Concept activities take students on an animated and narrated tour of select Visualizing the Concept modules from the text, offering students the chance to review key concepts in a digital learning modality. MasteringBiology® for *Campbell Biology: Concepts & Connections*, Eighth Edition, will help students to see strong connections through their print textbook, and the additional practice available online allows instructors to capture powerful data on student performance, thereby making the most of class time.

## This Book’s Flexibility

Although a biology textbook’s table of contents is by design linear, biology itself is more like a web of related concepts without a single starting point or prescribed path. Courses can navigate this network by starting with molecules, with ecology, or somewhere in between, and courses can omit topics. *Campbell Biology: Concepts & Connections* is uniquely suited to offer flexibility and thus serve a variety of courses. The seven units of the book are largely self-contained, and in a number of the units, chapters can be assigned in a different order without much loss of coherence. The use of numbered modules makes it easy to skip topics or reorder the presentation of material.



For many students, introductory biology is the only science course that they will take during their college years. Long after today’s students have forgotten most of the specific

content of their biology course, they will be left with general impressions and attitudes about science and scientists. We hope that this new edition of *Campbell Biology: Concepts & Connections* helps make those impressions positive and supports instructors' goals for sharing the fun of biology. In our continuing efforts to improve the book and its supporting materials, we benefit tremendously from instructor and student feedback, not only in formal reviews but also via informal communication. Please let us know how we are doing and how we can improve the next edition of the book.

*Jane Reece, janereece@cal.berkeley.edu*

*Martha Taylor (Chapter 1 and Unit I), mrt2@cornell.edu*

*Eric Simon (Units II and VI and Chapters 21 and 27), esimon@nec.edu*

*Jean Dickey (Units III, IV, and VII and Chapters 22, 23, and 30),  
dickeyj@clemson.edu*

*Kelly Hogan (Chapters 20, 24–26, 28, and 29), leek@email.unc.edu*

# New Content

**B**elow are some important highlights of new content and organizational improvements in *Campbell Biology: Concepts & Connections*, Eighth Edition.

**Chapter 1, Biology: Exploring Life** The snowy owl, our cover organism for the Eighth Edition, is featured in the chapter introduction. The discussion of the evolutionary adaptations of these owls to life on the arctic tundra links to a new Scientific Thinking module on testing the hypothesis that camouflage coloration protects some animals from predation. An expanded module on evolution as the core theme of biology now includes a phylogenetic tree of elephants to enhance the discussion of the unity and diversity of life.

**Unit I, The Life of the Cell** Throughout the Eighth Edition, the themes introduced in new chapter introductions are expanded and further explored in either Scientific Thinking or Evolution Connection modules. For instance, in this unit, Chapter 5, The Working Cell, begins with the question “How can water flow through a membrane?” and an essay that describes the role these water channels play in kidney function; the essay is illustrated with a computer model of aquaporins spanning a membrane. Module 5.7, a Scientific Thinking module, then details the serendipitous discovery of aquaporins and presents data from a study that helped identify their function. Chapter 7, Photosynthesis: Using Light to Make Food, begins with the question “Will global climate change make you itch?” and uses the example of proliferation of poison ivy to introduce this chapter on photosynthesis. Then, Module 7.13, another Scientific Thinking module, explores various ways that scientists test the effects of rising atmospheric CO<sub>2</sub> levels on plant growth and presents results from a study on poison ivy growth. The Scientific Thinking question at the end of the chapter continues this theme, with data from a study on pollen production by ragweed under varying CO<sub>2</sub> concentrations, beginning with the question “Will global climate change make you sneeze as well as itch?” This unit also has three of the new Visualizing the Concept modules: Module 3.14: A protein’s functional shape results from four levels of structure; Module 5.1: Membranes are fluid mosaics of lipids and proteins with many functions; and Module 7.9: The light reactions take place within the thylakoid membranes. These modules use both new and highly revised art to guide students through these challenging topics in a visual, highly intuitive manner. Chapter 6, How Cells Harvest Chemical Energy, now includes a new figure and expanded explanation of the amazing molecular motor, ATP synthase. The art program in Chapter 4, A Tour of the Cell, has been completely reimagined and revised. The beautiful new diagrams of animal and plant cells and their component parts are designed to help students appreciate the complexities of cell structure and explore the relationship between structure and function.

**Unit II, Cellular Reproduction and Genetics** The purpose of this unit is to help students understand the relationship between DNA, chromosomes, and organisms and to help them see that genetics is not purely hypothetical but connects in many important and interesting ways to their lives, human society, and other life on Earth. In preparing this edition, we worked to clarify difficult concepts, enhancing text and illustrations and providing timely new applications of genetic principles. The content is reinforced with updated discussions of relevant topics, such as personalized cancer therapy, the H1N1 and H5N1 influenza viruses, umbilical cord blood banking, and the science and controversy surrounding genetically modified foods. This edition includes discussion of many recent advances in the field. Some new topics concern our basic understanding of genetics and the cell cycle, such as how sister chromatids are physically attached during meiosis, how chemical modifications such as methylation and acetylation affect inheritance, and the roles of activators and enhancers in controlling gene expression. Other topics include recent advances in our understanding of genetics, such as the analysis of recent human evolution of high-altitude-dwelling Sherpas, expanded roles for microRNAs in the control of genetic information, and our improved understanding of the cellular basis of health problems in cloned animals. In some cases, sections within chapters have been reorganized to present a more logical flow of materials. Examples of new organization include the discussion of human karyotypes and the diagnosis of chromosomal abnormalities (Modules 8.18–8.20) and the processes of reproductive and therapeutic cloning (Modules 11.12–11.14). Material throughout the unit has been updated to reflect recent data, such as the latest cancer statistics and results from whole-genome sequencing.

**Unit III, Concepts of Evolution** This unit presents the basic principles of evolution and natural selection, the overwhelming evidence that supports these theories, and their relevance to all of biology—and to the lives of students. A new chapter introduction in Chapter 13, How Populations Evolve, highlights the role that evolution plays in thwarting human attempts to eradicate disease. The chapter has been reorganized so that the opening module on Darwin’s development of the theory of evolution is followed immediately by evidence for evolution, including a Scientific Thinking module on fossils of transitional forms. Another new module (13.4) assembles evidence from homologies, including an example of “pseudogenes.” New material in this unit also supports our goal of directly addressing student misconceptions about evolution. For example, a new chapter introduction and Scientific Thinking module in Chapter 14, The Origin of Species, tackle the question “Can we observe speciation occurring?” and a new chapter introduction in Chapter 15, Tracing Evolutionary History, poses the question (answered in Module 15.12) “How do brand-new structures arise by evolution?”



**Unit IV, The Evolution of Biological Diversity** The diversity unit surveys all life on Earth in less than a hundred pages! Consequently, descriptions and illustrations of the unifying characteristics of each major group of organisms, along with a small sample of its diversity, make up the bulk of the content. Two recurring elements are interwoven with these descriptions: evolutionary history and examples of relevance to our everyday lives and society at large. For the Eighth Edition, we have improved and updated those two elements. For example, Chapter 16, Microbial Life: Prokaryotes and Protists, opens with a new introduction on human microbiota and the question “Are antibiotics making us fat?” The related Scientific Thinking module (16.11) updates the story of Marshall’s discovery of the role of *Helicobacter pylori* in ulcers with a new hypothesis about a possible connection between *H. pylori* and obesity. A new chapter introduction and Scientific Thinking module in Chapter 17, The Evolution of Plant and Fungal Diversity, highlight the interdependence of plants and fungi. The alternation of generations and the life cycle in mosses and ferns are presented in an attractive two-page Visualizing the Concept module (17.3), while details of the pine life cycle have been replaced with a new Module 17.5 that emphasizes pollen and seeds as key adaptations for terrestrial life. The animal diversity chapters (18, The Evolution of Invertebrate Diversity; and 19, The Evolution of Vertebrate Diversity) also have new opening essays. A Visualizing the Concept module (18.3) beautifully illustrates features of the animal body plan. A new Module 18.16 calls attention to the value of invertebrate diversity. Chapter 19 includes a Visualizing the Concept module (19.9) on primate diversity and also updates the story of hominin evolution, including the recently described *Australopithecus sediba*.

**Unit V, Animals: Form and Function** This unit combines a comparative approach with an exploration of human anatomy and physiology. Many chapters begin with an overview of a general problem that animals face and a comparative discussion of how different animals address this problem, all framed within an evolutionary context. For example, the introduction to Chapter 20, Unifying Concepts of Animal Structure and Function, begins with the question “Does evolution lead to the perfect animal form?” Module 20.1 is a new Evolution Connection that discusses the long, looped laryngeal nerve in vertebrates (using the giraffe as an example) to illustrate that a structure in an ancestral organism can become adapted to function in a descendant organism without being “perfected,” thereby combating common student misconceptions about evolution. The main portion of every chapter is devoted to detailed presentations of human body systems, frequently illuminated by discussion of the health consequences of disorders in those systems. For example, Chapter 28, Nervous Systems, includes new material describing a genetic risk for developing Alzheimer’s disease, the long-term consequences of traumatic brain injury, and how some antidepressants may not be as effective at combating depression as once thought. In many areas, content has been updated to reflect

newer issues in biology. The chapter introduction and new Scientific Thinking module in Chapter 26, Hormones and the Endocrine System, discuss the consequences of endocrine disruptors in the environment. The Scientific Thinking module in Chapter 23 describes large clinical trials investigating the hypothesis that heart attacks are caused by the body’s inflammatory response. Chapter 27, Reproduction and Embryonic Development, has a new chapter introduction on viral STDs, improved figures presenting embryonic development, as well as a Visualizing the Concept module on human pregnancy. Improvements to this unit also include a significant revision to the presentation of nutrition in Modules 21.14 to 21.21 and a reorganization of text and art in Modules 25.6 and 25.7 to guide students through the anatomy and physiology of the kidneys.

**Unit VI, Plants: Form and Function** To help students gain an appreciation of the importance of plants, this unit presents the anatomy and physiology of angiosperms with frequent connections to the importance of plants to society. New Connections in this edition include an increased discussion of the importance of agriculture to human civilization (including presentation of genomic data investigating this question) in Chapter 31, issues surrounding organic farming (including presentation of data on the nutritional value of organic versus conventionally grown produce) in Chapter 32, an expanded discussion of phytoestrogens, as well as a new discussion on the production of seedless vegetables in Chapter 33. Throughout the unit, the text has been revised with the goal of making the material more engaging and accessible to students. For example, the difficult topic of transpiration is now presented in an entirely new, visual style within a Visualizing the Concept module (Module 32.3), and streamlined and simplified discussions were written for such topics as the auxin hormones and phytochromes. All of these changes are meant to make the point that human society is inexorably connected to the health of plants.

**Unit VII, Ecology** In this unit, students learn the fundamental principles of ecology and how these principles apply to environmental problems. Along with a new introduction in each chapter, the Eighth Edition features many new photos and two Visualizing the Concept modules (35.7 and 37.9)—one focuses on whether animal movement is a response to stimuli or requires spatial learning and the other explores the interconnection of food chains and food webs. Scientific Thinking modules sample the variety of approaches to studying ecology, including the classic field study that led to the concept of keystone species (37.11); the “natural experiment” of returning gray wolves to the Yellowstone ecosystem (38.11); and the combination of historical records, long-term experimentation, and modern technology to investigate the snowshoe hare–lynx population cycle (36.6). The pioneering work of Rachel Carson (34.2) and Jane Goodall (35.22) is also described in Scientific Thinking modules. Modules that present data on human population (36.3, 36.9–36.11), declining biodiversity (38.1), and global climate change (38.3, 38.4) have all been updated.

# Acknowledgments

This Eighth Edition of *Campbell Biology: Concepts & Connections* is a result of the combined efforts of many talented and hardworking people, and the authors wish to extend heartfelt thanks to all those who contributed to this and previous editions. Our work on this edition was shaped by input from the biologists acknowledged in the reviewer list on pages xx–xxii, who shared with us their experiences teaching introductory biology and provided specific suggestions for improving the book. Feedback from the authors of this edition's supplements and the unsolicited comments and suggestions we received from many biologists and biology students were also extremely helpful. In addition, this book has benefited in countless ways from the stimulating contacts we have had with the coauthors of *Campbell Biology*, Tenth Edition.

We wish to offer special thanks to the students and faculty at our teaching institutions. Marty Taylor thanks her students at Cornell University for their valuable feedback on the book. Eric Simon thanks his colleagues and friends at New England College, especially within the collegium of Natural Sciences and Mathematics, for their continued support and assistance. Jean Dickey thanks her colleagues at Clemson University for their expertise and support. And Kelly Hogan thanks her students for their enthusiasm and thanks her colleagues at the University of North Carolina, Chapel Hill, for their continued support.

We thank Paul Corey, president, Science, Business, and Technology, Pearson Higher Education. In addition, the superb publishing team for this edition was headed up by acquisitions editor Alison Rodal, with the invaluable support of editor-in-chief Beth Wilbur. We cannot thank them enough for their unstinting efforts on behalf of the book and for their commitment to excellence in biology education. We are fortunate to have had once again the contributions of executive director of development Deborah Gale and executive editorial manager Ginnie Simone Jutson. We are similarly grateful to the members of the editorial development team—Debbie Hardin, who also served as the day-to-day editorial project manager, and Susan Teahan—for their steadfast commitment to quality. We thank them for their thoroughness, hard work, and good humor; the book is far better than it would have been without their efforts. Thanks also to senior supplements project editor Susan Berge for her oversight of the supplements program and to editorial assistants Rachel Brickner, Katherine Harrison-Adcock, and Libby Reiser for the efficient and enthusiastic support they provided.

This book and all the other components of the teaching package are both attractive and pedagogically effective in large part because of the hard work and creativity of the production professionals on our team. We wish to thank managing editor Mike Early and production project manager Lori Newman. We also acknowledge copyeditor Joanna Dinsmore, proofreader Pete Shanks, and indexer Lynn Armstrong. We again thank senior photo editor Donna Kalal and photo researcher Kristin

Piljay for their contributions, as well as project manager for text permissions Alison Bruckner. S4Carlisle Publishing Services was responsible for composition, headed by senior project editor Emily Bush, with help from paging specialist Donna Healy; and Precision Graphics, headed by project manager Amanda Bickel, was responsible for rendering new and revised illustrations. We also thank manufacturing buyer Jeffrey Sargent.

We thank Gary Hespeneide for creating a beautiful and functional interior design and a stunning cover, and we are again indebted to design manager Marilyn Perry for her oversight and design leadership. The new Visualizing the Concept modules benefited from her vision, as well as from the early input of art editor Elisheva Marcus and the continuing contributions of artist Andrew Recher of Precision Graphics. Art editor Kelly Murphy envisioned the beautiful new cell art throughout the book.

The value of *Campbell Biology: Concepts & Connections* as a learning tool is greatly enhanced by the hard work and creativity of the authors of the supplements that accompany this book: Ed Zalisko (*Instructor's Guide* and *PowerPoint® Lecture Presentations*); Jean DeSaix, Tanya Smutka, Kristen Miller, and Justin Shaffer (*Test Bank*); Dana Kurpius (*Active Reading Guide*); Robert Iwan and Amaya Garcia (*Reading Quizzes* and media correlations); and Shannon Datwyler (*Clicker Questions* and *Quiz Shows*). In addition to senior supplements project editor Susan Berge, the editorial and production staff for the supplements program included supplements production project manager Jane Brundage, *PowerPoint® Lecture Presentations* editor Joanna Dinsmore, and project manager Sylvia Rebert of Progressive Publishing Alternatives. And the superlative MasteringBiology® program for this book would not exist without Lauren Fogel, Stacy Treco, Tania Mlawer, Katie Foley, Sarah Jensen, Juliana Tringali, Daniel Ross, Dario Wong, Taylor Merck, Caroline Power, and David Kokorowski and his team. And a special thanks to Sarah Young-Dualan for her thoughtful work on the Visualizing the Concepts interactive videos.

For their important roles in marketing the book, we are very grateful to senior marketing manager Ameer Mosley, executive marketing manager Lauren Harp, and vice president of marketing Christy Lesko. We also appreciate the work of the executive marketing manager for MasteringBiology®, Scott Dustan. The members of the Pearson Science sales team have continued to help us connect with biology instructors and their teaching needs, and we thank them.

Finally, we are deeply grateful to our families and friends for their support, encouragement, and patience throughout this project. Our special thanks to Paul, Dan, Maria, Armelle, and Sean (J.B.R.); Josie, Jason, Marnie, Alice, Jack, David, Paul, Ava, and Daniel (M.R.T.); Amanda, Reed, Forest, and dear friends Jamey, Nick, Jim, and Bethany (E.J.S.); Jessie and Katherine (J.L.D.); and Tracey, Vivian, Carolyn, Brian, Jake, and Lexi (K.H.)

Jane Reece, Martha Taylor, Eric Simon, Jean Dickey, and Kelly Hogan

# Reviewers

## Visualizing the Concept Review Panel, Eighth Edition

Erica Kipp, *Pace University*  
David Loring, *Johnson County Community College*  
Sheryl Love, *Temple University*  
Sukanya Subramanian, *Collin County Community College*  
Jennifer J. Yeh, *San Francisco, California*

## Reviewers of the Eighth Edition

Steven Armstrong, *Tarrant County College*  
Michael Battaglia, *Greenville Technical College*  
Lisa Bonneau, *Metropolitan Community College*  
Stephen T. Brown, *Los Angeles Mission College*  
Nancy Buschhaus, *University of Tennessee at Martin*  
Glenn Cohen, *Troy University*  
Nora Espinoza, *Clemson University*  
Karen E. Francl, *Radford University*  
Jennifer Greenwood, *University of Tennessee at Martin*  
Joel Hagen, *Radford University*  
Chris Haynes, *Shelton State Community College*  
Duane A. Hinton, *Washburn University*  
Amy Hollingsworth, *The University of Akron*  
Erica Kipp, *Pace University*  
Cindy Klevickis, *James Madison University*  
Dubear Kroening, *University of Wisconsin, Fox Valley*  
Dana Kurpius, *Elgin Community College*  
Dale Lambert, *Tarrant County College*  
David Loring, *Johnson County Community College*  
Mark Meade, *Jacksonville State University*  
John Mersfelder, *Sinclair Community College*  
Andrew Miller, *Thomas University*  
Zia Nisani, *Antelope Valley College*  
Camellia M. Okpodu, *Norfolk State University*  
James Rayburn, *Jacksonville State University*  
Ashley Rhodes, *Kansas State University*  
Lori B. Robinson, *Georgia College & State University*  
Ursula Roese, *University of New England*  
Doreen J. Schroeder, *University of St. Thomas*  
Justin Shaffer, *North Carolina A&T State University*  
Marilyn Shopper, *Johnson County Community College*  
Ayesha Siddiqui, *Schoolcraft College*  
Ashley Spring, *Brevard Community College*  
Thaxton Springfield, *St. Petersburg College*  
Linda Brooke Stabler, *University of Central Oklahoma*  
Patrick Stokley, *East Central Community College*  
Lori Tolley-Jordan, *Jacksonville State University*  
Jimmy Triplett, *Jacksonville State University*  
Lisa Weasel, *Portland State University*  
Martin Zahn, *Thomas Nelson Community College*

## Reviewers of Previous Editions

Michael Abbott, *Westminster College*  
Tanveer Abidi, *Kean University*  
Daryl Adams, *Mankato State University*

Dawn Adrian Adams, *Baylor University*  
Olushola Adeyeye, *Duquesne University*  
Shylaja Akkaraju, *Bronx Community College*  
Felix Akojie, *Paducah Community College*  
Dan Alex, *Chabot College*  
John Aliff, *Georgia Perimeter College*  
Sylvester Allred, *Northern Arizona University*  
Jane Aloi-Horlings, *Saddleback College*  
Loren Ammerman, *University of Texas at Arlington*  
Dennis Anderson, *Oklahoma City Community College*  
Marjay Anderson, *Howard University*  
Bert Atsma, *Union County College*  
Yael Avissar, *Rhode Island College*  
Gail Baker, *LaGuardia Community College*  
Caroline Ballard, *Rock Valley College*  
Andrei Barkovskii, *Georgia College and State University*  
Mark Barnby, *Ohlone College*  
Chris Barnhart, *University of San Diego*  
Stephen Barnhart, *Santa Rosa Junior College*  
William Barstow, *University of Georgia*  
Kirk A. Bartholomew, *Central Connecticut State University*  
Michael Battaglia, *Greenville Technical College*  
Gail Baughman, *Mira Costa College*  
Jane Beiswenger, *University of Wyoming*  
Tania Beliz, *College of San Mateo*  
Lisa Bellows, *North Central Texas College*  
Ernest Benfield, *Virginia Polytechnic Institute*  
Rudi Berkelhamer, *University of California, Irvine*  
Harry Bernheim, *Tufts University*  
Richard Bliss, *Yuba College*  
Lawrence Blumer, *Morehouse College*  
Dennis Bogyo, *Valdosta State University*  
Lisa K. Bonneau, *Metropolitan Community College, Blue River*  
Mehdi Borhan, *Johnson County Community College*  
Kathleen Bossy, *Bryant College*  
William Bowen, *University of Arkansas at Little Rock*  
Robert Boyd, *Auburn University*  
Bradford Boyer, *State University of New York, Suffolk County Community College*  
Paul Boyer, *University of Wisconsin*  
William Bradshaw, *Brigham Young University*  
Agnello Braganza, *Chabot College*  
James Bray, *Blackburn College*  
Peggy Brickman, *University of Georgia*  
Chris Brinegar, *San Jose State University*  
Chad Brommer, *Emory University*  
Charles Brown, *Santa Rosa Junior College*  
Carole Browne, *Wake Forest University*  
Becky Brown-Watson, *Santa Rosa Junior College*  
Delia Brownson, *University of Texas at Austin and Austin Community College*  
Michael Bucher, *College of San Mateo*  
Virginia Buckner, *Johnson County Community College*  
Joseph C. Bundy, Jr., *University of North Carolina at Greensboro*  
Ray Burton, *Germanna Community College*

Warren Buss, *University of Northern Colorado*  
Linda Butler, *University of Texas at Austin*  
Jerry Button, *Portland Community College*  
Carolee Caffrey, *University of California, Los Angeles*  
George Cain, *University of Iowa*  
Beth Campbell, *Itawamba Community College*  
John Campbell, *Northern Oklahoma College*  
John Capeheart, *University of Houston, Downtown*  
James Cappuccino, *Rockland Community College*  
M. Carabelli, *Broward Community College*  
Jocelyn Cash, *Central Piedmont Community College*  
Cathryn Cates, *Tyler Junior College*  
Russell Centanni, *Boise State University*  
David Chambers, *Northeastern University*  
Ruth Chesnut, *Eastern Illinois University*  
Vic Chow, *San Francisco City College*  
Van Christman, *Ricks College*  
Craig Clifford, *Northeastern State University, Tahlequah*  
Richard Cobb, *South Maine Community College*  
Mary Colavito, *Santa Monica College*  
Jennifer Cooper, *Itawamba Community College*  
Bob Cowling, *Ouachita Technical College*  
Don Cox, *Miami University*  
Robert Creek, *Western Kentucky University*  
Hillary Cressey, *George Mason University*  
Norma Criley, *Illinois Wesleyan University*  
Jessica Crowe, *South Georgia College*  
Mitch Cruzan, *Portland State University*  
Judy Daniels, *Monroe Community College*  
Michael Davis, *Central Connecticut State University*  
Pat Davis, *East Central Community College*  
Lewis Deaton, *University of Louisiana*  
Lawrence DeFilippi, *Lurleen B. Wallace College*  
James Dekloe, *Solano Community College*  
Veronique Delesalle, *Gettysburg College*  
Loren Denney, *Southwest Missouri State University*  
Jean DeSaix, *University of North Carolina at Chapel Hill*  
Mary Dettman, *Seminole Community College of Florida*  
Kathleen Diamond, *College of San Mateo*  
Alfred Diboll, *Macon College*  
Jean Dickey, *Clemson University*  
Stephen Dina, *St. Louis University*  
Robert P. Donaldson, *George Washington University*  
Gary Donnermeyer, *Iowa Central Community College*  
Charles Duggins, *University of South Carolina*  
Susan Dunford, *University of Cincinnati*  
Lee Edwards, *Greenville Technical College*  
Betty Eidemiller, *Lamar University*  
Jamin Eisenbach, *Eastern Michigan University*  
Norman Ellstrand, *University of California, Riverside*  
Thomas Emmel, *University of Florida*  
Cindy Erwin, *City College of San Francisco*  
Gerald Esch, *Wake Forest University*  
David Essar, *Winona State University*



Cory Etchberger, *Longview Community College*  
Nancy Eyster-Smith, *Bentley College*  
William Ezell, *University of North Carolina at Pembroke*  
Laurie Faber, *Grand Rapids Community College*  
Terence Farrell, *Stetson University*  
Shannon Kuchel Fehlberg, *Colorado Christian University*  
Jerry Feldman, *University of California, Santa Cruz*  
Eugene Fenster, *Longview Community College*  
Dino Fiabane, *Community College of Philadelphia*  
Kathleen Fisher, *San Diego State University*  
Edward Fliss, *St. Louis Community College, Florissant Valley*  
Linda Flora, *Montgomery County Community College*  
Dennis Forsythe, *The Citadel Military College of South Carolina*  
Robert Frankis, *College of Charleston*  
James French, *Rutgers University*  
Bernard Frye, *University of Texas at Arlington*  
Anne Galbraith, *University of Wisconsin*  
Robert Galbraith, *Crafton Hills College*  
Rosa Gambier, *State University of New York, Suffolk County Community College*  
George Garcia, *University of Texas at Austin*  
Linda Gardner, *San Diego Mesa College*  
Sandi Gardner, *Triton College*  
Gail Gasparich, *Towson University*  
Janet Gaston, *Troy University*  
Shelley Gaudia, *Lane Community College*  
Douglas Gayou, *University of Missouri at Columbia*  
Robert Gendron, *Indiana University of Pennsylvania*  
Bagie George, *Georgia Gwinnett College*  
Rebecca German, *University of Cincinnati*  
Grant Gerrish, *University of Hawaii*  
Julie Gibbs, *College of DuPage*  
Frank Gilliam, *Marshall University*  
Patricia Glas, *The Citadel Military College of South Carolina*  
David Glenn-Lewin, *Wichita State University*  
Robert Grammer, *Belmont University*  
Laura Grayson-Roselli, *Burlington County College*  
Peggy Green, *Broward Community College*  
Miriam L. Greenberg, *Wayne State University*  
Sylvia Greer, *City University of New York*  
Eileen Gregory, *Rollins College*  
Dana Griffin, *University of Florida*  
Richard Groover, *J. Sargeant Reynolds Community College*  
Peggy Guthrie, *University of Central Oklahoma*  
Maggie Haag, *University of Alberta*  
Richard Haas, *California State University, Fresno*  
Martin Hahn, *William Paterson College*  
Leah Haimo, *University of California, Riverside*  
James Hampton, *Salt Lake Community College*  
Blanche Haning, *North Carolina State University*  
Richard Hanke, *Rose State College*  
Laszlo Hanzely, *Northern Illinois University*  
David Harbster, *Paradise Valley Community College*  
Sig Harden, *Troy University Montgomery*  
Reba Harrell, *Hinds Community College*  
Jim Harris, *Utah Valley Community College*  
Mary Harris, *Louisiana State University*  
Chris Haynes, *Shelton State Community College*  
Janet Haynes, *Long Island University*  
Jean Helgeson, *Collin County Community College*  
Ira Herskowitz, *University of California, San Francisco*  
Paul Hertz, *Barnard College*  
Margaret Hicks, *David Lipscomb University*  
Jean Higgins-Fonda, *Prince George's Community College*  
Phyllis Hirsch, *East Los Angeles College*  
William Hixon, *St. Ambrose University*  
Carl Hoagstrom, *Ohio Northern University*  
Kim Hodgson, *Longwood College*  
Jon Hoekstra, *Gainesville State College*  
Kelly Hogan, *University of North Carolina at Chapel Hill*  
John Holt, *Michigan State University*  
Laura Hoopes, *Occidental College*  
Lauren Howard, *Norwich University*  
Robert Howe, *Suffolk University*  
Michael Hudecki, *State University of New York, Buffalo*  
George Hudock, *Indiana University*  
Kris Hueftle, *Pensacola Junior College*  
Barbara Hunnicutt, *Seminole Community College*  
Brenda Hunzinger, *Lake Land College*  
Catherine Hurlbut, *Florida Community College*  
Charles Ide, *Tulane University*  
Mark Ikeda, *San Bernardino Valley College*  
Georgia Ineichen, *Hinds Community College*  
Robert Iwan, *Inver Hills Community College*  
Mark E. Jackson, *Central Connecticut State University*  
Charles Jacobs, *Henry Ford Community College*  
Fred James, *Presbyterian College*  
Ursula Jander, *Washburn University*  
Alan Jaworski, *University of Georgia*  
R. Jensen, *Saint Mary's College*  
Robert Johnson, *Pierce College, Lakewood Campus*  
Roishene Johnson, *Bossier Parish Community College*  
Russell Johnson, *Ricks College*  
John C. Jones, *Calhoun Community College*  
Florence Juillerat, *Indiana University at Indianapolis*  
Tracy Kahn, *University of California, Riverside*  
Hinrich Kaiser, *Victor Valley College*  
Klaus Kalthoff, *University of Texas at Austin*  
Tom Kantz, *California State University, Sacramento*  
Jennifer Katcher, *Pima Community College*  
Judy Kaufman, *Monroe Community College*  
Marlene Kayne, *The College of New Jersey*  
Mahlon Kelly, *University of Virginia*  
Kenneth Kerrick, *University of Pittsburgh at Johnstown*  
Joyce Kille-Marino, *College of Charleston*  
Joanne Kilpatrick, *Auburn University, Montgomery*  
Stephen Kilpatrick, *University of Pittsburgh at Johnstown*  
Lee Kirkpatrick, *Glendale Community College*  
Peter Kish, *Southwestern Oklahoma State University*  
Cindy Klevickis, *James Madison University*  
Robert Koch, *California State University, Fullerton*  
Eliot Krause, *Seton Hall University*  
Dubear Kroening, *University of Wisconsin, Fox Valley*  
Kevin Krown, *San Diego State University*  
Margaret Maile Lam, *Kapiolani Community College*  
MaryLynne LaMantia, *Golden West College*  
Mary Rose Lamb, *University of Puget Sound*  
Dale Lambert, *Tarrant County College, Northeast*  
Thomas Lammers, *University of Wisconsin, Oshkosh*  
Carmine Lanciani, *University of Florida*  
Vic Landrum, *Washburn University*  
Deborah Langsam, *University of North Carolina at Charlotte*  
Geneen Lannom, *University of Central Oklahoma*  
Brenda Latham, *Merced College*  
Liz Lawrence, *Miles Community College*  
Steven Lebsack, *Linn-Benton Community College*  
Karen Lee, *University of Pittsburgh at Johnstown*  
Tom Lehman, *Morgan Community College*  
William Lemon, *Southwestern Oregon Community College*  
Laurie M. Len, *El Camino College*  
Peggy Lepley, *Cincinnati State University*  
Richard Liebaert, *Linn-Benton Community College*  
Kevin Lien, *Portland Community College*  
Harvey Liftin, *Broward Community College*  
Ivo Lindauer, *University of Northern Colorado*  
William Lindsay, *Monterey Peninsula College*  
Kirsten Lindstrom, *Santa Rosa Junior College*  
Melanie Loo, *California State University, Sacramento*  
David Loring, *Johnson County Community College*  
Eric Lovely, *Arkansas Tech University*  
Paul Lurquin, *Washington State University*  
James Mack, *Monmouth University*  
David Magrane, *Morehead State University*  
Joan Maloof, *Salisbury State University*  
Joseph Marshall, *West Virginia University*  
Presley Martin, *Drexel University*  
William McComas, *University of Iowa*  
Steven McCullagh, *Kennesaw State College*  
Mitchell McGinnis, *North Seattle Community College*  
James McGivern, *Gannon University*  
Colleen McNamara, *Albuquerque TVI Community College*  
Caroline McNutt, *Schoolcraft College*  
Scott Meissner, *Cornell University*  
Joseph Mendelson, *Utah State University*  
Timothy Metz, *Campbell University*  
Iain Miller, *University of Cincinnati*  
Robert Miller, *University of Duquesne*  
V. Christine Minor, *Clemson University*  
Brad Mogen, *University of Wisconsin, River Falls*  
James Moné, *Millersville University*  
Jamie Moon, *University of North Florida*  
Juan Morata, *Miami Dade College*  
Richard Mortensen, *Albion College*  
Henry Mulcahy, *Suffolk University*  
Christopher Murphy, *James Madison University*  
Kathryn Nette, *Cuyamaca College*  
James Newcomb, *New England College*  
Zia Nisani, *Antelope Valley College*  
James Nivison, *Mid Michigan Community College*  
Peter Nordloh, *Southeastern Community College*  
Stephen Novak, *Boise State University*  
Bette Nybakken, *Hartnell College*  
Michael O'Donnell, *Trinity College*  
Steven Oliver, *Worcester State College*  
Karen Olmstead, *University of South Dakota*

Steven O'Neal, *Southwestern Oklahoma State University*  
Lowell Orr, *Kent State University*  
William Outlaw, *Florida State University*  
Phillip Pack, *Woodbury University*  
Kevin Padian, *University of California, Berkeley*  
Kay Pauling, *Foothill College*  
Mark Paulissen, *Northeastern State University, Tahlequah*  
Debra Pearce, *Northern Kentucky University*  
David Pearson, *Bucknell University*  
Patricia Pearson, *Western Kentucky University*  
Kathleen Pelkki, *Saginaw Valley State University*  
Andrew Penniman, *Georgia Perimeter College*  
John Peters, *College of Charleston*  
Gary Peterson, *South Dakota State University*  
Margaret Peterson, *Concordia Lutheran College*  
Russell L. Peterson, *Indiana University of Pennsylvania*  
Paula Piehl, *Potomac State College*  
Ben Pierce, *Baylor University*  
Jack Plaggemeyer, *Little Big Horn College*  
Barbara Pleasants, *Iowa State University*  
Kathryn Podwall, *Nassau Community College*  
Judith Pottmeyer, *Columbia Basin College*  
Donald Potts, *University of California, Santa Cruz*  
Nirmala Prabhu, *Edison Community College*  
Elena Pravosudova, *University of Nevada, Reno*  
James Pru, *Belleville Area College*  
Rongsun Pu, *Kean University*  
Charles Pumpuni, *Northern Virginia Community College*  
Kimberly Puvalowski, *Old Bridge High School*  
Rebecca Pyles, *East Tennessee State University*  
Shanmugavel Rajendran, *Baltimore City Community College*  
Bob Ratterman, *Jamestown Community College*  
Jill Raymond, *Rock Valley College*  
Michael Read, *Germanna Community College*  
Brian Reeder, *Morehead State University*  
Bruce Reid, *Kean College*  
David Reid, *Blackburn College*  
Stephen Reinbold, *Longview Community College*  
Erin Rempala, *San Diego Mesa College*  
Michael Renfroe, *James Madison University*  
Tim Revell, *Mt. San Antonio College*  
Douglas Reynolds, *Central Washington University*  
Fred Rhoades, *Western Washington University*  
John Rinehart, *Eastern Oregon University*  
Laura Ritt, *Burlington County College*  
Lynn Rivers, *Henry Ford Community College*  
Bruce Robart, *University of Pittsburgh at Johnstown*  
Jennifer Roberts, *Lewis University*  
Laurel Roberts, *University of Pittsburgh*  
Luis A. Rodriguez, *San Antonio Colleges*  
Duane Rohlfing, *University of South Carolina*  
Jeanette Rollinger, *College of the Sequoias*

Steven Roof, *Fairmont State College*  
Jim Rosowski, *University of Nebraska*  
Stephen Rothstein, *University of California, Santa Barbara*  
Donald Roush, *University of North Alabama*  
Lynette Rushton, *South Puget Sound Community College*  
Connie Rye, *East Mississippi Community College*  
Linda Sabatino, *State University of New York, Suffolk County Community College*  
David Schamel, *University of Alaska, Fairbanks*  
Douglas Schelhaas, *University of Mary*  
Beverly Schieltz, *Wright State University*  
Fred Schindler, *Indian Hills Community College*  
Robert Schoch, *Boston University*  
Brian Scholtens, *College of Charleston*  
John Richard Schrock, *Emporia State University*  
Julie Schroer, *Bismarck State College*  
Fayla Schwartz, *Everett Community College*  
Judy Shea, *Kutztown University of Pennsylvania*  
Daniela Shebitz, *Kean University*  
Thomas Shellberg, *Henry Ford Community College*  
Cara Shillington, *Eastern Michigan University*  
Lisa Shimeld, *Crafton Hills College*  
Brian Shmaefsky, *Kingwood College*  
Mark Shotwell, *Slippery Rock University*  
Jane Shoup, *Purdue University*  
Michele Shuster, *New Mexico State University*  
Linda Simpson, *University of North Carolina at Charlotte*  
Gary Smith, *Tarrant County Junior College*  
Marc Smith, *Sinclair Community College*  
Michael Smith, *Western Kentucky University*  
Phil Snider, *University of Houston*  
Sam C. Sochet, *Thomas Edison Career and Technical Education High School*  
Gary Sojka, *Bucknell University*  
Ralph Sorensen, *Gettysburg College*  
Ruth Sporer, *Rutgers University*  
Linda Brooke Stabler, *University of Central Oklahoma*  
David Stanton, *Saginaw Valley State University*  
Amanda Starnes, *Emory University*  
John Stolz, *Duquesne University*  
Ross Strayer, *Washtenaw Community College*  
Donald Streuble, *Idaho State University*  
Megan Stringer, *Jones County Junior College*  
Mark Sugalski, *New England College*  
Gerald Summers, *University of Missouri*  
Marshall Sundberg, *Louisiana State University*  
Christopher Tabit, *University of West Georgia*  
David Tauck, *Santa Clara University*  
Hilda Taylor, *Acadia University*  
Franklin Te, *Miami Dade College*  
Gene Thomas, *Solano Community College*  
Kenneth Thomas, *Northern Essex Community College*

Kathy Thompson, *Louisiana State University*  
Laura Thurlow, *Jackson Community College*  
Anne Tokazewski, *Burlington County College*  
John Tolli, *Southwestern College*  
Bruce Tomlinson, *State University of New York, Fredonia*  
Nancy Tress, *University of Pittsburgh at Titusville*  
Donald Trisel, *Fairmont State College*  
Kimberly Turk, *Mitchell Community College*  
Virginia Turner, *Harper College*  
Mike Tveten, *Pima College*  
Michael Twaddle, *University of Toledo*  
Rani Vajravelu, *University of Central Florida*  
Leslie VanderMolen, *Humboldt State University*  
Cinnamon VanPutte, *Southwestern Illinois College*  
Sarah VanVickle-Chavez, *Washington University*  
John Vaughan, *Georgetown College*  
Martin Vaughan, *Indiana University*  
Mark Venable, *Appalachian State University*  
Ann Vernon, *St. Charles County Community College*  
Rukmani Viswanath, *Laredo Community College*  
Frederick W. Vogt, *Elgin Community College*  
Mary Beth Voltura, *State University of New York, Cortland*  
Jerry Waldvogel, *Clemson University*  
Robert Wallace, *Ripon College*  
Dennis Walsh, *MassBay Community College*  
Patricia Walsh, *University of Delaware*  
Lisa Weasel, *Portland State University*  
James Wee, *Loyola University*  
Harrington Wells, *University of Tulsa*  
Jennifer Wiatrowski, *Pasco-Hernando Community College*  
Larry Williams, *University of Houston*  
Ray S. Williams, *Appalachian State University*  
Lura Williamson, *University of New Orleans*  
Sandra Winicur, *Indiana University, South Bend*  
Robert R. Wise, *University of Wisconsin Oshkosh*  
Mary E. Wisgirda, *San Jacinto College*  
Mary Jo Witz, *Monroe Community College*  
Neil Woffinden, *University of Pittsburgh at Johnstown*  
Michael Womack, *Macon State University*  
Patrick Woolley, *East Central College*  
Maury Wrightson, *Germanna Community College*  
Tumen Wuliji, *University of Nevada, Reno*  
Mark Wygoda, *McNeese State University*  
Tony Yates, *Seminole State College*  
William Yurkiewicz, *Millersville University of Pennsylvania*  
Gregory Zagursky, *Radford University*  
Martin Zahn, *Thomas Nelson Community College*  
Edward J. Zalisko, *Blackburn College*  
David Zeigler, *University of North Carolina at Pembroke*  
Uko Zylstra, *Calvin College*



# Detailed Contents

## 1 Biology: Exploring Life 1

### ▶ Themes in the Study of Biology 2

- 1.1 All forms of life share common properties 2
- 1.2 In life's hierarchy of organization, new properties emerge at each level 3
- 1.3 Cells are the structural and functional units of life 4
- 1.4 Organisms interact with their environment, exchanging matter and energy 5



### ▶ Evolution, the Core Theme of Biology 6

- 1.5 The unity of life is based on DNA and a common genetic code 6
- 1.6 The diversity of life can be arranged into three domains 6
- 1.7 Evolution explains the unity and diversity of life 8

### ▶ The Process of Science 10

- 1.8 In studying nature, scientists make observations and form and test hypotheses 10
- 1.9 **SCIENTIFIC THINKING** Hypotheses can be tested using controlled field studies 11

### ▶ Biology and Everyday Life 12

- 1.10 **EVOLUTION CONNECTION** Evolution is connected to our everyday lives 12
- 1.11 **CONNECTION** Biology, technology, and society are connected in important ways 12

Chapter Review 13

## UNIT I

## The Life of the Cell 15

## 2 The Chemical Basis of Life 16

### ▶ Elements, Atoms, and Compounds 18

- 2.1 Organisms are composed of elements, in combinations called compounds 18
- 2.2 **CONNECTION** Trace elements are common additives to food and water 19
- 2.3 Atoms consist of protons, neutrons, and electrons 20
- 2.4 **CONNECTION** Radioactive isotopes can help or harm us 21



### ▶ Chemical Bonds 22

- 2.5 The distribution of electrons determines an atom's chemical properties 22
- 2.6 Covalent bonds join atoms into molecules through electron sharing 23
- 2.7 Ionic bonds are attractions between ions of opposite charge 24
- 2.8 Hydrogen bonds are weak bonds important in the chemistry of life 24
- 2.9 Chemical reactions make and break chemical bonds 25

### ▶ Water's Life-Supporting Properties 26

- 2.10 Hydrogen bonds make liquid water cohesive 26
- 2.11 Water's hydrogen bonds moderate temperature 26
- 2.12 Ice floats because it is less dense than liquid water 27
- 2.13 Water is the solvent of life 27
- 2.14 The chemistry of life is sensitive to acidic and basic conditions 28
- 2.15 **SCIENTIFIC THINKING** Scientists study the effects of rising atmospheric CO<sub>2</sub> on coral reef ecosystems 28
- 2.16 **EVOLUTION CONNECTION** The search for extraterrestrial life centers on the search for water 29

Chapter Review 30

## 3 The Molecules of Cells 32

### ▶ Introduction to Organic Compounds 34

- 3.1 Life's molecular diversity is based on the properties of carbon 34
- 3.2 A few chemical groups are key to the functioning of biological molecules 35
- 3.3 Cells make large molecules from a limited set of small molecules 36



### ▶ Carbohydrates 37

- 3.4 Monosaccharides are the simplest carbohydrates 37
- 3.5 Two monosaccharides are linked to form a disaccharide 38
- 3.6 **CONNECTION** What is high-fructose corn syrup, and is it to blame for obesity? 38
- 3.7 Polysaccharides are long chains of sugar units 39

### ▶ Lipids 40

- 3.8 Fats are lipids that are mostly energy-storage molecules 40
- 3.9 **SCIENTIFIC THINKING** Scientific studies document the health risks of trans fats 41
- 3.10 Phospholipids and steroids are important lipids with a variety of functions 42
- 3.11 **CONNECTION** Anabolic steroids pose health risks 42

## ▶ Proteins 43

- 3.12 Proteins have a wide range of functions and structures 43
- 3.13 Proteins are made from amino acids linked by peptide bonds 44
- 3.14 **VISUALIZING THE CONCEPT** A protein's functional shape results from four levels of structure 45

## ▶ Nucleic Acids 46

- 3.15 DNA and RNA are the two types of nucleic acids 46
- 3.16 Nucleic acids are polymers of nucleotides 46
- 3.17 **EVOLUTION CONNECTION** Lactose tolerance is a recent event in human evolution 47

Chapter Review 48

# 4 A Tour of the Cell 50

## ▶ Introduction to the Cell 52

- 4.1 Microscopes reveal the world of the cell 52
- 4.2 The small size of cells relates to the need to exchange materials across the plasma membrane 54
- 4.3 Prokaryotic cells are structurally simpler than eukaryotic cells 55
- 4.4 Eukaryotic cells are partitioned into functional compartments 56



## ▶ The Nucleus and Ribosomes 58

- 4.5 The nucleus contains the cell's genetic instructions 58
- 4.6 Ribosomes make proteins for use in the cell and for export 59

## ▶ The Endomembrane System 59

- 4.7 Many organelles are connected in the endomembrane system 59
- 4.8 The endoplasmic reticulum is a biosynthetic workshop 60
- 4.9 The Golgi apparatus modifies, sorts, and ships cell products 61
- 4.10 Lysosomes are digestive compartments within a cell 62
- 4.11 Vacuoles function in the general maintenance of the cell 62
- 4.12 A review of the structures involved in manufacturing and breakdown 63

## ▶ Energy-Converting Organelles 63

- 4.13 Mitochondria harvest chemical energy from food 63
- 4.14 Chloroplasts convert solar energy to chemical energy 64
- 4.15 **EVOLUTION CONNECTION** Mitochondria and chloroplasts evolved by endosymbiosis 64

## ▶ The Cytoskeleton and Cell Surfaces 65

- 4.16 The cell's internal skeleton helps organize its structure and activities 65

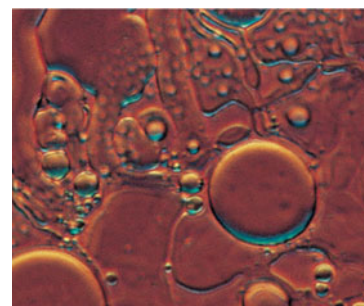
- 4.17 **SCIENTIFIC THINKING** Scientists discovered the cytoskeleton using the tools of biochemistry and microscopy 66
- 4.18 Cilia and flagella move when microtubules bend 66
- 4.19 The extracellular matrix of animal cells functions in support and regulation 67
- 4.20 Three types of cell junctions are found in animal tissues 68
- 4.21 Cell walls enclose and support plant cells 68
- 4.22 Review: Eukaryotic cell structures can be grouped on the basis of four main functions 69

Chapter Review 70

# 5 The Working Cell 72

## ▶ Membrane Structure and Function 74

- 5.1 **VISUALIZING THE CONCEPT** Membranes are fluid mosaics of lipids and proteins with many functions 74
- 5.2 **EVOLUTION CONNECTION** The spontaneous formation of membranes was a critical step in the origin of life 75
- 5.3 Passive transport is diffusion across a membrane with no energy investment 75
- 5.4 Osmosis is the diffusion of water across a membrane 76
- 5.5 Water balance between cells and their surroundings is crucial to organisms 76
- 5.6 Transport proteins can facilitate diffusion across membranes 77
- 5.7 **SCIENTIFIC THINKING** Research on another membrane protein led to the discovery of aquaporins 78
- 5.8 Cells expend energy in the active transport of a solute 78
- 5.9 Exocytosis and endocytosis transport large molecules across membranes 79



## ▶ Energy and the Cell 80

- 5.10 Cells transform energy as they perform work 80
- 5.11 Chemical reactions either release or store energy 81
- 5.12 ATP drives cellular work by coupling exergonic and endergonic reactions 82

## ▶ How Enzymes Function 83

- 5.13 Enzymes speed up the cell's chemical reactions by lowering energy barriers 83
- 5.14 A specific enzyme catalyzes each cellular reaction 84
- 5.15 Enzyme inhibition can regulate enzyme activity in a cell 85
- 5.16 **CONNECTION** Many drugs, pesticides, and poisons are enzyme inhibitors 85

Chapter Review 86



## 6 How Cells Harvest Chemical Energy 88

### ▶ Cellular Respiration: Aerobic Harvesting of Energy 90

- 6.1 Photosynthesis and cellular respiration provide energy for life 90
- 6.2 Breathing supplies  $O_2$  for use in cellular respiration and removes  $CO_2$  90
- 6.3 Cellular respiration banks energy in ATP molecules 91
- 6.4 **CONNECTION** The human body uses energy from ATP for all its activities 91
- 6.5 Cells capture energy from electrons “falling” from organic fuels to oxygen 92

### ▶ Stages of Cellular Respiration 93

- 6.6 Overview: Cellular respiration occurs in three main stages 93
- 6.7 Glycolysis harvests chemical energy by oxidizing glucose to pyruvate 94
- 6.8 Pyruvate is oxidized in preparation for the citric acid cycle 96
- 6.9 The citric acid cycle completes the oxidation of organic molecules, generating many NADH and  $FADH_2$  molecules 96
- 6.10 Most ATP production occurs by oxidative phosphorylation 98
- 6.11 **SCIENTIFIC THINKING** Scientists have discovered heat-producing, calorie-burning brown fat in adults 99
- 6.12 Review: Each molecule of glucose yields many molecules of ATP 100

### ▶ Fermentation: Anaerobic Harvesting of Energy 100

- 6.13 Fermentation enables cells to produce ATP without oxygen 100
- 6.14 **EVOLUTION CONNECTION** Glycolysis evolved early in the history of life on Earth 102

### ▶ Connections Between Metabolic Pathways 102

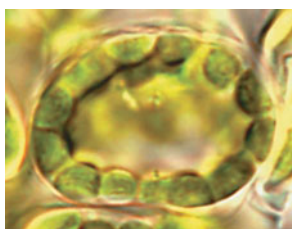
- 6.15 Cells use many kinds of organic molecules as fuel for cellular respiration 102
- 6.16 Organic molecules from food provide raw materials for biosynthesis 103

Chapter Review 104

## 7 Photosynthesis: Using Light to Make Food 106

### ▶ An Introduction to Photosynthesis 108

- 7.1 Photosynthesis fuels the biosphere 108
- 7.2 Photosynthesis occurs in chloroplasts in plant cells 109



- 7.3 Scientists traced the process of photosynthesis using isotopes 110
- 7.4 Photosynthesis is a redox process, as is cellular respiration 110
- 7.5 The two stages of photosynthesis are linked by ATP and NADPH 111

### ▶ The Light Reactions: Converting Solar Energy to Chemical Energy 112

- 7.6 Visible radiation absorbed by pigments drives the light reactions 112
- 7.7 Photosystems capture solar energy 113
- 7.8 Two photosystems connected by an electron transport chain generate ATP and NADPH 114
- 7.9 **VISUALIZING THE CONCEPT** The light reactions take place within the thylakoid membranes 115

### ▶ The Calvin Cycle: Reducing $CO_2$ to Sugar 116

- 7.10 ATP and NADPH power sugar synthesis in the Calvin cycle 116
- 7.11 **EVOLUTION CONNECTION** Other methods of carbon fixation have evolved in hot, dry climates 117

### ▶ The Global Significance of Photosynthesis 118

- 7.12 Photosynthesis makes sugar from  $CO_2$  and  $H_2O$ , providing food and  $O_2$  for almost all living organisms 118
- 7.13 **SCIENTIFIC THINKING** Rising atmospheric levels of carbon dioxide and global climate change will affect plants in various ways 119
- 7.14 Scientific research and international treaties have helped slow the depletion of Earth's ozone layer 120

Chapter Review 121

## UNIT II

# Cellular Reproduction and Genetics 123

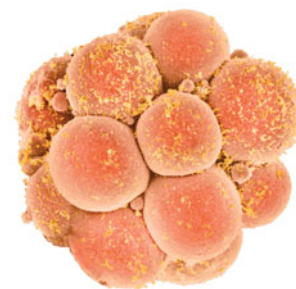
## 8 The Cellular Basis of Reproduction and Inheritance 124

### ▶ Cell Division and Reproduction 126

- 8.1 Cell division plays many important roles in the lives of organisms 126
- 8.2 Prokaryotes reproduce by binary fission 127

### ▶ The Eukaryotic Cell Cycle and Mitosis 128

- 8.3 The large, complex chromosomes of eukaryotes duplicate with each cell division 128
- 8.4 The cell cycle includes growing and division phases 129
- 8.5 Cell division is a continuum of dynamic changes 130



- 8.6 Cytokinesis differs for plant and animal cells 132
- 8.7 Anchorage, cell density, and chemical growth factors affect cell division 133
- 8.8 Growth factors signal the cell cycle control system 134
- 8.9 **CONNECTION** Growing out of control, cancer cells produce malignant tumors 135
- 8.10 **SCIENTIFIC THINKING** Tailoring treatment to each patient may improve cancer therapy 136

### ▷ Meiosis and Crossing Over 136

- 8.11 Chromosomes are matched in homologous pairs 136
- 8.12 Gametes have a single set of chromosomes 137
- 8.13 Meiosis reduces the chromosome number from diploid to haploid 138
- 8.14 **VISUALIZING THE CONCEPT** Mitosis and meiosis have important similarities and differences 140
- 8.15 Independent orientation of chromosomes in meiosis and random fertilization lead to varied offspring 141
- 8.16 Homologous chromosomes may carry different versions of genes 142
- 8.17 Crossing over further increases genetic variability 142

### ▷ Alterations of Chromosome Number and Structure 144

- 8.18 Accidents during meiosis can alter chromosome number 144
- 8.19 A karyotype is a photographic inventory of an individual's chromosomes 145
- 8.20 **CONNECTION** An extra copy of chromosome 21 causes Down syndrome 146
- 8.21 **CONNECTION** Abnormal numbers of sex chromosomes do not usually affect survival 147
- 8.22 **EVOLUTION CONNECTION** New species can arise from errors in cell division 147
- 8.23 **CONNECTION** Alterations of chromosome structure can cause birth defects and cancer 148

Chapter Review 149

## 9 Patterns of Inheritance 152

### ▷ Mendel's Laws 154

- 9.1 The study of genetics has ancient roots 154
- 9.2 The science of genetics began in an abbey garden 154
- 9.3 Mendel's law of segregation describes the inheritance of a single character 156
- 9.4 Homologous chromosomes bear the alleles for each character 157
- 9.5 The law of independent assortment is revealed by tracking two characters at once 158
- 9.6 Geneticists can use a testcross to determine unknown genotypes 159
- 9.7 Mendel's laws reflect the rules of probability 160
- 9.8 **VISUALIZING THE CONCEPT** Genetic traits in humans can be tracked through family pedigrees 161
- 9.9 **CONNECTION** Many inherited traits in humans are controlled by a single gene 162



- 9.10 **CONNECTION** New technologies can provide insight into one's genetic legacy 164

### ▷ Variations on Mendel's Laws 166

- 9.11 Incomplete dominance results in intermediate phenotypes 166
- 9.12 Many genes have more than two alleles in the population 167
- 9.13 A single gene may affect many phenotypic characters 168
- 9.14 A single character may be influenced by many genes 169
- 9.15 The environment affects many characters 170

### ▷ The Chromosomal Basis of Inheritance 170

- 9.16 Chromosome behavior accounts for Mendel's laws 170
- 9.17 **SCIENTIFIC THINKING** Genes on the same chromosome tend to be inherited together 172
- 9.18 Crossing over produces new combinations of alleles 172
- 9.19 Geneticists use crossover data to map genes 174

### ▷ Sex Chromosomes and Sex-Linked Genes 174

- 9.20 Chromosomes determine sex in many species 174
- 9.21 Sex-linked genes exhibit a unique pattern of inheritance 176
- 9.22 **CONNECTION** Human sex-linked disorders affect mostly males 177
- 9.23 **EVOLUTION CONNECTION** The Y chromosome provides clues about human male evolution 177

Chapter Review 178

## 10 Molecular Biology of the Gene 180

### ▷ The Structure of the Genetic Material 182

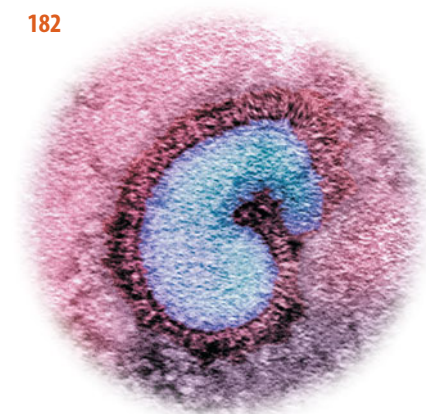
- 10.1 **SCIENTIFIC THINKING** Experiments showed that DNA is the genetic material 182
- 10.2 DNA and RNA are polymers of nucleotides 184
- 10.3 DNA is a double-stranded helix 186

### ▷ DNA Replication 188

- 10.4 DNA replication depends on specific base pairing 188
- 10.5 DNA replication proceeds in two directions at many sites simultaneously 188

### ▷ The Flow of Genetic Information from DNA to RNA to Protein 190

- 10.6 Genes control phenotypic traits through the expression of proteins 190
- 10.7 Genetic information written in codons is translated into amino acid sequences 191
- 10.8 The genetic code dictates how codons are translated into amino acids 192
- 10.9 **VISUALIZING THE CONCEPT** Transcription produces genetic messages in the form of RNA 193



- 10.10 Eukaryotic RNA is processed before leaving the nucleus as mRNA 194
- 10.11 Transfer RNA molecules serve as interpreters during translation 194
- 10.12 Ribosomes build polypeptides 196
- 10.13 An initiation codon marks the start of an mRNA message 196
- 10.14 Elongation adds amino acids to the polypeptide chain until a stop codon terminates translation 197
- 10.15 Review: The flow of genetic information in the cell is DNA → RNA → protein 198
- 10.16 Mutations can affect genes 199

### ▶ The Genetics of Viruses and Bacteria 200

- 10.17 Viral DNA may become part of the host chromosome 200
- 10.18 CONNECTION Many viruses cause disease in animals and plants 201
- 10.19 EVOLUTION CONNECTION Emerging viruses threaten human health 202
- 10.20 The AIDS virus makes DNA on an RNA template 203
- 10.21 Viroids and prions are formidable pathogens in plants and animals 203
- 10.22 Bacteria can transfer DNA in three ways 204
- 10.23 Bacterial plasmids can serve as carriers for gene transfer 205

Chapter Review 206

## 11 How Genes Are Controlled 208

### ▶ Control of Gene Expression 210

- 11.1 Proteins interacting with DNA turn prokaryotic genes on or off in response to environmental changes 210
- 11.2 Chromosome structure and chemical modifications can affect gene expression 212
- 11.3 Complex assemblies of proteins control eukaryotic transcription 214
- 11.4 Eukaryotic RNA may be spliced in more than one way 214
- 11.5 Small RNAs play multiple roles in controlling gene expression 215
- 11.6 Later stages of gene expression are also subject to regulation 216
- 11.7 VISUALIZING THE CONCEPT Multiple mechanisms regulate gene expression in eukaryotes 217
- 11.8 Cell signaling and waves of gene expression direct animal development 218
- 11.9 CONNECTION Scientists use DNA microarrays to test for the transcription of many genes at once 219
- 11.10 Signal transduction pathways convert messages received at the cell surface to responses within the cell 220
- 11.11 EVOLUTION CONNECTION Cell-signaling systems appeared early in the evolution of life 220



### ▶ Cloning of Plants and Animals 221

- 11.12 Plant cloning shows that differentiated cells may retain all of their genetic potential 221
- 11.13 SCIENTIFIC THINKING Biologists can clone animals via nuclear transplantation 222
- 11.14 CONNECTION Therapeutic cloning can produce stem cells with great medical potential 223

### ▶ The Genetic Basis of Cancer 224

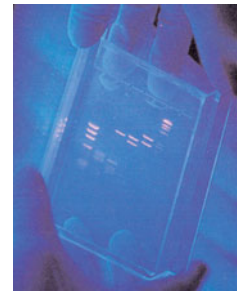
- 11.15 Cancer results from mutations in genes that control cell division 224
- 11.16 Multiple genetic changes underlie the development of cancer 225
- 11.17 Faulty proteins can interfere with normal signal transduction pathways 226
- 11.18 CONNECTION Lifestyle choices can reduce the risk of cancer 227

Chapter Review 228

## 12 DNA Technology and Genomics 230

### ▶ Gene Cloning 232

- 12.1 Genes can be cloned in recombinant plasmids 232
- 12.2 VISUALIZING THE CONCEPT Enzymes are used to “cut and paste” DNA 234
- 12.3 Cloned genes can be stored in genomic libraries 235
- 12.4 Reverse transcriptase can help make genes for cloning 235
- 12.5 Nucleic acid probes identify clones carrying specific genes 236



### ▶ Genetically Modified Organisms 236

- 12.6 Recombinant cells and organisms can mass-produce gene products 236
- 12.7 CONNECTION DNA technology has changed the pharmaceutical industry and medicine 238
- 12.8 CONNECTION Genetically modified organisms are transforming agriculture 239
- 12.9 SCIENTIFIC THINKING Genetically modified organisms raise health concerns 240
- 12.10 CONNECTION Gene therapy may someday help treat a variety of diseases 241

### ▶ DNA Profiling 242

- 12.11 The analysis of genetic markers can produce a DNA profile 242
- 12.12 The PCR method is used to amplify DNA sequences 242
- 12.13 Gel electrophoresis sorts DNA molecules by size 243
- 12.14 Short tandem repeat analysis is commonly used for DNA profiling 244
- 12.15 CONNECTION DNA profiling has provided evidence in many forensic investigations 245
- 12.16 RFLPs can be used to detect differences in DNA sequences 246



## ▶ Genomics 247

- 12.17 Genomics is the scientific study of whole genomes 247
- 12.18 **CONNECTION** The Human Genome Project revealed that most of the human genome does not consist of genes 248
- 12.19 The whole-genome shotgun method of sequencing a genome can provide a wealth of data quickly 249
- 12.20 Proteomics is the scientific study of the full set of proteins encoded by a genome 249
- 12.21 **EVOLUTION CONNECTION** Genomes hold clues to human evolution 250

Chapter Review 250

## UNIT III

# Concepts of Evolution 253

## 13 How Populations Evolve 254

### ▶ Darwin's Theory of Evolution 256

- 13.1 A sea voyage helped Darwin frame his theory of evolution 256
- 13.2 The study of fossils provides strong evidence for evolution 258
- 13.3 **SCIENTIFIC THINKING** Fossils of transitional forms support Darwin's theory of evolution 259
- 13.4 Homologies provide strong evidence for evolution 260
- 13.5 Homologies indicate patterns of descent that can be shown on an evolutionary tree 261
- 13.6 Darwin proposed natural selection as the mechanism of evolution 262
- 13.7 Scientists can observe natural selection in action 263



### ▶ The Evolution of Populations 264

- 13.8 Mutation and sexual reproduction produce the genetic variation that makes evolution possible 264
- 13.9 Evolution occurs within populations 265
- 13.10 The Hardy-Weinberg equation can test whether a population is evolving 266
- 13.11 **CONNECTION** The Hardy-Weinberg equation is useful in public health science 267

### ▶ Mechanisms of Microevolution 268

- 13.12 Natural selection, genetic drift, and gene flow can cause microevolution 268
- 13.13 Natural selection is the only mechanism that consistently leads to adaptive evolution 269
- 13.14 Natural selection can alter variation in a population in three ways 270
- 13.15 Sexual selection may lead to phenotypic differences between males and females 271

- 13.16 **EVOLUTION CONNECTION** The evolution of drug-resistant microorganisms is a serious public health concern 272
- 13.17 Diploidy and balancing selection preserve genetic variation 272
- 13.18 Natural selection cannot fashion perfect organisms 273

Chapter Review 274

## 14 The Origin of Species 276

### ▶ Defining Species 278

- 14.1 The origin of species is the source of biological diversity 278
- 14.2 There are several ways to define a species 278
- 14.3 **VISUALIZING THE CONCEPT** Reproductive barriers keep species separate 280



### ▶ Mechanisms of Speciation 282

- 14.4 In allopatric speciation, geographic isolation leads to speciation 282
- 14.5 Reproductive barriers can evolve as populations diverge 283
- 14.6 Sympatric speciation takes place without geographic isolation 284
- 14.7 **EVOLUTION CONNECTION** The origin of most plant species can be traced to polyploid speciation 285
- 14.8 Isolated islands are often showcases of speciation 286
- 14.9 **SCIENTIFIC THINKING** Lake Victoria is a living laboratory for studying speciation 287
- 14.10 Hybrid zones provide opportunities to study reproductive isolation 288
- 14.11 Speciation can occur rapidly or slowly 289

Chapter Review 290

## 15 Tracing Evolutionary History 292

### ▶ Early Earth and the Origin of Life 294

- 15.1 Conditions on early Earth made the origin of life possible 294
- 15.2 **SCIENTIFIC THINKING** Experiments show that the abiotic synthesis of organic molecules is possible 295
- 15.3 Stages in the origin of the first cells probably included the formation of polymers, protocells, and self-replicating RNA 296



### ▶ Major Events in the History of Life 297

- 15.4 The origins of single-celled and multicellular organisms and the colonization of land were key events in life's history 297
- 15.5 The actual ages of rocks and fossils mark geologic time 298
- 15.6 The fossil record documents the history of life 298

### ▶ **Mechanisms of Macroevolution** 300

- 15.7 Continental drift has played a major role in macroevolution 300
- 15.8 **CONNECTION** Plate tectonics may imperil human life 302
- 15.9 During mass extinctions, large numbers of species are lost 302
- 15.10 Adaptive radiations have increased the diversity of life 304
- 15.11 Genes that control development play a major role in evolution 304
- 15.12 **EVOLUTION CONNECTION** Novel traits may arise in several ways 306
- 15.13 Evolutionary trends do not mean that evolution is goal directed 307

### ▶ **Phylogeny and the Tree of Life** 308

- 15.14 Phylogenies based on homologies reflect evolutionary history 308
- 15.15 Systematics connects classification with evolutionary history 308
- 15.16 Shared characters are used to construct phylogenetic trees 310
- 15.17 An organism's evolutionary history is documented in its genome 312
- 15.18 Molecular clocks help track evolutionary time 313
- 15.19 Constructing the tree of life is a work in progress 314

Chapter Review 315

## UNIT IV

# The Evolution of Biological Diversity 317

## 16 Microbial Life: *Prokaryotes and Protists* 318

### ▶ **Prokaryotes** 320

- 16.1 Prokaryotes are diverse and widespread 320
- 16.2 External features contribute to the success of prokaryotes 320
- 16.3 Populations of prokaryotes can adapt rapidly to changes in the environment 322
- 16.4 Prokaryotes have unparalleled nutritional diversity 323
- 16.5 **CONNECTION** Biofilms are complex associations of microbes 324
- 16.6 **CONNECTION** Prokaryotes help clean up the environment 324
- 16.7 Bacteria and archaea are the two main branches of prokaryotic evolution 325



- 16.8 Archaea thrive in extreme environments—and in other habitats 326
- 16.9 Bacteria include a diverse assemblage of prokaryotes 326
- 16.10 **CONNECTION** Some bacteria cause disease 328
- 16.11 **SCIENTIFIC THINKING** Stomach microbiota affect health and disease 328

### ▶ **Protists** 330

- 16.12 Protists are an extremely diverse assortment of eukaryotes 330
- 16.13 **EVOLUTION CONNECTION** Endosymbiosis of unicellular algae is the key to much of protist diversity 331
- 16.14 The “SAR” supergroup represents the range of protist diversity 332
- 16.15 **CONNECTION** Can algae provide a renewable source of energy? 334
- 16.16 Some excavates have modified mitochondria 334
- 16.17 Unikonts include protists that are closely related to fungi and animals 335
- 16.18 Archaeplastids include red algae, green algae, and land plants 336
- 16.19 **EVOLUTION CONNECTION** Multicellularity evolved several times in eukaryotes 337

Chapter Review 338

## 17 The Evolution of Plant and Fungal Diversity 340

### ▶ **Plant Evolution and Diversity** 342

- 17.1 Plants have adaptations for life on land 342
- 17.2 Plant diversity reflects the evolutionary history of the plant kingdom 344

### ▶ **Alternation of Generations and Plant Life Cycles** 346

- 17.3 **VISUALIZING THE CONCEPT** Haploid and diploid generations alternate in plant life cycles 346
- 17.4 Seedless vascular plants dominated vast “coal forests” 348
- 17.5 Pollen and seeds are key adaptations for life on land 348
- 17.6 The flower is the centerpiece of angiosperm reproduction 350
- 17.7 The angiosperm plant is a sporophyte with gametophytes in its flowers 350
- 17.8 The structure of a fruit reflects its function in seed dispersal 352
- 17.9 **CONNECTION** Angiosperms sustain us—and add spice to our diets 352
- 17.10 **EVOLUTION CONNECTION** Pollination by animals has influenced angiosperm evolution 353
- 17.11 **CONNECTION** Plant diversity is vital to the future of the world's food supply 354



## ▷ Diversity of Fungi 355

- 17.12 Fungi absorb food after digesting it outside their bodies 355
- 17.13 Fungi produce spores in both asexual and sexual life cycles 356
- 17.14 Fungi are classified into five groups 356
- 17.15 **CONNECTION** Fungi have enormous ecological benefits 358
- 17.16 **CONNECTION** Fungi have many practical uses 358
- 17.17 Lichens are symbiotic associations of fungi and photosynthetic organisms 359
- 17.18 **SCIENTIFIC THINKING** Mycorrhizae may have helped plants colonize land 360
- 17.19 **CONNECTION** Parasitic fungi harm plants and animals 361

Chapter Review 362

## 18 The Evolution of Invertebrate Diversity 364

### ▷ Animal Evolution and Diversity 366

- 18.1 What is an animal? 366
- 18.2 Animal diversification began more than half a billion years ago 367
- 18.3 **VISUALIZING THE CONCEPT** Animals can be characterized by basic features of their “body plan” 368
- 18.4 Body plans and molecular comparisons of animals can be used to build phylogenetic trees 369



### ▷ Invertebrate Diversity 370

- 18.5 Sponges have a relatively simple, porous body 370
- 18.6 Cnidarians are radial animals with tentacles and stinging cells 371
- 18.7 Flatworms are the simplest bilateral animals 372
- 18.8 Nematodes have a body cavity and a complete digestive tract 373
- 18.9 Diverse molluscs are variations on a common body plan 374
- 18.10 Annelids are segmented worms 376
- 18.11 Arthropods are segmented animals with jointed appendages and an exoskeleton 378
- 18.12 **EVOLUTION CONNECTION** Insects are the most successful group of animals 380
- 18.13 **SCIENTIFIC THINKING** The genes that build animal bodies are ancient 382

- 18.14 Echinoderms have spiny skin, an endoskeleton, and a water vascular system for movement 383
- 18.15 Our own phylum, Chordata, is distinguished by four features 384
- 18.16 **CONNECTION** Invertebrate diversity is a valuable but threatened resource 385

Chapter Review 386

## 19 The Evolution of Vertebrate Diversity 388

### ▷ Vertebrate Evolution and Diversity 390

- 19.1 Derived characters define the major clades of chordates 390
- 19.2 Hagfishes and lampreys lack hinged jaws 391
- 19.3 Jawed vertebrates with gills and paired fins include sharks, ray-finned fishes, and lobe-finned fishes 392
- 19.4 **EVOLUTION CONNECTION** New fossil discoveries are filling in the gaps of tetrapod evolution 394
- 19.5 Amphibians are tetrapods—vertebrates with two pairs of limbs 396
- 19.6 Reptiles are amniotes—tetrapods with a terrestrially adapted egg 397
- 19.7 Birds are feathered reptiles with adaptations for flight 398
- 19.8 Mammals are amniotes that have hair and produce milk 399



### ▷ Primate Diversity 400

- 19.9 **VISUALIZING THE CONCEPT** Primates include lemurs, monkeys, and apes 400
- 19.10 The human story begins with our primate heritage 402

### ▷ Hominin Evolution 403

- 19.11 The hominin branch of the primate tree includes species that coexisted 403
- 19.12 Australopiths were bipedal and had small brains 404
- 19.13 Larger brains mark the evolution of *Homo* 405
- 19.14 From origins in Africa, *Homo sapiens* spread around the world 406
- 19.15 **SCIENTIFIC THINKING** New discoveries raise new questions about the history of hominins 406
- 19.16 **EVOLUTION CONNECTION** Human skin color reflects adaptations to varying amounts of sunlight 407
- 19.17 **CONNECTION** Our knowledge of animal diversity is far from complete 408

Chapter Review 409



## Animals: Form and Function 411

### 20 Unifying Concepts of Animal Structure and Function 412

#### ▶ Structure and Function in Animal Tissues 414

- 20.1 **EVOLUTION CONNECTION** An animal's form is not the perfect design 414
- 20.2 Structure fits function at all levels of organization in the animal body 415
- 20.3 Tissues are groups of cells with a common structure and function 416
- 20.4 Epithelial tissue covers the body and lines its organs and cavities 416
- 20.5 Connective tissue binds and supports other tissues 417
- 20.6 Muscle tissue functions in movement 418
- 20.7 Nervous tissue forms a communication network 418



#### ▶ Organs and Organ Systems 419

- 20.8 Organs are made up of tissues 419
- 20.9 **CONNECTION** Bioengineers are learning to produce organs for transplants 419
- 20.10 Organ systems work together to perform life's functions 420
- 20.11 The integumentary system protects the body 422
- 20.12 **SCIENTIFIC THINKING** Well-designed studies help answer scientific questions 423

#### ▶ External Exchange and Internal Regulation 424

- 20.13 Structural adaptations enhance exchange with the environment 424
- 20.14 Animals regulate their internal environment 425
- 20.15 Homeostasis depends on negative feedback 426

Chapter Review 426

### 21 Nutrition and Digestion 428

#### ▶ Obtaining and Processing Food 430

- 21.1 Animals obtain and ingest their food in a variety of ways 430
- 21.2 Overview: Food processing occurs in four stages 431
- 21.3 Digestion occurs in specialized compartments 432



#### ▶ The Human Digestive System 433

- 21.4 The human digestive system consists of an alimentary canal and accessory glands 433
- 21.5 Digestion begins in the oral cavity 434
- 21.6 After swallowing, peristalsis moves food through the esophagus to the stomach 434
- 21.7 **CONNECTION** The Heimlich maneuver can save lives 435
- 21.8 The stomach stores food and breaks it down with acid and enzymes 436
- 21.9 **CONNECTION** Digestive ailments include acid reflux and gastric ulcers 437
- 21.10 The small intestine is the major organ of chemical digestion and nutrient absorption 438
- 21.11 The liver processes and detoxifies blood from the intestines 440
- 21.12 The large intestine reclaims water and compacts the feces 440
- 21.13 **EVOLUTION CONNECTION** Evolutionary adaptations of vertebrate digestive systems relate to diet 441

#### ▶ Nutrition 442

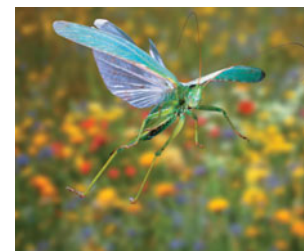
- 21.14 An animal's diet must provide sufficient energy 442
- 21.15 An animal's diet must supply essential nutrients 443
- 21.16 A proper human diet must include sufficient vitamins and minerals 444
- 21.17 **CONNECTION** Food labels provide nutritional information 446
- 21.18 **CONNECTION** Dietary deficiencies can have a number of causes 446
- 21.19 **EVOLUTION CONNECTION** The human health problem of obesity may reflect our evolutionary past 447
- 21.20 **SCIENTIFIC THINKING** Scientists use a variety of methods to test weight-loss claims 448
- 21.21 **CONNECTION** Diet can influence risk of cardiovascular disease and cancer 449

Chapter Review 450

### 22 Gas Exchange 452

#### ▶ Mechanisms of Gas Exchange 454

- 22.1 Gas exchange in humans involves breathing, transport of gases, and exchange with body cells 454
- 22.2 Animals exchange O<sub>2</sub> and CO<sub>2</sub> across moist body surfaces 454
- 22.3 **VISUALIZING THE CONCEPT** Gills are adapted for gas exchange in aquatic environments 456
- 22.4 The tracheal system of insects provides direct exchange between the air and body cells 457
- 22.5 **EVOLUTION CONNECTION** The evolution of lungs facilitated the movement of tetrapods onto land 458



## ▶ The Human Respiratory System 458

- 22.6 In mammals, branching tubes convey air to lungs located in the chest cavity 458
- 22.7 **SCIENTIFIC THINKING** Warning: Cigarette smoking is hazardous to your health 460
- 22.8 Negative pressure breathing ventilates your lungs 460
- 22.9 Breathing is automatically controlled 461

## ▶ Transport of Gases in the Human Body 462

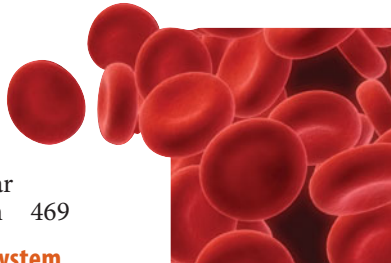
- 22.10 Blood transports respiratory gases 462
- 22.11 Hemoglobin carries O<sub>2</sub>, helps transport CO<sub>2</sub>, and buffers the blood 462
- 22.12 **CONNECTION** The human fetus exchanges gases with the mother's blood 463

Chapter Review 464

# 23 Circulation 466

## ▶ Circulatory Systems 468

- 23.1 Circulatory systems facilitate exchange with all body tissues 468
- 23.2 **EVOLUTION CONNECTION** Vertebrate cardiovascular systems reflect evolution 469



## ▶ The Human Cardiovascular System and Heart 470

- 23.3 **VISUALIZING THE CONCEPT** The human cardiovascular system illustrates the double circulation of mammals 470
- 23.4 The heart contracts and relaxes rhythmically 471
- 23.5 The SA node sets the tempo of the heartbeat 472
- 23.6 **SCIENTIFIC THINKING** What causes heart attacks? 473

## ▶ Structure and Function of Blood Vessels 474

- 23.7 The structure of blood vessels fits their functions 474
- 23.8 Blood pressure and velocity reflect the structure and arrangement of blood vessels 475
- 23.9 **CONNECTION** Measuring blood pressure can reveal cardiovascular problems 476
- 23.10 Smooth muscle controls the distribution of blood 477
- 23.11 Capillaries allow the transfer of substances through their walls 478

## ▶ Structure and Function of Blood 479

- 23.12 Blood consists of red and white blood cells suspended in plasma 479
- 23.13 **CONNECTION** Too few or too many red blood cells can be unhealthy 480
- 23.14 Blood clots plug leaks when blood vessels are injured 480
- 23.15 **CONNECTION** Stem cells offer a potential cure for blood cell diseases 481

Chapter Review 482

# 24 The Immune System 484

## ▶ Innate Immunity 486

- 24.1 All animals have innate immunity 486
- 24.2 Inflammation mobilizes the innate immune response 487

## ▶ Adaptive Immunity 488

- 24.3 The adaptive immune response counters specific invaders 488
- 24.4 The lymphatic system becomes a crucial battleground during infection 489
- 24.5 Lymphocytes mount a dual defense 490
- 24.6 Antigen receptors and antibodies bind to specific regions on an antigen 491
- 24.7 **VISUALIZING THE CONCEPT** Clonal selection mobilizes defensive forces against specific antigens 492
- 24.8 The primary and secondary responses differ in speed, strength, and duration 493
- 24.9 The structure of an antibody matches its function 494
- 24.10 **CONNECTION** Antibodies are powerful tools in the lab and clinic 495
- 24.11 **SCIENTIFIC THINKING** Scientists measure antibody levels to look for waning immunity after HPV vaccination 496
- 24.12 Helper T cells stimulate the humoral and cell-mediated immune responses 497
- 24.13 Cytotoxic T cells destroy infected body cells 498
- 24.14 **CONNECTION** HIV destroys helper T cells, compromising the body's defenses 498
- 24.15 **EVOLUTION CONNECTION** The rapid evolution of HIV complicates AIDS treatment 499
- 24.16 The immune system depends on our molecular fingerprints 500

## ▶ Disorders of the Immune System 500

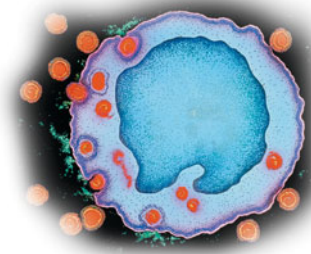
- 24.17 **CONNECTION** Immune system disorders result from self-directed or underactive responses 500
- 24.18 **CONNECTION** Allergies are overreactions to certain environmental antigens 501

Chapter Review 502

# 25 Control of Body Temperature and Water Balance 504

## ▶ Thermoregulation 506

- 25.1 An animal's regulation of body temperature helps maintain homeostasis 506
- 25.2 Thermoregulation involves adaptations that balance heat gain and loss 506
- 25.3 **SCIENTIFIC THINKING** Coordinated waves of movement in huddles help penguins thermoregulate 507



### ▶ **Osmoregulation and Excretion** 508

- 25.4 Animals balance their levels of water and solutes through osmoregulation 508
  - 25.5 **EVOLUTION CONNECTION** Several ways to dispose of nitrogenous wastes have evolved in animals 509
  - 25.6 The urinary system plays several major roles in homeostasis 510
  - 25.7 Reabsorption and secretion refine the filtrate 512
  - 25.8 Hormones regulate the urinary system 513
  - 25.9 **CONNECTION** Kidney dialysis can save lives 513
- Chapter Review 514

## 26 Hormones and the Endocrine System 516

### ▶ **The Nature of Chemical Regulation** 518

- 26.1 Chemical and electrical signals coordinate body functions 518
- 26.2 Hormones affect target cells using two main signaling mechanisms 519
- 26.3 **SCIENTIFIC THINKING** A widely used weed killer demasculinizes male frogs 520



### ▶ **The Vertebrate Endocrine System** 520

- 26.4 The vertebrate endocrine system consists of more than a dozen major glands 520
- 26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems 522

### ▶ **Hormones and Homeostasis** 524

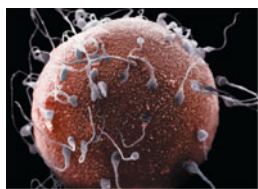
- 26.6 The thyroid regulates development and metabolism 524
- 26.7 The gonads secrete sex hormones 525
- 26.8 **VISUALIZING THE CONCEPT** Pancreatic hormones regulate blood glucose level 526
- 26.9 **CONNECTION** Diabetes is a common endocrine disorder 527
- 26.10 The adrenal glands mobilize responses to stress 528
- 26.11 **EVOLUTION CONNECTION** A single hormone can perform a variety of functions in different animals 529
- 26.12 **CONNECTION** Hormones can promote social behaviors 530

Chapter Review 530

## 27 Reproduction and Embryonic Development 532

### ▶ **Asexual and Sexual Reproduction** 534

- 27.1 Asexual reproduction results in the generation of genetically identical offspring 534



- 27.2 Sexual reproduction results in the generation of genetically unique offspring 534

### ▶ **Human Reproduction** 536

- 27.3 The human female reproductive system includes the ovaries and structures that deliver gametes 536
- 27.4 The human male reproductive system includes the testes and structures that deliver gametes 538
- 27.5 The formation of sperm and egg cells requires meiosis 540
- 27.6 Hormones synchronize cyclic changes in the ovary and uterus 542
- 27.7 **SCIENTIFIC THINKING** Sexual activity can transmit disease 544
- 27.8 **CONNECTION** Contraception can prevent unwanted pregnancy 545

### ▶ **Principles of Embryonic Development** 546

- 27.9 Fertilization results in a zygote and triggers embryonic development 546
- 27.10 Cleavage produces a blastula from the zygote 548
- 27.11 Gastrulation produces a three-layered embryo 549
- 27.12 Organs start to form after gastrulation 550
- 27.13 Multiple processes give form to the developing animal 552
- 27.14 **EVOLUTION CONNECTION** Pattern formation during embryonic development is controlled by ancient genes 552

### ▶ **Human Development** 554

- 27.15 The embryo and placenta take shape during the first month of pregnancy 554
- 27.16 **VISUALIZING THE CONCEPT** Human pregnancy is divided into trimesters 556
- 27.17 Childbirth is induced by hormones and other chemical signals 558
- 27.18 **CONNECTION** Reproductive technologies increase our reproductive options 559

Chapter Review 560

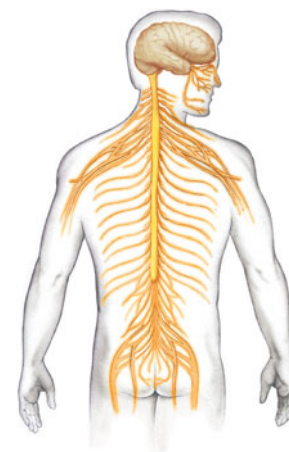
## 28 Nervous Systems 562

### ▶ **Nervous System Structure and Function** 564

- 28.1 Nervous systems receive sensory input, interpret it, and send out commands 564
- 28.2 Neurons are the functional units of nervous systems 565

### ▶ **Nerve Signals and Their Transmission** 566

- 28.3 Nerve function depends on charge differences across neuron membranes 566





- 28.4 A nerve signal begins as a change in the membrane potential 566
- 28.5 The action potential propagates itself along the axon 568
- 28.6 Neurons communicate at synapses 569
- 28.7 Chemical synapses enable complex information to be processed 570
- 28.8 A variety of small molecules function as neurotransmitters 570
- 28.9 **CONNECTION** Many drugs act at chemical synapses 571
- 28.10 **SCIENTIFIC THINKING** Published data are biased toward positive findings 572

### ▶ **An Overview of Animal Nervous Systems 573**

- 28.11 **EVOLUTION CONNECTION** The evolution of animal nervous systems reflects changes in body symmetry 573
- 28.12 Vertebrate nervous systems are highly centralized 574
- 28.13 The peripheral nervous system of vertebrates can be divided into functional components 575
- 28.14 The vertebrate brain develops from three anterior bulges of the neural tube 576

### ▶ **The Human Brain 576**

- 28.15 The structure of a living supercomputer: The human brain 576
- 28.16 The cerebral cortex is a mosaic of specialized, interactive regions 578
- 28.17 **CONNECTION** Injuries and brain operations provide insight into brain function 579
- 28.18 **CONNECTION** fMRI scans provide insight into brain structure and function 580
- 28.19 The reticular formation is involved in arousal and sleep 580
- 28.20 The limbic system is involved in emotions and memory 581
- 28.21 **CONNECTION** Changes in brain physiology can produce neurological disorders 582

Chapter Review 584

## 29 The Senses 586

### ▶ **Sensory Reception 588**

- 29.1 Sensory receptors convert stimulus energy to action potentials 588
- 29.2 **SCIENTIFIC THINKING** The model for magnetic sensory reception is incomplete 589
- 29.3 Specialized sensory receptors detect five categories of stimuli 590



### ▶ **Hearing and Balance 592**

- 29.4 The ear converts air pressure waves to action potentials that are perceived as sound 592

- 29.5 The inner ear houses our organs of balance 594
- 29.6 **CONNECTION** What causes motion sickness? 594

### ▶ **Vision 595**

- 29.7 **EVOLUTION CONNECTION** Several types of eyes have evolved among animals 595
- 29.8 Humans have single-lens eyes that focus by changing shape 596
- 29.9 **CONNECTION** Artificial lenses or surgery can correct focusing problems 597
- 29.10 The human retina contains two types of photoreceptors: rods and cones 598

### ▶ **Taste and Smell 599**

- 29.11 Taste and odor receptors detect chemicals present in solution or air 599
- 29.12 **CONNECTION** “Supertasters” have a heightened sense of taste 599
- 29.13 Review: The central nervous system couples stimulus with response 600

Chapter Review 600

## 30 How Animals Move 602

### ▶ **Movement and Locomotion 604**

- 30.1 Locomotion requires energy to overcome friction and gravity 604
- 30.2 Skeletons function in support, movement, and protection 606



### ▶ **The Vertebrate Skeleton 608**

- 30.3 **EVOLUTION CONNECTION** Vertebrate skeletons are variations on an ancient theme 608
- 30.4 Bones are complex living organs 609
- 30.5 **CONNECTION** Healthy bones resist stress and heal from injuries 610
- 30.6 Joints permit different types of movement 611

### ▶ **Muscle Contraction and Movement 611**

- 30.7 The skeleton and muscles interact in movement 611
- 30.8 Each muscle cell has its own contractile apparatus 612
- 30.9 A muscle contracts when thin filaments slide along thick filaments 612
- 30.10 Motor neurons stimulate muscle contraction 614
- 30.11 **CONNECTION** Aerobic respiration supplies most of the energy for exercise 615
- 30.12 **SCIENTIFIC THINKING** Characteristics of muscle fiber affect athletic performance 616

Chapter Review 617

## Plants: Form and Function 619

### 31 Plant Structure, Growth, and Reproduction 620

#### ▶ Plant Structure and Function 622

- 31.1 **SCIENTIFIC THINKING** The domestication of crops changed the course of human history 622
- 31.2 The two major groups of angiosperms are the monocots and the eudicots 623
- 31.3 A typical plant body contains three basic organs: roots, stems, and leaves 624
- 31.4 Many plants have modified roots, stems, and leaves 625
- 31.5 Three tissue systems make up the plant body 626
- 31.6 Plant cells are diverse in structure and function 628



#### ▶ Plant Growth 630

- 31.7 Primary growth lengthens roots and shoots 630
- 31.8 Secondary growth increases the diameter of woody plants 632

#### ▶ Reproduction of Flowering Plants 634

- 31.9 The flower is the organ of sexual reproduction in angiosperms 634
- 31.10 The development of pollen and ovules culminates in fertilization 635
- 31.11 The ovule develops into a seed 636
- 31.12 The ovary develops into a fruit 637
- 31.13 Seed germination continues the life cycle 638
- 31.14 Asexual reproduction produces plant clones 638
- 31.15 **EVOLUTION CONNECTION** Evolutionary adaptations help some plants to live very long lives 640

Chapter Review 640

### 32 Plant Nutrition and Transport 642

#### ▶ The Uptake and Transport of Plant Nutrients 644

- 32.1 Plants acquire nutrients from air, water, and soil 644
- 32.2 The plasma membranes of root cells control solute uptake 645
- 32.3 **VISUALIZING THE CONCEPT** Transpiration pulls water up xylem vessels 646



32.4 Guard cells control transpiration 647

32.5 Phloem transports sugars 648

#### ▶ Plant Nutrients and the Soil 650

- 32.6 Plant health depends on obtaining all of the essential inorganic nutrients 650
- 32.7 **CONNECTION** Fertilizers can help prevent nutrient deficiencies 651
- 32.8 Fertile soil supports plant growth 652
- 32.9 **CONNECTION** Soil conservation is essential to human life 653
- 32.10 **SCIENTIFIC THINKING** Organic farmers follow principles meant to promote health 654
- 32.11 **CONNECTION** Agricultural research is improving the yields and nutritional values of crops 654

#### ▶ Plant Nutrition and Symbiosis 655

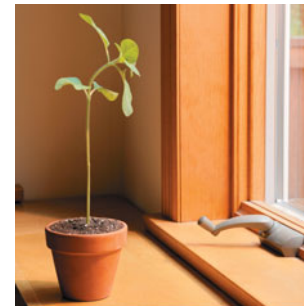
- 32.12 Most plants depend on bacteria to supply nitrogen 655
- 32.13 **EVOLUTION CONNECTION** Plants have evolved mutually beneficial symbiotic relationships 656
- 32.14 The plant kingdom includes epiphytes, parasites, and carnivores 657

Chapter Review 658

### 33 Control Systems in Plants 660

#### ▶ Plant Hormones 662

- 33.1 **SCIENTIFIC THINKING** A series of experiments by several scientists led to the discovery of a plant hormone 662
- 33.2 Botanists have identified several major types of hormones 664
- 33.3 Auxin stimulates the elongation of cells in young shoots 664
- 33.4 Cytokinins stimulate cell division 666
- 33.5 Gibberellins affect stem elongation and have numerous other effects 666
- 33.6 Abscisic acid inhibits many plant processes 667
- 33.7 Ethylene triggers fruit ripening and other aging processes 668
- 33.8 **CONNECTION** Plant hormones have many agricultural uses 669



#### ▶ Responses to Stimuli 670

- 33.9 Tropisms orient plant growth toward or away from environmental stimuli 670
- 33.10 Plants have internal clocks 671
- 33.11 Plants mark the seasons by measuring photoperiod 672
- 33.12 Phytochromes are light detectors that help set the biological clock 673
- 33.13 **EVOLUTION CONNECTION** Defenses against herbivores and infectious microbes have evolved in plants 674

Chapter Review 675

## Ecology 677

### 34 The Biosphere: An Introduction to Earth's Diverse Environments 678

#### ▷ The Biosphere 680

- 34.1 Ecologists study how organisms interact with their environment at several levels 680
- 34.2 **SCIENTIFIC THINKING** The science of ecology provides insight into environmental problems 681
- 34.3 Physical and chemical factors influence life in the biosphere 682
- 34.4 **EVOLUTION CONNECTION** Organisms are adapted to abiotic and biotic factors by natural selection 683
- 34.5 Regional climate influences the distribution of terrestrial communities 684



#### ▷ Aquatic Biomes 686

- 34.6 Sunlight and substrate are key factors in the distribution of marine organisms 686
- 34.7 Current, sunlight, and nutrients are important abiotic factors in freshwater biomes 688

#### ▷ Terrestrial Biomes 689

- 34.8 Terrestrial biomes reflect regional variations in climate 689
- 34.9 Tropical forests cluster near the equator 690
- 34.10 Savannas are grasslands with scattered trees 690
- 34.11 Deserts are defined by their dryness 691
- 34.12 Spiny shrubs dominate the chaparral 692
- 34.13 Temperate grasslands include the North American prairie 692
- 34.14 Broadleaf trees dominate temperate forests 693
- 34.15 Coniferous forests are often dominated by a few species of trees 693
- 34.16 Long, bitter-cold winters characterize the tundra 694
- 34.17 Polar ice covers the land at high latitudes 694
- 34.18 The global water cycle connects aquatic and terrestrial biomes 695

Chapter Review 696

### 35 Behavioral Adaptations to the Environment 698

#### ▷ The Scientific Study of Behavior 700

- 35.1 Behavioral ecologists ask both proximate and ultimate questions 700



- 35.2 Fixed action patterns are innate behaviors 700
- 35.3 Behavior is the result of both genetic and environmental factors 702

#### ▷ Learning 703

- 35.4 Habituation is a simple type of learning 703
- 35.5 Imprinting requires both innate behavior and experience 704
- 35.6 **CONNECTION** Imprinting poses problems and opportunities for conservation programs 705
- 35.7 **VISUALIZING THE CONCEPT** Animal movement may be a response to stimuli or require spatial learning 706
- 35.8 A variety of cues guide migratory movements 707
- 35.9 Animals may learn to associate a stimulus or behavior with a response 708
- 35.10 Social learning employs observation and imitation of others 708
- 35.11 Problem-solving behavior relies on cognition 709

#### ▷ Survival and Reproductive Success 710

- 35.12 Behavioral ecologists use cost–benefit analysis to study foraging 710
- 35.13 Communication is an essential element of interactions between animals 711
- 35.14 Mating behavior often includes elaborate courtship rituals 712
- 35.15 Mating systems and parental care enhance reproductive success 713
- 35.16 **CONNECTION** Chemical pollutants can cause abnormal behavior 714

#### ▷ Social Behavior and Sociobiology 715

- 35.17 Sociobiology places social behavior in an evolutionary context 715
- 35.18 Territorial behavior parcels out space and resources 715
- 35.19 Agonistic behavior often resolves confrontations between competitors 716
- 35.20 Dominance hierarchies are maintained by agonistic behavior 716
- 35.21 **EVOLUTION CONNECTION** Altruistic acts can often be explained by the concept of inclusive fitness 717
- 35.22 **SCIENTIFIC THINKING** Jane Goodall revolutionized our understanding of chimpanzee behavior 718
- 35.23 Human behavior is the result of both genetic and environmental factors 719

Chapter Review 720

### 36 Population Ecology 722

#### ▷ Population Structure and Dynamics 724

- 36.1 Population ecology is the study of how and why populations change 724
- 36.2 Density and dispersion patterns are important population variables 724
- 36.3 Life tables track survivorship in populations 725





- 36.4 Idealized models predict patterns of population growth 726
- 36.5 Multiple factors may limit population growth 728
- 36.6 **SCIENTIFIC THINKING** Some populations have “boom-and-bust” cycles 729
- 36.7 **EVOLUTION CONNECTION** Evolution shapes life histories 730
- 36.8 **CONNECTION** Principles of population ecology have practical applications 731

### ▷ The Human Population 732

- 36.9 The human population continues to increase, but the growth rate is slowing 732
- 36.10 **CONNECTION** Age structures reveal social and economic trends 734
- 36.11 **CONNECTION** An ecological footprint is a measure of resource consumption 735

Chapter Review 736

## 37 Communities and Ecosystems 738

### ▷ Community Structure and Dynamics 740

- 37.1 A community includes all the organisms inhabiting a particular area 740
- 37.2 Interspecific interactions are fundamental to community structure 740
- 37.3 Competition may occur when a shared resource is limited 741
- 37.4 Mutualism benefits both partners 741
- 37.5 **EVOLUTION CONNECTION** Predation leads to diverse adaptations in prey species 742
- 37.6 **EVOLUTION CONNECTION** Herbivory leads to diverse adaptations in plants 742
- 37.7 Parasites and pathogens can affect community composition 743
- 37.8 Trophic structure is a key factor in community dynamics 744
- 37.9 **VISUALIZING THE CONCEPT** Food chains interconnect, forming food webs 745
- 37.10 Species diversity includes relative abundance and species richness 746
- 37.11 **SCIENTIFIC THINKING** Some species have a disproportionate impact on diversity 747
- 37.12 Disturbance is a prominent feature of most communities 748
- 37.13 **CONNECTION** Invasive species can devastate communities 749



### ▷ Ecosystem Structure and Dynamics 750

- 37.14 Ecosystem ecology emphasizes energy flow and chemical cycling 750
- 37.15 Primary production sets the energy budget for ecosystems 750
- 37.16 Energy supply limits the length of food chains 751
- 37.17 **CONNECTION** A pyramid of production explains the ecological cost of meat 752
- 37.18 Chemicals are cycled between organic matter and abiotic reservoirs 752

- 37.19 The carbon cycle depends on photosynthesis and respiration 753
- 37.20 The phosphorus cycle depends on the weathering of rock 754
- 37.21 The nitrogen cycle depends on bacteria 754
- 37.22 **CONNECTION** A rapid inflow of nutrients degrades aquatic ecosystems 756
- 37.23 **CONNECTION** Ecosystem services are essential to human well-being 757

Chapter Review 758

## 38 Conservation Biology 760

### ▷ The Loss of Biodiversity 762

- 38.1 Loss of biodiversity includes the loss of ecosystems, species, and genes 762
- 38.2 **CONNECTION** Habitat loss, invasive species, overharvesting, pollution, and climate change are major threats to biodiversity 764
- 38.3 **CONNECTION** Rapid warming is changing the global climate 766
- 38.4 **CONNECTION** Human activities are responsible for rising concentrations of greenhouse gases 767
- 38.5 Global climate change affects biomes, ecosystems, communities, and populations 768
- 38.6 **EVOLUTION CONNECTION** Climate change is an agent of natural selection 769



### ▷ Conservation Biology and Restoration Ecology 770

- 38.7 Protecting endangered populations is one goal of conservation biology 770
- 38.8 Sustaining ecosystems and landscapes is a conservation priority 771
- 38.9 Establishing protected areas slows the loss of biodiversity 772
- 38.10 Zoned reserves are an attempt to reverse ecosystem disruption 773
- 38.11 **SCIENTIFIC THINKING** The Yellowstone to Yukon Conservation Initiative seeks to preserve biodiversity by connecting protected areas 774
- 38.12 **CONNECTION** The study of how to restore degraded habitats is a developing science 776
- 38.13 Sustainable development is an ultimate goal 777

Chapter Review 778

**Appendix 1 Metric Conversion Table A-1**

**Appendix 2 The Periodic Table A-2**

**Appendix 3 The Amino Acids of Proteins A-3**

**Appendix 4 Chapter Review Answers A-4**

**Appendix 5 Credits A-26**

**Glossary G-1**

**Index I-1**

# Biology: *Exploring Life*

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



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

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





# BIG IDEAS

## Themes in the Study of Biology (1.1–1.4)

Common themes help to organize the study of life.



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

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



## The Process of Science (1.8–1.9)

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



## Biology and Everyday Life (1.10–1.11)

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



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

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

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





# ► Themes in the Study of Biology

## 1.1 All forms of life share common properties

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

1. **Order.** This sunflower illustrates the ordered structure that typifies life. Living cells make up this complex organization.
2. **Reproduction.** Organisms reproduce their own kind. Here a baby African elephant walks beneath its mother.
3. **Growth and development.** Inherited information in the form of DNA controls the pattern of growth and development of all organisms, including this hatching crocodile.
4. **Energy processing.** This caterpillar will use the chemical energy stored in the plant it is eating to power its own activities and chemical reactions.
5. **Regulation.** Many types of mechanisms regulate an organism's internal environment, keeping it within limits that sustain life. Pictured here is a lizard "sunbathing"—which helps raise its body temperature on cool mornings.
6. **Response to the environment.** All organisms respond to environmental stimuli. This Venus flytrap closed its trap rapidly in response to the stimulus of a damselfly landing on it.

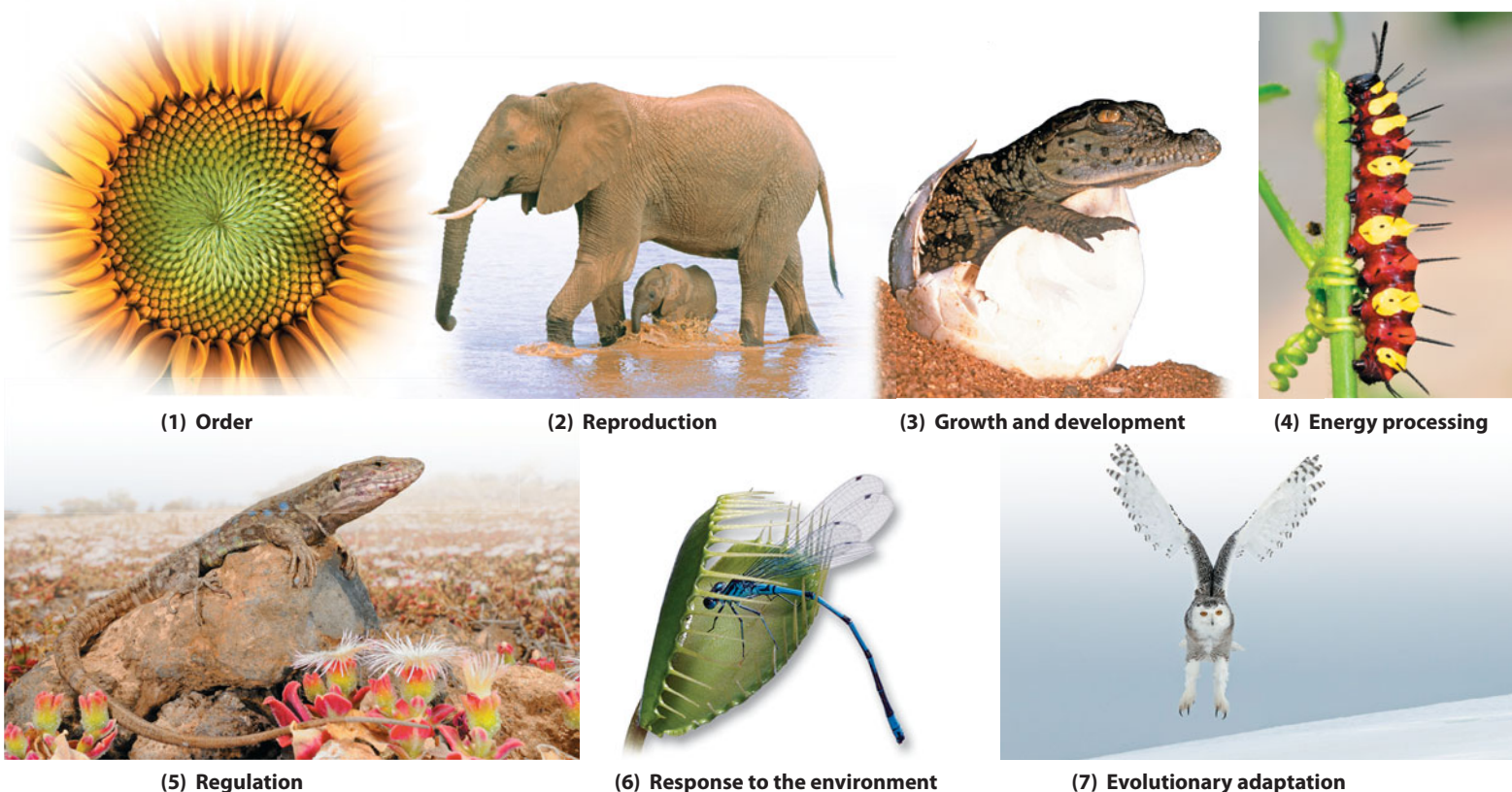
7. **Evolutionary adaptation.** A snowy owl's sharp talons facilitate prey capture and its feathered feet keep it warm in its cold habitat. Such adaptations evolve over many generations as individuals with traits best suited to their environment have greater reproductive success and pass their traits to offspring.

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

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

### ? How would you define life?

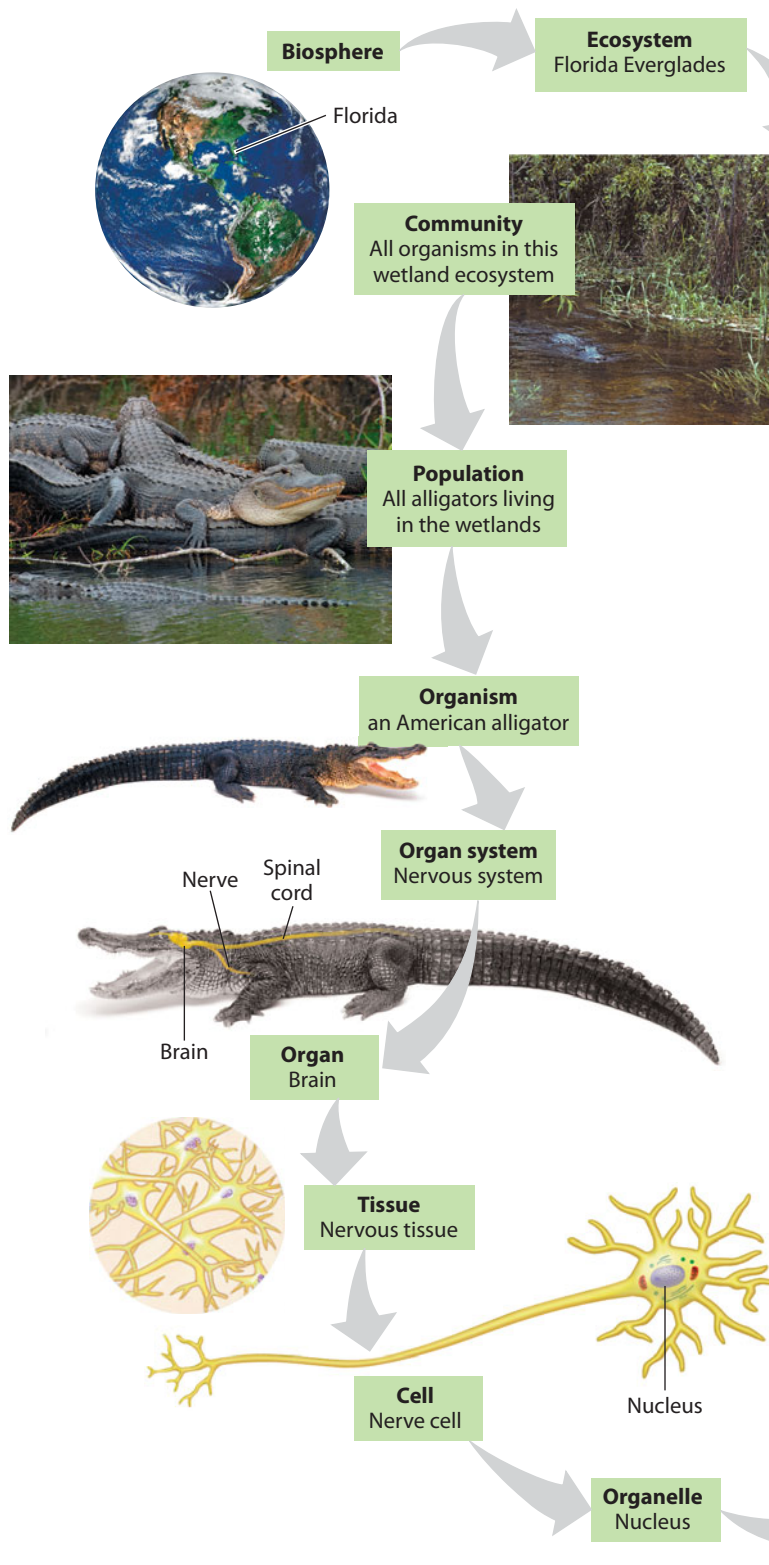
Life can be defined by a set of common properties such as those described in this module.



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

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

As **Figure 1.2** illustrates, the study of life extends from the global scale of the biosphere to the microscopic level of molecules. At the upper left we take a distant view of the **biosphere**, all of the environments on Earth that support life.



These include most regions of land, bodies of water, and the lower atmosphere. A closer look at one of these environments brings us to the level of an **ecosystem**, which consists of all the organisms living in a particular area, as well as the physical components with which the organisms interact, such as air, soil, water, and sunlight.

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

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

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

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

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

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

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

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



## 1.3 Cells are the structural and functional units of life

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

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

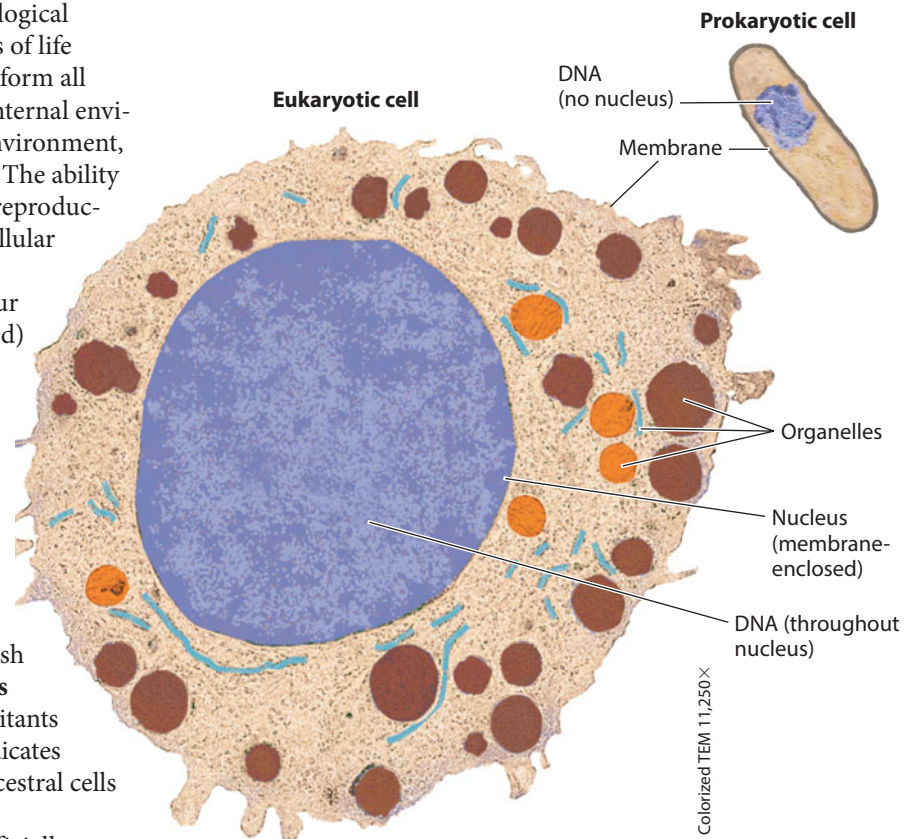
All cells share certain characteristics. For example, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. And every cell uses DNA as its genetic information. However, we can distinguish between two main forms of cells. **Prokaryotic cells**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

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

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

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

Cells illustrate another theme of biology: the correlation of structure and function. Experience shows you that form



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

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

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

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

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



## 1.4 Organisms interact with their environment, exchanging matter and energy

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

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

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

The dynamics of ecosystems include two major processes—the recycling of chemicals and the flow of energy. These processes are illustrated in **Figure 1.4**. The most basic chemicals necessary for life—carbon dioxide, oxygen, water, and various

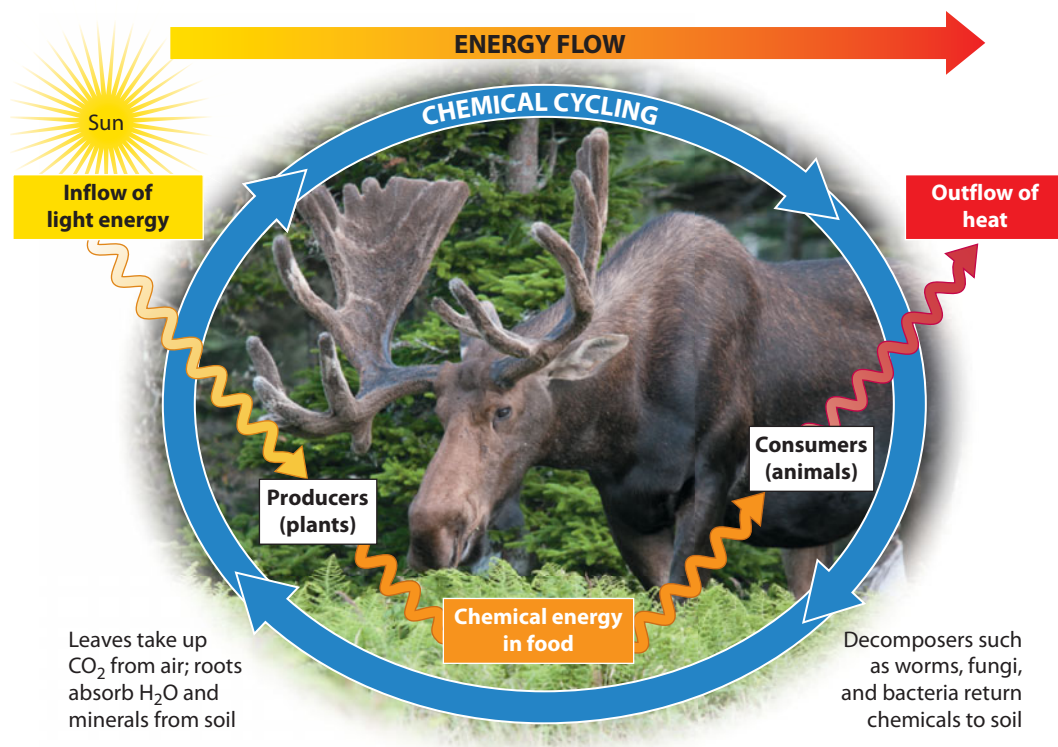
minerals—cycle within an ecosystem from the air and soil to plants, to animals and decomposers, and back to the air and soil (shown with blue arrows in the figure).

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

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

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

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



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

# ▶ Evolution, the Core Theme of Biology

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

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

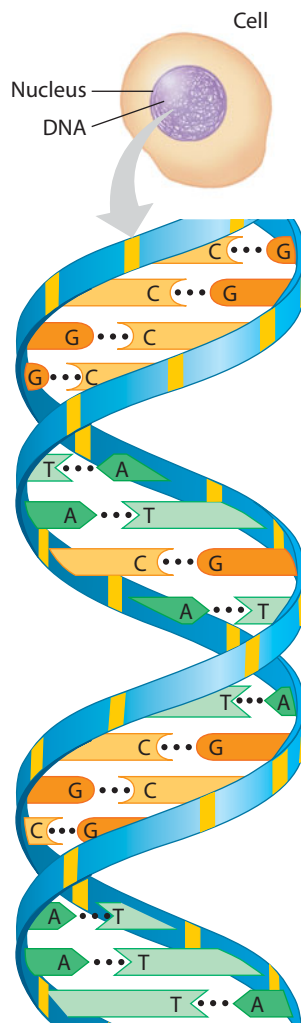
How does the molecular structure of DNA account for its ability to encode and transmit information? Each DNA molecule is made up of two long chains, called strands, coiled together into a double helix. The strands are made up of four kinds of chemical building blocks. **Figure 1.5** (left side) illustrates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

Each time a cell divides, its DNA is first replicated, or copied—the double helix unzips and new complementary strands assemble along the separated strands. Thus, each new cell inherits a complete set of DNA, identical to that of the parent cell. You began as a single cell stocked with DNA inherited from your two parents.

The replication of that DNA during each round of cell division transmitted copies of the DNA to what eventually became the trillions of cells of your body.

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

The DNA of genes provides the blueprints for making proteins, and proteins serve as the tools that actually build and maintain the cell and carry out its activities. A bacterial gene may direct the cell to “Make a yellow pigment.” A particular human gene may mean “Make the hormone insulin.” All



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

forms of life use essentially the same genetic code to translate the information stored in DNA into proteins. This makes it possible to engineer cells to produce proteins normally found only in some other organism. Thus, bacteria can be used to produce insulin for the treatment of diabetes by inserting a gene for human insulin into bacterial cells.

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

The entire “library” of genetic instructions that an organism inherits is called its **genome**. A typical human cell has two similar sets of chromosomes, and each set contains about 3 billion nucleotide pairs. In recent years, scientists have determined the entire sequence of nucleotides in the human genome, as well as the genomes of thousands of other species. More species continue to be added to the list of species whose genomes have been sequenced as the rate at which sequencing can be done has accelerated rapidly in recent years. To deal with the resulting deluge of data, scientists are applying a systems biology approach at the molecular level. In an emerging field known as genomics, researchers now study whole sets of genes in a species and then compare genes across multiple species. The benefits from such an approach range from identifying genes that may be implicated in human cancers to

revealing the evolutionary relationships among diverse organisms based on similarities in their genomes. Genomics affirms the unity of life based on the universal genetic material—DNA.

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

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

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

## 1.6 The diversity of life can be arranged into three domains

We can think of biology's enormous scope as having two dimensions. The “vertical” dimension, which we examined in Module 1.2, is the size scale that stretches from molecules to

the biosphere. But biology also has a “horizontal” dimension, spanning across the great diversity of organisms existing now and over the long history of life on Earth.



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

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

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

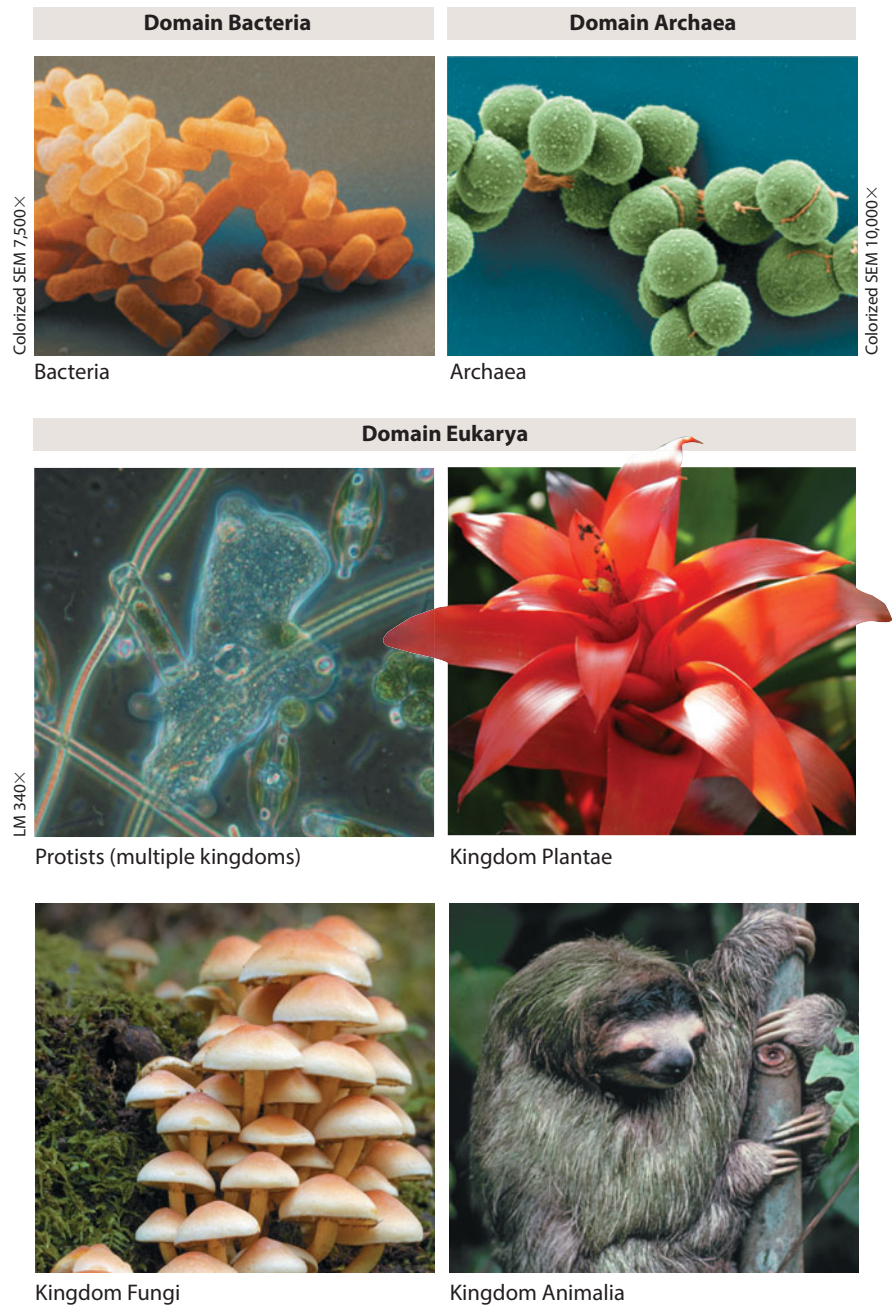
Domains **Bacteria** and **Archaea** both consist of prokaryotes, organisms with prokaryotic cells. Bacteria are the most diverse and widespread prokaryotes. Many of the prokaryotes known as archaea live in Earth's extreme environments, such as salty lakes and boiling hot springs. Each rod-shaped or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

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

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

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

Animals obtain food by eating other organisms. The sloth in Figure 1.6 resides in South American rain forests. There are actually members of two other groups in the sloth photo. The sloth is clinging to a tree (kingdom **Plantae**), and the greenish tinge in its hair is a luxuriant growth of photosynthetic prokaryotes (domain **Bacteria**). This photograph exemplifies a theme reflected in our book's title: connections between living things. The sloth depends on trees for food and



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

shelter; the tree uses nutrients from the decomposition of the sloth's feces; the prokaryotes gain access to the sunlight necessary for photosynthesis by living on the sloth; and the sloth is camouflaged from predators by its green coat.

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



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

● Eukarya



## 1.7 Evolution explains the unity and diversity of life

**Evolution** can be defined as the process of change that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. The fossil record documents the fact that life has been evolving on Earth for billions of years, and patterns of ancestry can be traced through this record. For example, the mammoth being excavated in

**Figure 1.7A** is clearly related to present-day elephants. We can explain the shared traits of mammoths and elephants with the premise that they descended from a common ancestor in the distant past. Their differences reflect the evolutionary changes that occurred within their separate lineages during the history of their existence on Earth. Thus, evolution accounts for life's dual nature of kinship and diversity.



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

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

As a young man, Darwin made key observations that greatly influenced his thinking. During a five-year, around-the-world voyage, he collected and documented plants and animals

in widely varying locations—from the isolated Galápagos Islands off the coast of Ecuador to the heights of the Andes mountains to the jungles of Brazil. He was particularly struck by the adaptations of these varied organisms that fit them to their diverse habitats. After returning to England, Darwin spent more than two decades continuing his observations, performing experiments, corresponding with other scientists, and refining his thinking before he finally published his work.

The first of two main points that Darwin presented in *The Origin of Species* was that species living today arose from a successor of ancestors that differed from them. Darwin called this process “descent with modification.” It was an insightful

phrase, because it captured both the unity of life (descent from a common ancestor) and the diversity of life (modifications that evolved as species diverged from their ancestors).

**Figure 1.7C** illustrates this unity and diversity among birds. These three birds all have a common “bird” body plan of wings, beak, feet, and feathers, but these features are highly specialized for each bird's unique lifestyle.

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

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

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

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

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

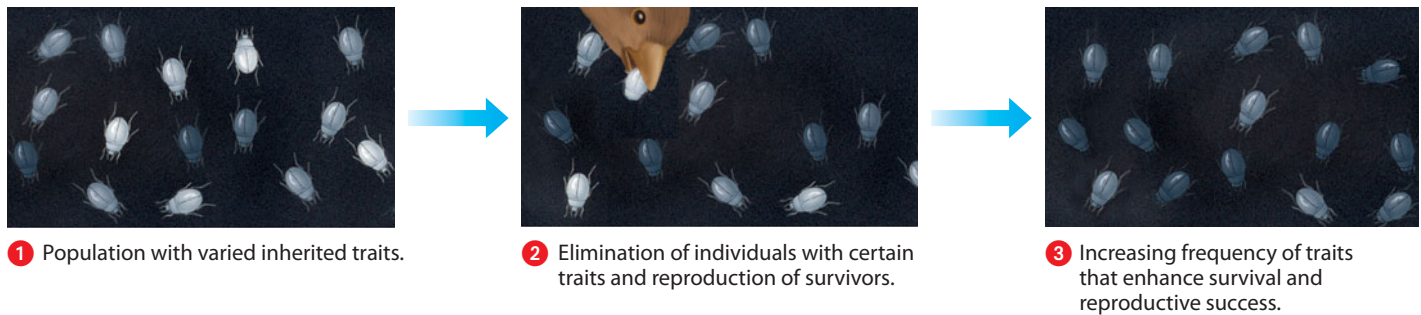


▲ **Figure 1.7B** Charles Darwin in 1859



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

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



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

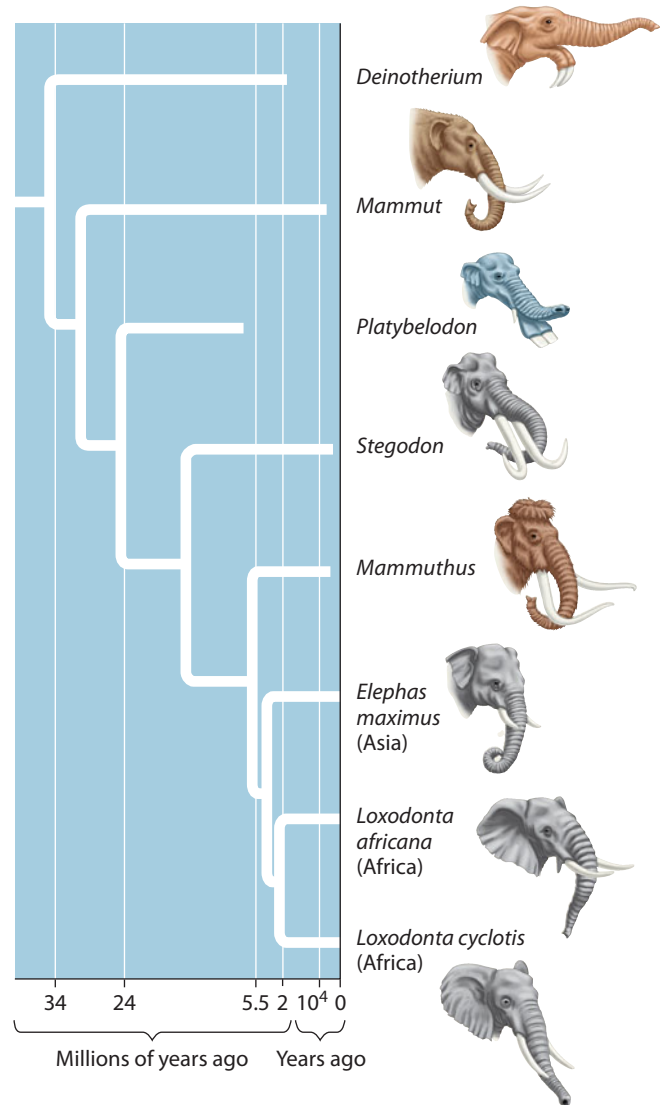
**Try This** Describe what might happen if some of these beetles colonized a sand dune habitat.

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

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

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

All of life is connected, and the basis for this kinship is evolution—the core theme that makes sense of everything we



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

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

know and learn about life. In the next module, we introduce scientific inquiry, the process we use to study the natural world.

**?** Explain the cause and effect of unequal reproductive success.

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