

CAMPBELL BIOLOGY

TWELFTH EDITION



Lisa A. Urry

MILLS COLLEGE, OAKLAND,
CALIFORNIA

Michael L. Cain

NEW MEXICO STATE UNIVERSITY

Steven A. Wasserman

UNIVERSITY OF CALIFORNIA,
SAN DIEGO

Peter V. Minorsky

MERCY COLLEGE, DOBBS FERRY,
NEW YORK

Rebecca B. Orr

COLLIN COLLEGE, PLANO, TEXAS



Pearson

Director, Global Higher Ed Content Management and Strategy, Science & Health Sciences: *Jeanne Zalesky*
Manager, Higher Ed Global Content Strategy, Life Sciences: *Joshua Frost*
Associate Content Analyst: *Chelsea Noack*
Editorial Assistant: *Ashley Fallon*
Director, Higher Ed Product Management, Life Sciences: *Michael Gillespie*
Product Manager: *Rebecca Berardy Schwartz*
Managing Producer: *Michael Early*
Senior Content Producer: *Lori Newman*
Director, Content Development & Partner Relationships: *Ginnie Simone Jutson*
Supervising Editors: *Beth N. Winickoff, Pat Burner*
Senior Developmental Editors: *John Burner, Mary Ann Murray, Hilair Chism, Andrew Recher, Mary Hill*
Specialist, Instructional Design and Development: *Sarah Young-Dualan*
Senior Content Developer, Mastering Biology: *Sarah Jensen*

Project Manager: *Katie Cook*
Content Producers, Mastering Biology: *Kaitlin Smith, Ashley Gordon*
Supervising Media Producer: *Tod Regan*
Media Producer: *Ziki Dekel*
Full-Service Vendor: *Integra Software Services, Inc.*
Design Manager: *Mark Ong*
Cover & Interior Designer: *Jeff Puda*
Illustrators: *Lachina Creative*
Rights & Permissions Project Manager: *Matt Perry, SPi Global*
Rights & Permissions Manager: *Ben Ferrini*
Photo Researcher: *Maureen Spuhler*
Product and Solutions Specialist: *Kelly Galli*
Senior Product Marketing Manager: *Alysun Estes*
Manufacturing Buyer: *Stacey Weinberger, LSC Communications*
Cover Photo Credit: *Robert Rohrbaugh/Rohrbaugh Photography*

Copyright © 2021, 2017, 2014 by Pearson Education, Inc. or its affiliates, 221 River Street, Hoboken, NJ 07030. 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 otherwise. For information regarding permissions, request forms, and the appropriate contacts within the Pearson Education Global Rights and Permissions department, please visit www.pearsoned.com/permissions/.

Acknowledgments of third-party content appear in the Credits section (beginning on page CR-1), which constitutes an extension of this copyright page.

PEARSON, ALWAYS LEARNING, Mastering™ Biology, and BioFlix® are exclusive trademarks owned by Pearson Education, Inc. or its affiliates in the U.S. and/or other countries.

Unless otherwise indicated herein, any third-party trademarks that may appear in this work are the property of their respective owners and any references to third-party trademarks, logos or other trade dress are for demonstrative or descriptive purposes only. Such references are not intended to imply any sponsorship, endorsement, authorization, or promotion of Pearson's products by the owners of such marks, or any relationship between the owner and Pearson Education, Inc. or its affiliates, authors, licensees or distributors.

Library of Congress Cataloging-in-Publication Data

Names: Urry, Lisa A., author. | Cain, Michael L. (Michael Lee), author. | Wasserman, Steven Alexander, author. | Minorsky, Peter V., author. | Orr, Rebecca B., author. | Campbell, Neil A., Biology.
Title: Campbell biology / Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Rebecca B. Orr, Neil A. Campbell.
Description: Twelfth edition. | New York, NY : Pearson, 2020. | Includes index.
Identifiers: LCCN 2019039139 | ISBN 9780135188743 (hardcover) | ISBN 9780135988046 (ebook)
Subjects: LCSH: Biology.
Classification: LCC QH308.2 .C34 2020 | DDC 570—dc23
LC record available at <https://lcn.loc.gov/2019039139>

ScoutAutomatedPrintCode

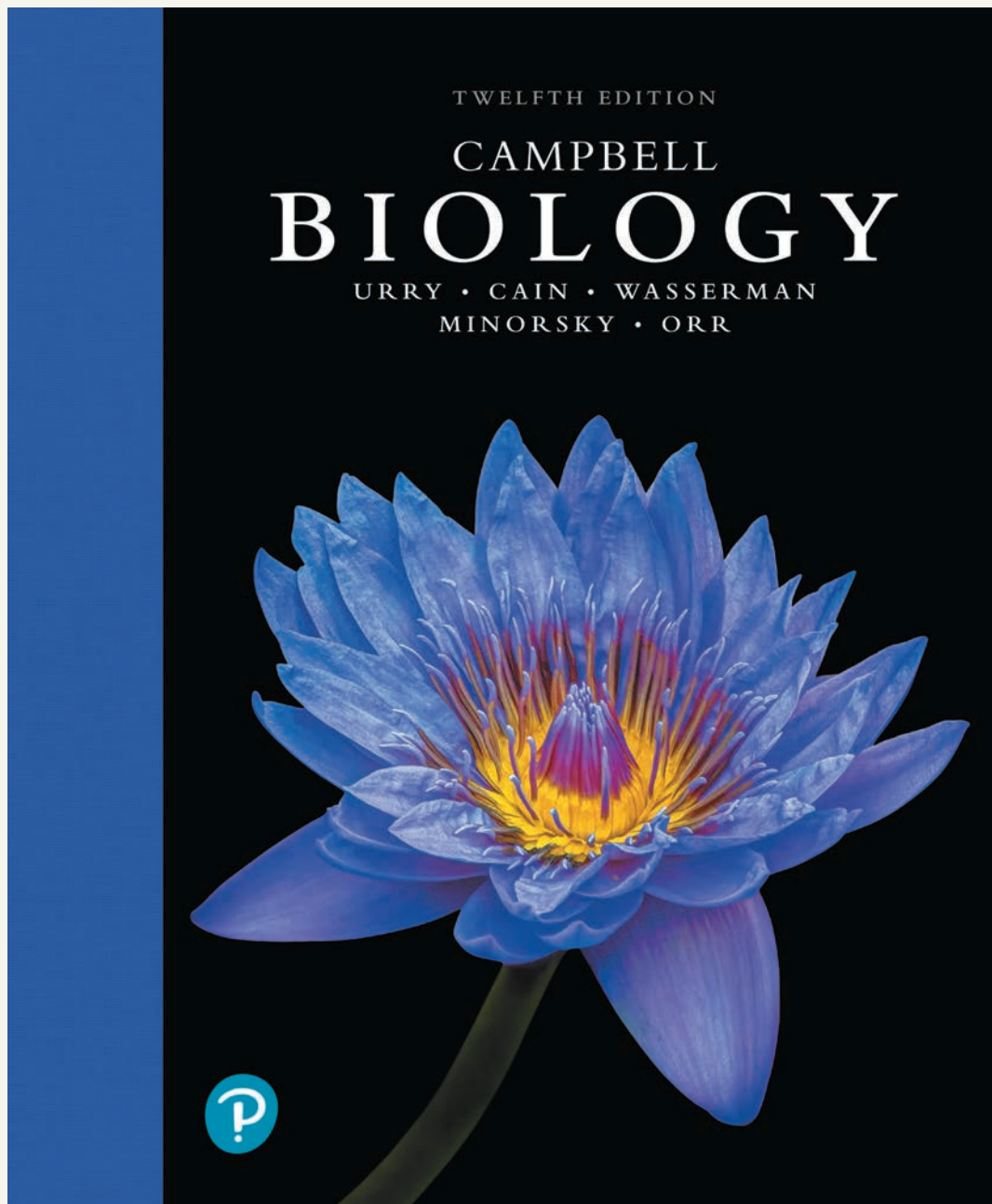


ISBN 10: 0-135-18874-1; ISBN 13: 978-0-135-18874-3 (Rental Edition)
ISBN 10: 0-136-62344-1; ISBN 13: 978-0-136-62344-1 (Instructor Review Copy)

www.pearson.com

Setting the Standard for Excellence, Accuracy, and Innovation

Campbell Biology, 12th Edition, delivers an authoritative, accurate, current, and pedagogically innovative experience that helps students make connections so they learn and understand biology. This edition presents new, engaging visual and digital resources that meet demonstrated student needs.



A New Visual Experience for Every Chapter

NEW! Chapter Openers introduce each chapter and feature a question answered with a clear, simple image to help students visualize and remember concepts as they move through each chapter. Each opener includes a Study Tip and highlights of interactive media in Mastering Biology.

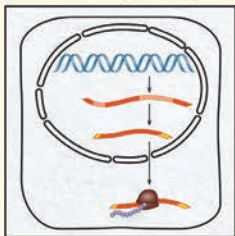
17 Gene Expression: From Gene to Protein

KEY CONCEPTS

- 17.1** Genes specify proteins via transcription and translation p. 336
- 17.2** Transcription is the DNA-directed synthesis of RNA: *A Closer Look* p. 342
- 17.3** Eukaryotic cells modify RNA after transcription p. 345
- 17.4** Translation is the RNA-directed synthesis of a polypeptide: *A Closer Look* p. 347
- 17.5** Mutations of one or a few nucleotides can affect protein structure and function p. 357

Study Tip

Make a visual study guide: Sketch the process shown below, and add labels and details as you read the chapter. (In this exercise, assume all processes take place in a eukaryotic cell.)



Go to Mastering Biology

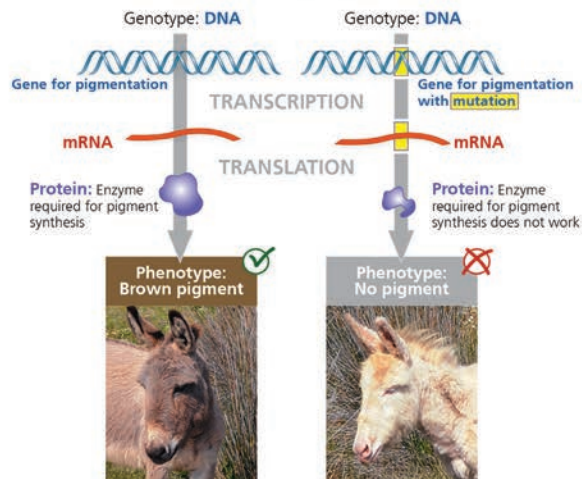
- For Students** (in eText and Study Area)
- Get Ready for Chapter 17
 - BioFlix® Animation: Protein Synthesis
 - Figure 17.27 Walkthrough: Types of Small-Scale Mutations that Affect mRNA Sequence
- For Instructors to Assign** (in Item Library)
- BioFlix® Tutorial: Protein Synthesis (1 of 3): Overview
 - Tutorial: CRISPR: A Revolution in Genome Editing
- Ready-to-Go Teaching Module** (in Instructor Resources)
- Gene Expression: Mutations (Concept 17.5)



Figure 17.1 A population of albino donkeys grazes on vegetation on the hillsides of Asinara, an Italian island. Several centuries ago, a recessive mutation that disables pigment synthesis arose in the DNA of one donkey and was passed down through the generations. Inbreeding has resulted in a large number of homozygous albino donkeys living on the island today.

How can one change in DNA result in such a dramatic change in appearance?

Proteins are the link between genotype and phenotype. Gene expression is the process by which DNA directs the synthesis of proteins.



NEW! A Visual Overview helps students start with the big picture.

39 Plant Responses to Internal and External Signals

KEY CONCEPTS

- 39.1** Signal transduction pathways link signal reception to response p. 843
- 39.2** Plants use chemicals to communicate p. 845
- 39.3** Responses to light are critical for plant success p. 855
- 39.4** Plants respond to a wide variety of stimuli other than light p. 861
- 39.5** Plants respond to attacks by pathogens and herbivores p. 866



Figure 39.1 Sunflowers track the sun from east to west each day. After sunset, they reverse direction, facing the direction of the next sunrise. By facing the hot sun during the day, the floral heads become warmer and release greater amounts of chemicals that attract pollinators. Light is just one of the many factors to which a plant responds.

Study Tip

Make a table: As you read the chapter, add specific examples for each of the general categories of responses shown in the diagram.

Factor	Example of plant response
Light	Seed germination in response to red light

NEW! A Study Tip provides an activity for students to help them organize and learn the information in the chapter.

Go to Mastering Biology

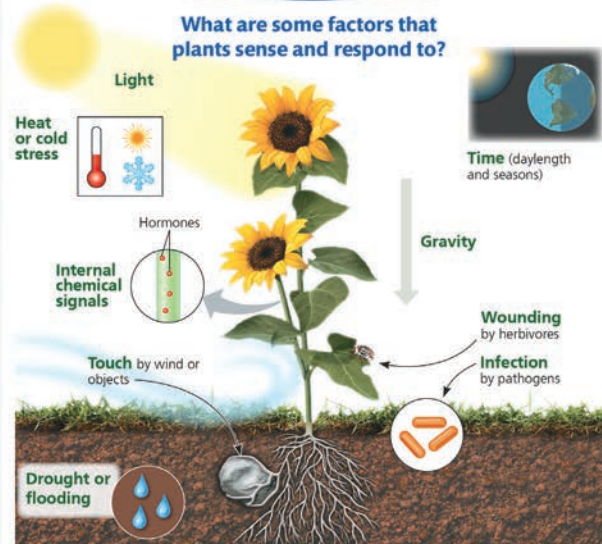
For Students (in eText and Study Area)

- Get Ready for Chapter 39
- Video: Gravitropism
- Video: *Mimosa* leaves

For Instructors to Assign (in Item Library)

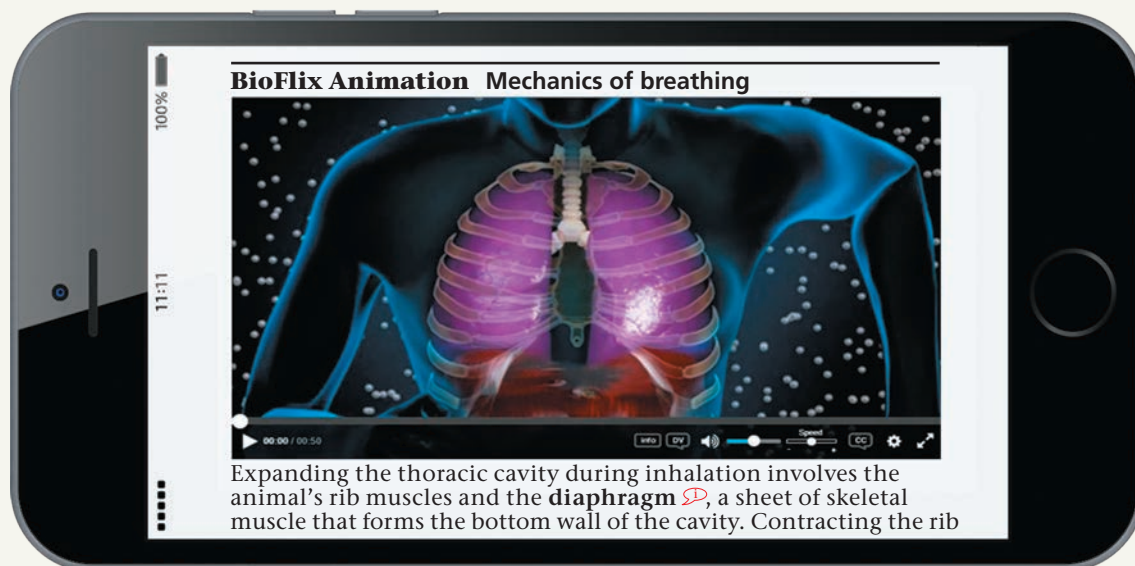
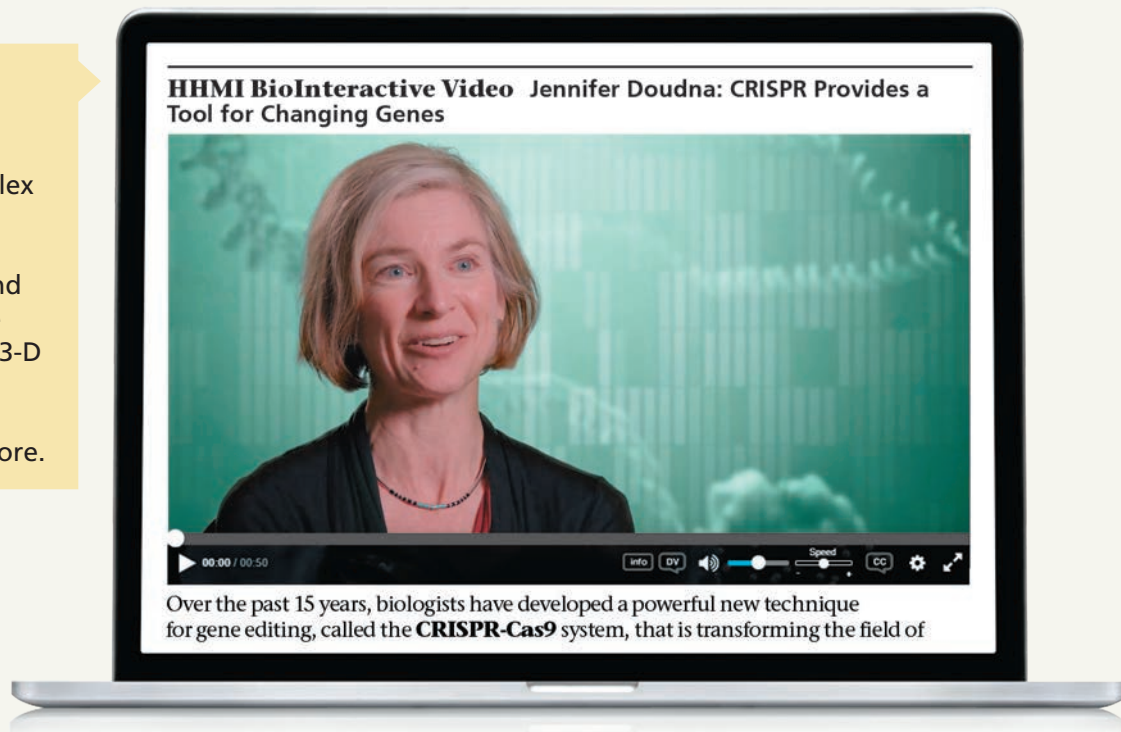
- Activity: Leaf Abscission
- Activity: Plant Hormones

NEW! Key Mastering Biology resources are highlighted for students and instructors.



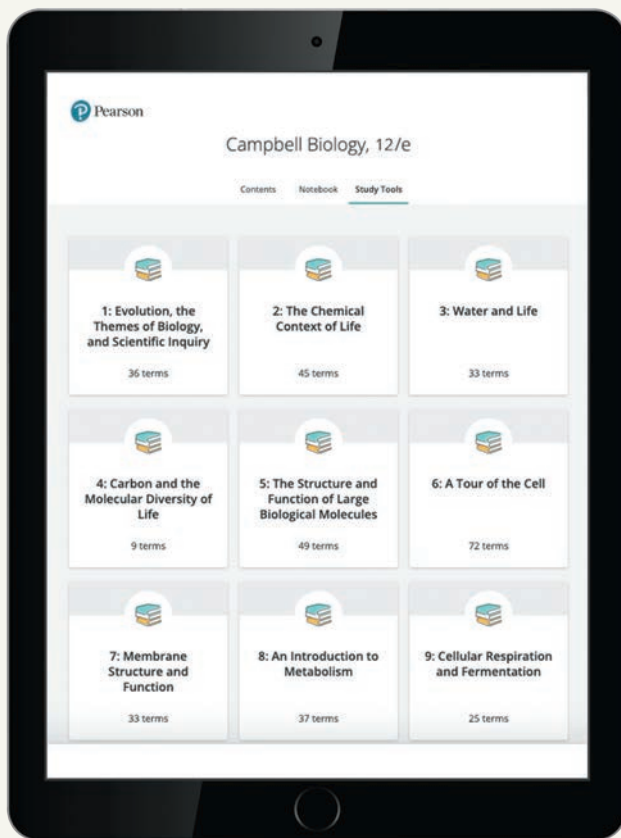
Pearson eText for *Campbell Biology*:

EXPANDED! 500 embedded Videos & Animations help students visualize complex biology topics. These include: new HHMI BioInteractive Videos and Animations, new Figure Walkthroughs, BioFlix® 3-D Animations, Galápagos Videos by Peter and Rosemary Grant, and more.

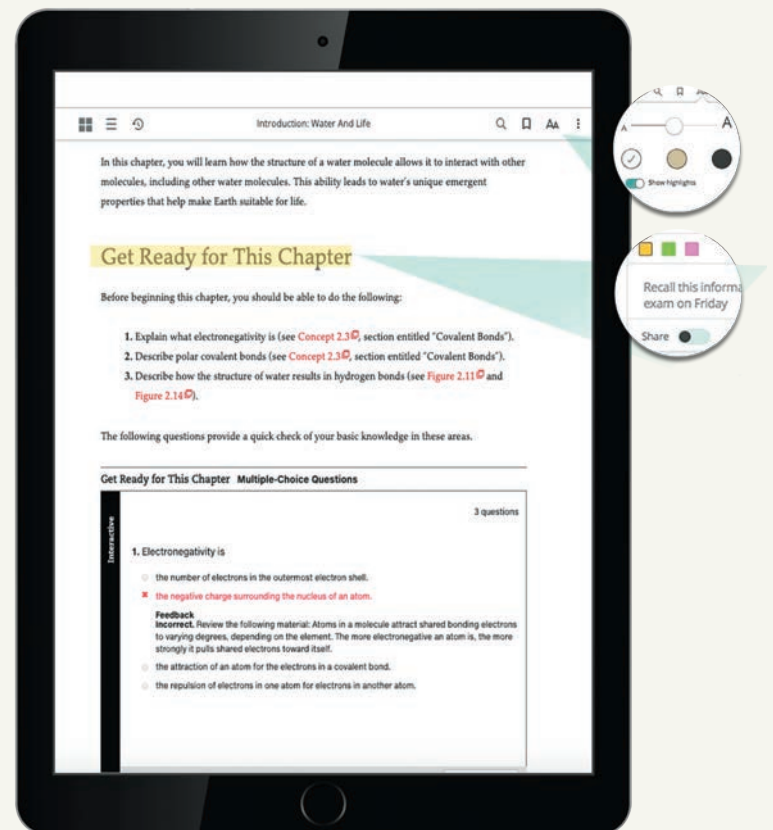


A Whole New Reading Experience

NEW! The **Pearson eText** is a simple-to-use, mobile-optimized, personalized reading experience. It allows students to easily highlight, take notes, and review vocabulary all in one place—even when offline. **Pearson eText for Campbell Biology** also includes **Get Ready for This Chapter Questions, Practice Tests, Figure Walkthroughs, and 500 videos and animations.**

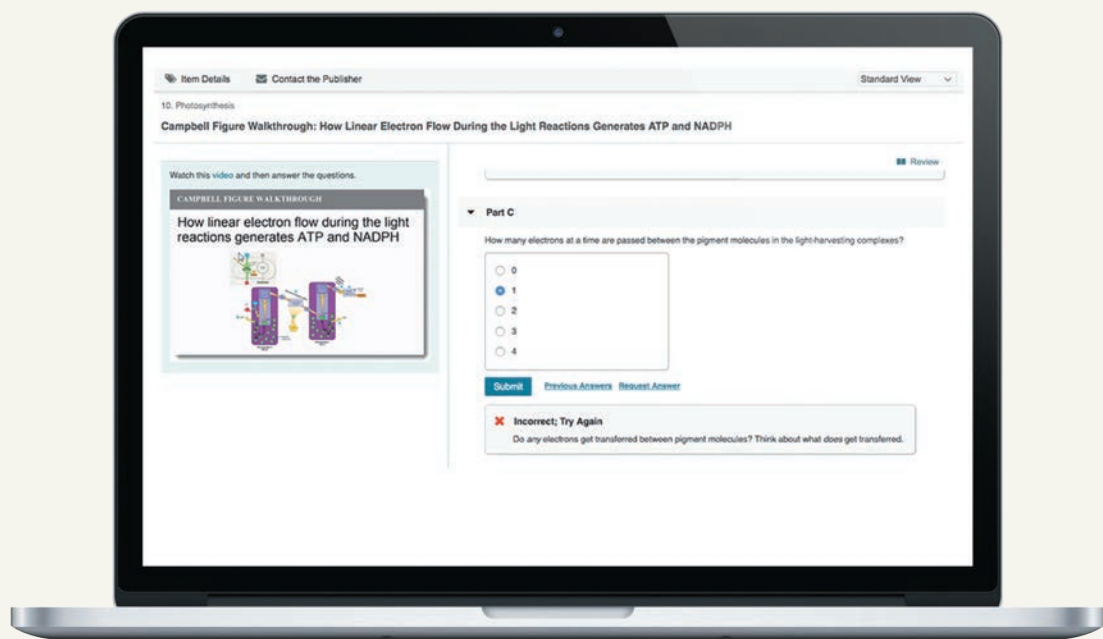
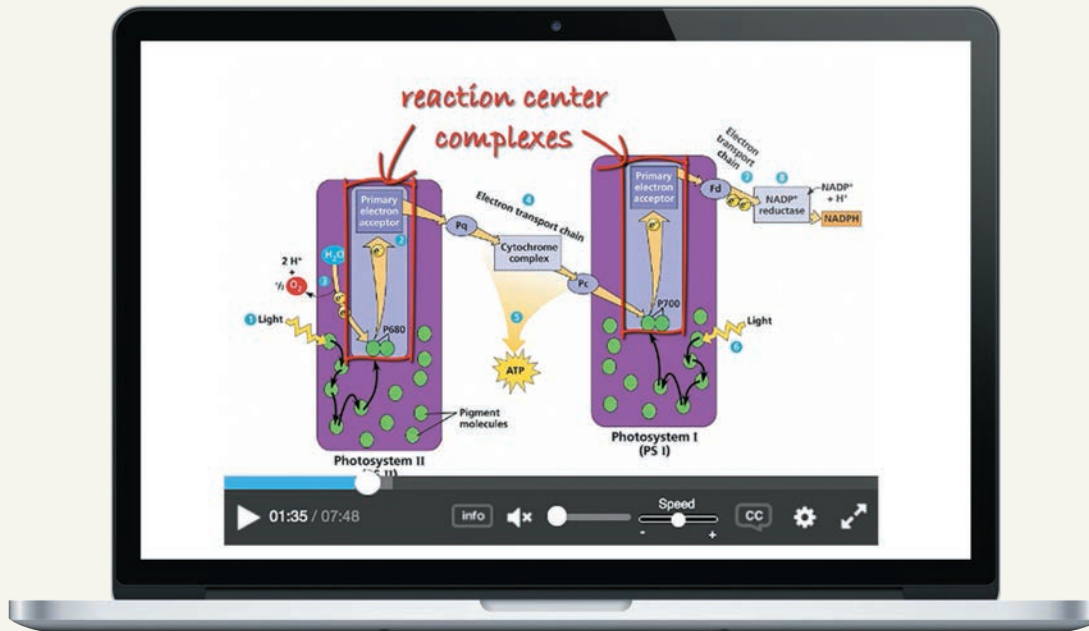


The Pearson eText app is available for download in the app store for approved devices.



Bringing Innovative Art to Life

NEW! An expanded collection of **Figure Walkthroughs** guide students through key figures with narrated explanations and figure mark-ups that reinforce important points. **These are embedded in the eText and available for assignment in Mastering Biology.**



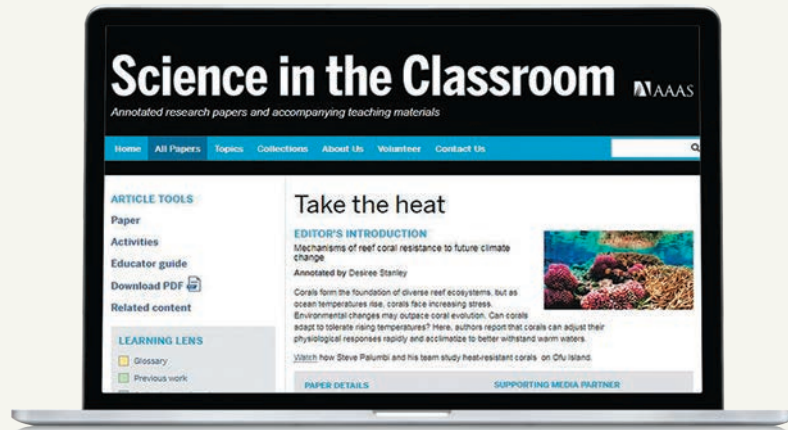
Giving Students the Tools They Need to Succeed

Explore Scientific Papers with Science in the Classroom AAAS

How are coral reefs responding to climate change?

Go to "Take the Heat" at www.scienceintheclassroom.org.

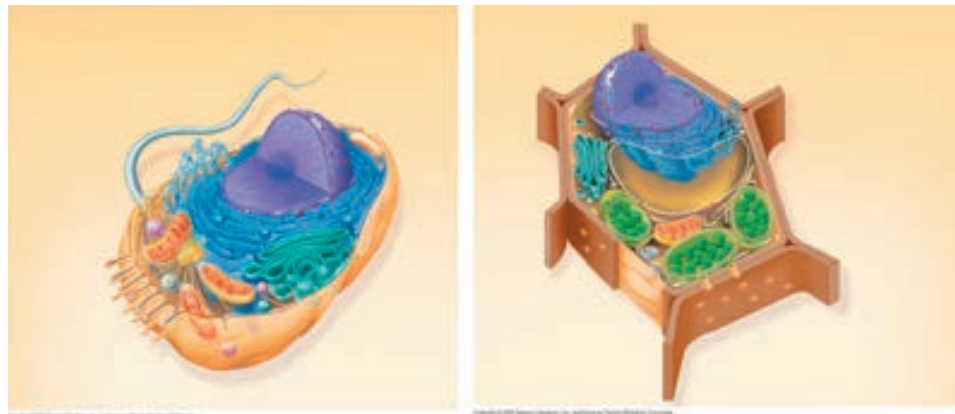
→ **Instructors:** Questions can be assigned in Mastering Biology.



NEW! Science in the Classroom presents annotated journal articles from the **American Association for the Advancement of Science (AAAS)** and makes reading and understanding primary literature easier for students. The articles include assessments in Mastering Biology, allowing instructors to assign the journal articles.

NEW! Active Reading Guides support students in actively reading their biology text. Students can download the worksheets from the Study Area in Mastering Biology.

35. On these diagrams of plant and animal cells, label each organelle and give a brief statement of its function.



Concept 6.6 The cytoskeleton is a network of fibers that organizes structures and activities in the cell

36. What is the cytoskeleton?
37. What are the three roles of the cytoskeleton?
38. There are three main types of fibers that make up the cytoskeleton. Name them.
39. *Microtubules* are hollow rods made of a globular protein called tubulin. Each tubulin protein is a dimer made of two subunits. These are easily assembled and disassembled. What are four functions of microtubules?

Make Connections Across Multiple Concepts

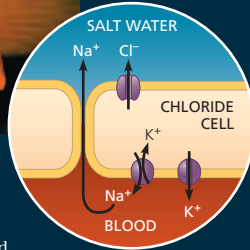
Make Connections Figures pull together content from different chapters, providing a visual representation of “big picture” relationships.

▼ Figure 44.17

MAKE CONNECTIONS

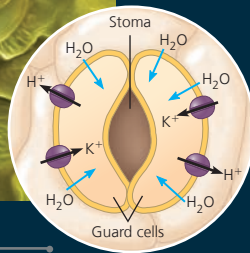
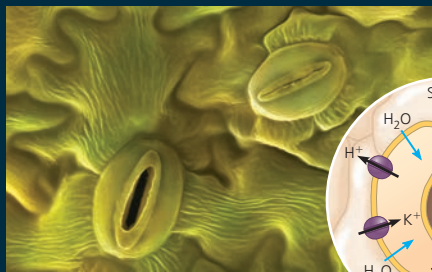
Ion Movement and Gradients

The transport of ions across the plasma membrane of a cell is a fundamental activity of all animals, and indeed of all living things. By generating ion gradients, ion transport provides the potential energy that powers processes ranging from an organism’s regulation of salts and gases in internal fluids to its perception of and locomotion through its environment.



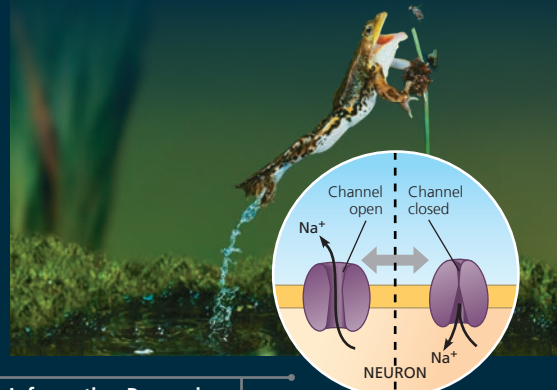
Osmoregulation

In marine bony fishes, ion gradients drive secretion of salt (NaCl), a process essential to avoid dehydration. Within gills, the pumps, cotransporters, and channels of specialized chloride cells function together to drive salt from the blood across the gill epithelium and into the surrounding salt water. (See Figure 44.3.)



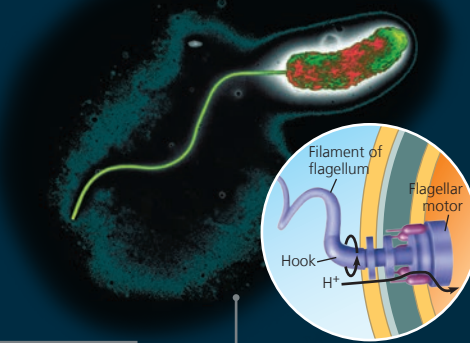
Gas Exchange

Ion gradients provide the basis for the opening of a plant stoma by surrounding guard cells. Active transport of H^+ out of a guard cell generates a voltage (membrane potential) that drives inward movement of K^+ . This uptake of K^+ by guard cells triggers an osmotic influx of water that changes cell shape, bowing the guard cells outward and thereby opening the stoma. (See Concept 36.4.)



Information Processing

In neurons, transmission of information as nerve impulses is made possible by the opening and closing of channels selective for sodium or other ions. These signals enable nervous systems to receive and process input and to direct appropriate output, such as this leap of a frog capturing prey. (See Concept 48.3 and Concept 50.5.)



Locomotion

A gradient of H^+ powers the bacterial flagellum. An electron transport chain generates this gradient, establishing a higher concentration of H^+ outside the bacterial cell. Protons reentering the cell provide a force that causes the flagellar motor to rotate. The rotating motor turns the curved hook, causing the attached filament to propel the cell. (See Concept 9.4 and Figure 27.7.)

MAKE CONNECTIONS

Explain why the set of forces driving ion movement across the plasma membrane of a cell is described as an electrochemical (electrical and chemical) gradient (see Concept 7.4).

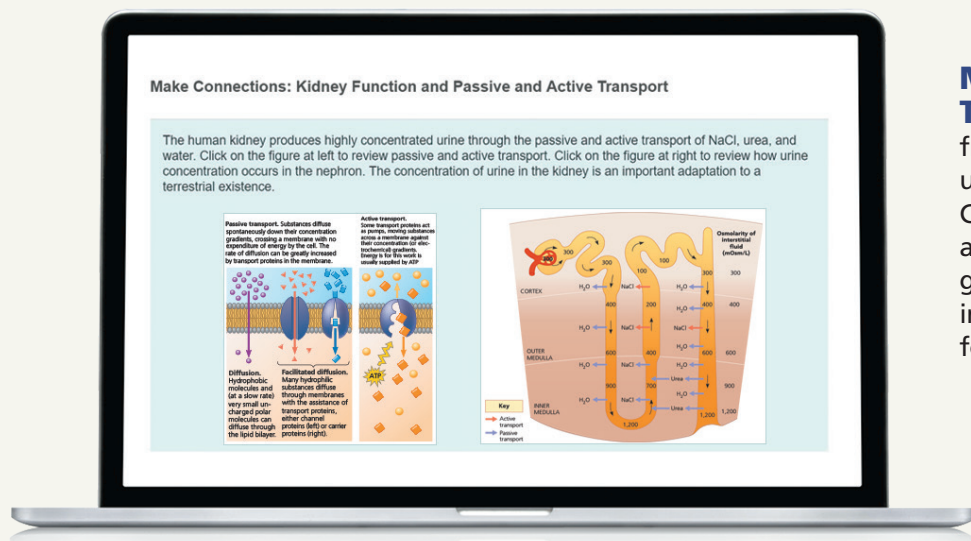
➔ Mastering Biology BioFlix® Animation: Membrane Transport

Make Connections Questions in every chapter ask students to relate content to material presented earlier in the course.

CONCEPT CHECK 24.2

1. Summarize key differences between allopatric and sympatric speciation. Which type of speciation is more common, and why?
2. Describe two mechanisms that can decrease gene flow in sympatric populations, thereby making sympatric speciation more likely to occur.
3. **WHAT IF?** Is allopatric speciation more likely to occur on an island close to a mainland or on a more isolated island of the same size? Explain your prediction.
4. **MAKE CONNECTIONS** Review the process of meiosis in Figure 13.8. Describe how an error during meiosis could lead to polyploidy.

For suggested answers, see Appendix A.



Make Connections Tutorials connect content from two different chapters using art from the book. Make Connections Tutorials are assignable and automatically graded in Mastering Biology and include answer-specific feedback for students.

Develop Scientific Skills

Scientific Skills Exercise

Analyzing Polypeptide Sequence Data

Are Rhesus Monkeys or Gibbons More Closely Related to Humans? In this exercise, you will look at amino acid sequence data for the β polypeptide chain of hemoglobin, often called β -globin. You will then interpret the data to hypothesize whether the monkey or the gibbon is more closely related to humans.

How Such Experiments Are Done Researchers can isolate the polypeptide of interest from an organism and then determine the amino acid sequence. More frequently, the DNA of the relevant gene is sequenced, and the amino acid sequence of the polypeptide is deduced from the DNA sequence of its gene.

Data from the Experiments In the data below, the letters give the sequence of the 146 amino acids in β -globin from humans,

Species	Alignment of Amino Acid Sequences of β -globin
Human	1 VHLTPEEKSA VTALNGKVVN DEVGGEALGR LLVVPMTQR FFESFGDLST
Monkey	1 VHLTPEEKNA VTTLNGKVVN DEVGGEALGR LLVVPMTQR FFESFGDLS5
Gibbon	1 VHLTPEEKSA VTALNGKVVN DEVGGEALGR LLVVPMTQR FFESFGDLST
Human	51 PDAVNGNPKV KAHGKKVLGA FSDGLAHLDN LKGTFAQLSE LKCDKLHVDP
Monkey	51 PDAVNGNPKV KAHGKKVLGA FSDGLAHLDN LKGTFAQLSE LKCDKLHVDP
Gibbon	51 PDAVNGNPKV KAHGKKVLGA FSDGLAHLDN LKGTFAQLSE LKCDKLHVDP
Human	101 ENFRLLGNVL VCVLAHFGK EFTPPVQAAV QKVVAGVANA LAHKYH
Monkey	101 ENFRLLGNVL VCVLAHFGK EFTPPVQAAV QKVVAGVANA LAHKYH
Gibbon	101 ENFRLLGNVL VCVLAHFGK EFTPPVQAAV QKVVAGVANA LAHKYH

Data from Human: <http://www.ncbi.nlm.nih.gov/protein/AAA21113.1>; **rhesus monkey:** <http://www.ncbi.nlm.nih.gov/protein/122634>; **gibbon:** <http://www.ncbi.nlm.nih.gov/protein/122616>



rhesus monkeys, and gibbons. Because a complete sequence would not fit on one line here, the sequences are divided into three segments: amino acids 1–50, 51–100, and 101–146. The sequences for the three different species are aligned so that you can compare them easily. For example, you can see that for all three species, the first amino acid is V (valine) and the 146th amino acid is H (histidine).

INTERPRET THE DATA

- Scan the monkey and gibbon sequences, letter by letter, circling any amino acids that do not match the human sequence. (a) How many amino acids differ between the monkey and the human sequences? (b) Between the gibbon and human?
- For each nonhuman species, what percent of its amino acids are identical to the human sequence of β -globin?
- Based on these data alone, state a hypothesis for which of these two species is more closely related to humans. What is your reasoning?
- What other evidence could you use to support your hypothesis?

Instructors: A version of this Scientific Skills Exercise can be assigned in **Mastering Biology**.

Scientific Skills Exercises in every chapter of the text use real data to build key skills needed for biology, including data analysis, graphing, experimental design, and math skills. Each exercise is also available as an automatically graded assignment in Mastering Biology with answer-specific feedback for students.

Problem-Solving Exercises guide students in applying scientific skills and interpreting real data in the context of solving a real-world problem. A version of each Problem-Solving Exercise can also be assigned in Mastering Biology.

PROBLEM-SOLVING EXERCISE

Can declining amphibian populations be saved by a vaccine?

Amphibian populations are declining rapidly worldwide. The fungus *Batrachochytrium dendrobatidis* (*Bd*) has contributed to this decline: This pathogen causes severe skin infections in many amphibian species, leading to massive die-offs. Efforts to save amphibians from *Bd* have had limited success, and there is little evidence that frogs and other amphibians have acquired resistance to *Bd* on their own.



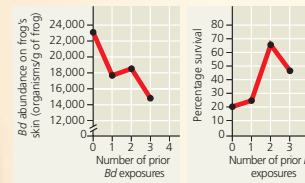
Yellow-legged frogs (*Rana muscosa*) in California killed by *Bd* infection

Instructors: A version of this Problem-Solving Exercise can be assigned in **Mastering Biology**.

In this exercise, you will investigate whether amphibians can acquire resistance to the fungal pathogen *Bd*.

Your Approach The principle guiding your investigation is that prior exposure to a pathogen can enable amphibians to acquire immunological resistance to that pathogen. To see whether this occurs after exposure to *Bd*, you will analyze data on acquired resistance in Cuban tree frogs (*Osteopilus septentrionalis*).

Your Data To create variation in number of prior exposures to *Bd*, Cuban tree frogs were exposed to *Bd* and cleared of their infection (using heat treatments) from zero to three times; frogs with no prior exposures are referred to as "naive." Researchers then exposed frogs to *Bd* and measured mean abundance of *Bd* on the frog's skin, frog survival, and abundance of lymphocytes (a type of white blood cell involved in the vertebrate immune response).

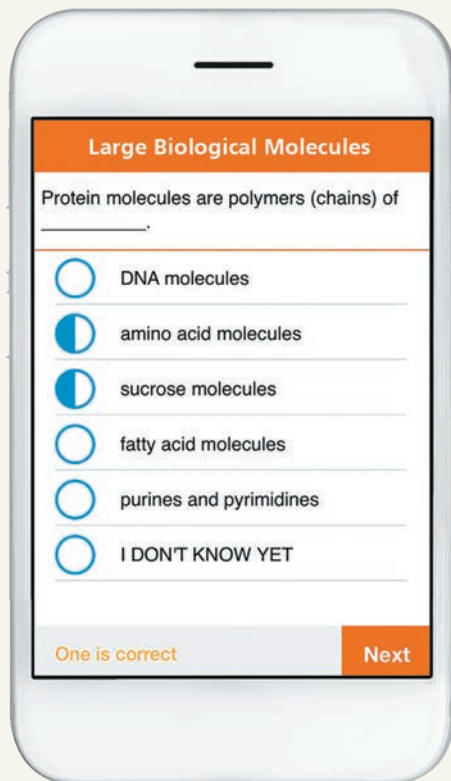


Number of prior <i>Bd</i> exposures	Thousands of lymphocytes per g of frog
0	134
1	240
2	244
3	227

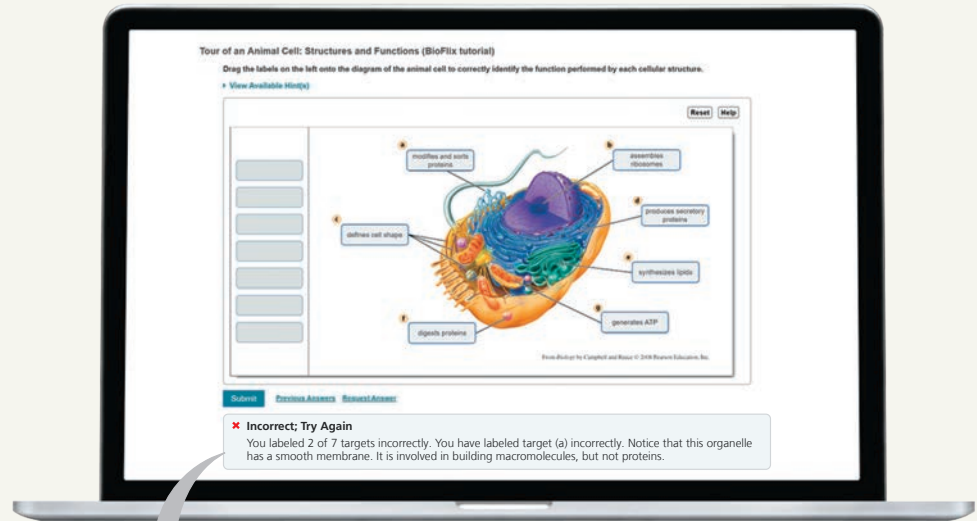
Your Analysis

- Describe and interpret the results shown in the figure.
- (a) Graph the data in the table. (b) Based on these data, develop a hypothesis that explains the results discussed in question 1.
- Breeding populations of amphibian species threatened by *Bd* have been established in captivity. In addition, evidence suggests that Cuban tree frogs can acquire resistance after exposure to dead *Bd*. Based on this information and your answers to questions 1 and 2, suggest a strategy for repopulating regions decimated by *Bd*.

Innovation in Assessment



Dynamic Study Modules use the latest developments in cognitive science to help students study by adapting to their performance in real time. Students build confidence and understanding, enabling them to participate and perform better, both in and out of class. Available on smartphones, tablets, and computers.



✘ Incorrect; Try Again

You labeled 2 of 7 targets incorrectly. You have labeled target (a) incorrectly. Notice that this organelle has a smooth membrane. It is involved in building macromolecules, but not proteins.



Wrong-Answer Feedback Using data gathered from all of the students using the program, **Mastering Biology** offers wrong-answer feedback that is specific to each student. Rather than simply providing feedback of the “right/wrong/try again” variety, Mastering Biology guides students toward the correct final answer without giving the answer away.

“I wouldn’t have passed my class without Mastering Biology. The feedback doesn’t just tell me I’m wrong, it gave me a paragraph of feedback on why I was wrong and how I could better understand it.”

—Student, University of Texas at Arlington

UPDATED! Test Bank questions have been analyzed and revised with student success in mind. Revisions account for how students read, analyze, and engage with the content.

Innovation in Instructor Resources

NEW! 5 new Ready-to-Go Teaching Modules expand the number of modules to 15. These instructor resources are designed to make use of teaching tools before, during, and after class, including new ideas for in-class activities. The modules incorporate the best that the text, **Mastering Biology**, and **Learning Catalytics** have to offer and can be accessed through the Instructor Resources area of Mastering Biology.



NEW! Early Alerts in **Mastering Biology** help instructors know when students may be struggling in the course. This insight enables instructors to provide personalized communication and support at the moment students need it so they can stay—and succeed—in the course.



About the Authors

The author team's contributions reflect their biological expertise as researchers and their teaching sensibilities gained from years of experience as instructors at diverse institutions. They are also experienced textbook authors, having written *Campbell Biology in Focus* in addition to *Campbell Biology*.



Lisa A. Urry (Chapter 1 and Units 1–3) is Professor of Biology at Mills College. After earning a B.A. at Tufts University, she completed her Ph.D. at the Massachusetts Institute of Technology (MIT). Lisa has conducted research on gene expression during embryonic and larval development in sea urchins. Deeply committed to promoting opportunities in science for women and underrepresented minorities, she has taught courses ranging from introductory and developmental biology to an immersive course on the U.S./Mexico border.



Michael L. Cain (Units 4, 5, and 8) is an ecologist and evolutionary biologist who is now writing full-time. Michael earned an A.B. from Bowdoin College, an M.Sc. from Brown University, and a Ph.D. from Cornell University. As a faculty member at New Mexico State University, he taught introductory biology, ecology, evolution, botany, and conservation biology. Michael is the author of dozens of scientific papers on topics that include foraging behavior in insects and plants, long-distance seed dispersal, and speciation in crickets. He is also a coauthor of an ecology textbook.



Steven A. Wasserman (Unit 7) is Professor of Biology at the University of California, San Diego (UCSD). He earned an A.B. from Harvard University and a Ph.D. from MIT. Working on the fruit fly *Drosophila*, Steve has done research on developmental biology, reproduction, and immunity. Having taught genetics, development, and physiology to undergraduate, graduate, and medical students, he now focuses on introductory biology, for which he has been honored with UCSD's Distinguished Teaching Award.



Peter V. Minorsky (Unit 6) is Professor of Biology at Mercy College in New York, where he teaches introductory biology, ecology, and botany. He received his A.B. from Vassar College and his Ph.D. from Cornell University. Peter taught at Kenyon College, Union College, Western Connecticut State University, and Vassar College; he is also the science writer for the journal *Plant Physiology*. His research interests concern how plants sense environmental change. Peter received the 2008 Award for Teaching Excellence at Mercy College.



Rebecca B. Orr (Ready-to-Go Teaching Modules, Interactive Visual Activities, eText Media Integration) is Professor of Biology at Collin College in Plano, Texas, where she teaches introductory biology. She earned her B.S. from Texas A&M University and her Ph.D. from University of Texas Southwestern Medical Center at Dallas. Rebecca has a passion for investigating strategies that result in more effective learning and retention, and she is a certified Team-Based Learning Collaborative Trainer Consultant. She enjoys focusing on the creation of learning opportunities that both engage and challenge students.



Neil A. Campbell (1946–2004) earned his M.A. from the University of California, Los Angeles, and his Ph.D. from the University of California, Riverside. His research focused on desert and coastal plants. Neil's 30 years of teaching included introductory biology courses at Cornell University, Pomona College, and San Bernardino Valley College, where he received the college's first Outstanding Professor Award in 1986. For many years he was also a visiting scholar at UC Riverside. Neil was the founding author of *Campbell Biology*.

To Jane, our coauthor, mentor, and friend. Enjoy your retirement! LAU, MLC, SAW, and PVM

Preface

We are honored to present the Twelfth Edition of *Campbell Biology*. For the last three decades, *Campbell Biology* has been the leading college text in the biological sciences. It has been translated into 19 languages and has provided millions of students with a solid foundation in college-level biology. This success is a testament not only to Neil Campbell's original vision but also to the dedication of hundreds of reviewers (listed on pages xxviii–xxxi), who, together with editors, artists, and contributors, have shaped and inspired this work.

Our goals for the Twelfth Edition include:

- **supporting students** with new visual presentations of content and new study tools
- **supporting instructors** by providing new teaching modules with tools and materials for introducing, teaching, and assessing important and often challenging topics
- **integrating text and media** to engage, guide, and inform students in an active process of inquiry and learning

Our starting point, as always, is our commitment to crafting text and visuals that are accurate, are current, and reflect our passion for teaching biology.

New to This Edition

Here we provide an overview of the new features that we have developed for the Twelfth Edition; we invite you to explore pages iii–xiv for more information and examples.

- **NEW! Chapter Openers Re-envisioned.** Catalyzed by feedback from students and instructors, informed by data analytics, and building on the results of science education research, we have redesigned the opening of every chapter of the text. The result is more visual, more interactive, and more engaging. In place of an opening narrative, the first page of each chapter is organized around three new elements that provide students with the specific tools and approaches needed to achieve the learning objectives of that chapter:
 - **NEW! Visual Overview.** Centered on a basic biological question related to the opening photo and legend, the Visual Overview illustrates a core idea of the chapter with straightforward art and text. Students get an immediate sense of what the chapter is about and what kinds of thinking will underlie its exploration.
 - **NEW! Study Tip.** Just as the Visual Overview introduces students to *what* they will learn, the study tip offers guidance in *how* to learn. It encourages students to learn actively through such proven strategies as drawing a flow chart, labeling a diagram, or making a table. Each tip provides an effective strategy for tackling important content in the chapter.



- **NEW! Highlights of Digital Resources.**

In conversations with users of the textbook, we often encounter a limited awareness of the digital tools the text provides to facilitate instruction and learning. We therefore created *Go to Mastering Biology*, a chapter opener section where we highlight some of the tutorials, animations, and other interactives available for students to explore

on their own or for instructors to assign. These resources include Get Ready for This Chapter questions, Figure Walkthroughs, HHMI BioInteractive videos, Ready-to-Go Teaching Modules, and more.

- **NEW! Updated Content.** As in each new edition of *Campbell Biology*, the Twelfth Edition incorporates new content, summarized on pages xviii–xx. Content updates reflect rapid, ongoing changes in knowledge about climate change, genomics, gene-editing technology (CRISPR), evolutionary biology, microbiome-based therapies, and more. In addition, Unit 7 includes a new section on “Biological Sex, Gender Identity, and Sexual Orientation in Human Sexuality,” which provides instructors and students with a thoughtful, clear, and current introduction to topics of tremendous relevance to biology, to student lives, and to current public discourse and events.
- **NEW! Active Reading Guides.** These worksheets provide students with self-assessment activities to complete as they read each chapter. Students can download the Active Reading Guides from the Mastering Biology Study Area.
- **5 NEW! Ready-to-Go Teaching Modules.** The Ready-to-Go Teaching Modules provide instructors with active learning exercises and questions to use in class, plus Mastering Biology assignments that can be assigned before and after class. A total of 15 modules are now available in the Instructor Resources area of Mastering Biology.

Pearson eText

Students using the Pearson eText will reap all the benefits of the new text features, while also benefiting from the following new and existing interactive resources, which are integrated directly into the online text:

- **NEW!** An expanded collection of the popular **Figure Walkthroughs** guide students through key figures with narrated explanations and figure mark-ups that reinforce important points.
- **NEW!** Links to the **AAAS Science in the Classroom** website provide research papers from *Science* with annotations to help students understand the papers. These links are included at the end of each appropriate chapter.

- **EXPANDED! 500 animations and videos** bring biology to life. These include new resources from **HHMI BioInteractive** that engage students in topics from CRISPR to coral reefs.
- **Get Ready for This Chapter** questions provide a quick check of student understanding of the background information needed to learn a new chapter's content, with feedback to bolster their preparation.
- **Vocabulary Self-Quizzes** and **Practice Tests** at the end of each chapter provide opportunities for students to test their understanding.
- Links to **Interviews** from all editions of *Campbell Biology* are included in the chapter where they are most relevant. The interviews show students the human side of science by featuring diverse scientists talking about how they became interested in biology and what inspires them.

For more information, see pages vi–ix.

Mastering Biology

Mastering Biology provides valuable resources for instructors to assign homework and for students to study on their own:

- **Assignments.** Mastering Biology is the most widely used online assessment and tutorial program for biology, providing an extensive library of thousands of tutorials and questions that are graded automatically.
 - **NEW! Early Alerts** give instructors a quick way to monitor students' progress and provide feedback, even before the first test.
 - **NEW! AAAS Science in the Classroom** journal articles can be assigned with automatically graded questions.
 - Hundreds of self-paced **tutorials** provide individualized coaching with specific hints and feedback on the most difficult topics in the course.
 - Optional **Adaptive Follow-up Assignments** provide additional questions tailored to each student's needs.
- **Pearson eText.** The Pearson eText, described above, can be directly accessed from Mastering Biology.
- **Dynamic Study Modules.** These popular review tools can be assigned, or students can use them for self-study.
- **Study Area.** Media references in the printed book direct students to the wealth of online self-study resources available to them in the Mastering Biology Study Area, including Active Reading Guides, Figure Walkthroughs, videos, animations, Get Ready for This Chapter, Practice Tests, Cumulative Test, and more.
- **Instructor Resources.** This area of Mastering Biology provides one-stop shopping for Ready-to-Go Teaching Modules, PowerPoints, Clicker Questions, animations, videos, the Test Bank, and more.

For more information, see pages xiii–xiv and xxiv–xxv and visit www.masteringbiology.com.

Our Hallmark Features

Teachers of general biology face a daunting challenge: to help students acquire a conceptual framework for organizing an ever-expanding amount of information. The hallmark features of *Campbell Biology* provide such a framework, while promoting a deeper understanding of biology and the process of science. As such, they are well-aligned with the core competencies outlined by the **Vision and Change** national conferences. Furthermore, the core concepts defined by Vision and Change have close parallels in the unifying themes that are introduced in Chapter 1 and integrated throughout the book.

Chief among the themes of both Vision and Change and *Campbell Biology* is **evolution**. Each chapter of this text includes at least one Evolution section that explicitly focuses on evolutionary aspects of the chapter material, and each chapter ends with an Evolution Connection Question and a Write About a Theme Question.

To help students distinguish “the forest from the trees,” each chapter is organized around a framework of three to seven carefully chosen **Key Concepts**. The text, Concept Check Questions, Summary of Key Concepts, and Mastering Biology resources all reinforce these main ideas and essential facts.

Because text and illustrations are equally important for learning biology, **integration of text and figures** has been a hallmark of *Campbell Biology* since the First Edition. The new Visual Overviews, together with our popular Visualizing Figures, Exploring Figures, and Make Connections Figures, epitomize this approach.

To encourage **active reading** of the text, *Campbell Biology* includes numerous opportunities for students to stop and think about what they are reading, often by putting pencil to paper to draw a sketch, annotate a figure, or graph data. Answering these questions requires students to write or draw as well as think and thus helps develop the core competency of communicating science.

Finally, *Campbell Biology* has always featured **scientific inquiry**. The inquiry activities provide students practice in applying the process of science and using quantitative reasoning, addressing core competencies from Vision and Change.

Our Partnership with Instructors and Students

The real test of any textbook is how well it helps instructors teach and students learn. We welcome comments from both students and instructors. Please address your suggestions to:

Lisa Urry (Chapter 1 and Units 1–3): lurry@mills.edu
 Michael Cain (Units 4, 5, and 8): mlcain@nmsu.edu
 Peter Minorsky (Unit 6): pminorsky@mercy.edu
 Steven Wasserman (Unit 7): stevenw@ucsd.edu
 Rebecca Orr (Media): rorr@collin.edu

Highlights of New Content

This section highlights selected new content in *Campbell Biology*, Twelfth Edition. In addition to the content updates noted here, every chapter has a **new Visual Overview** on the chapter opening page.

Unit 1 THE CHEMISTRY OF LIFE

In Unit 1, new content engages students in learning foundational chemistry. Chapter 2 includes a new micrograph of the tiny hairs on a gecko's foot that allow it to walk up a wall. The opening photo for Chapter 3 features a ringed seal, a species endangered by the melting of Arctic sea ice due to climate change. Chapter 3 also has added coverage on the discovery of a large subsurface reservoir of liquid water on Mars and the first CO₂ enhancement study done on an unconfined natural coral reef (both reported in 2018). Chapter 4 now includes the discovery of carbon-based compounds on Mars reported by NASA in 2018. In Chapter 5, the technique of cryo-electron microscopy is introduced, due to its increasing importance in the determination of molecular structure.

Unit 2 THE CELL

Our main goal for this unit was to make the material more accessible, inviting, and exciting to students. Chapter 6 includes a new text description of cryo-electron microscopy (cryo-EM) and a new cryo-EM image in Figure 6.3. Art has been added to Figure 6.17 to illustrate the dynamic nature of mitochondrial networks. Chapter 7 begins with a new chapter-opening image showing neurotransmitter release during exocytosis.

Figure 8.1 includes a new photo of bioluminescent click beetle larvae on the

outside of a termite mound and a new Visual Overview that illustrates how the laws of thermodynamics apply to metabolic reactions like bioluminescence.

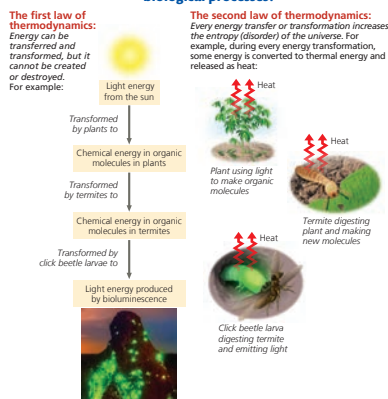
Chapter 9 includes new information on human brown fat usage, the role of fermentation during the production of chocolate, and recent research on the role of lactate in mammalian metabolism. Chapter

▼ **Figure 8.1**



Figure 8.1 The green glowing spots on the outside of this Brazilian termite mound are larvae of the click beetle, *Pyrophorus rictiphanius*. These larvae convert the energy stored in organic molecules to light, a process called bioluminescence, which attracts termites that the larvae eat. Bioluminescence and other metabolic activities in a cell are energy transformations that are subject to physical laws.

How do the laws of thermodynamics relate to biological processes?



10 begins with a new concept that puts photosynthesis into a big-picture ecological context. Chapter 10 also includes a discussion of the 2018 discovery of a new form of chlorophyll found in cyanobacteria that can carry out photosynthesis using far-red light. In Chapter 11, the relevance of synaptic signaling is underscored by mentioning that it is a target for treatment of depression, anxiety, and PTSD. In Chapter 12, the cell cycle figure (Figure 12.6) now includes cell images and labels describing the events of each phase.

Unit 3 GENETICS

Chapters 13–17 incorporate changes that help students grasp the more abstract concepts of genetics and their chromosomal and molecular underpinnings. For example, a new Concept Check 13.2 question asks students about shoes as an analogy for chromosomes. In Chapter 14, the classic idea of a single gene determining hair or eye color, or even earlobe attachment, is discussed as an oversimplification. Also, the “Fetal Testing” section has been updated to reflect current practices in obstetrics. Chapter 15 now includes new information on “three-parent” babies. In Concept 16.3, the text and Figure 16.23 have been extensively revised to reflect recent models of the structure and organization of interphase chromatin, as well as how chromosomes condense during preparation for mitosis. Chapter 17 now describes the mutation responsible for the albino phenotype of the Asinara donkeys featured in the chapter-opening photo. To make it easier to cover CRISPR, a new section has been added to Concept 17.5 describing the CRISPR-Cas9 system, including Figure 17.28, “Gene editing using the CRISPR-Cas9 system” (formerly Figure 20.14).

Chapters 18–21 are extensively updated, driven by exciting new discoveries based on DNA sequencing and gene-editing technology. In Chapter 18, the coverage of epigenetic inheritance has been enhanced and updated, including the new **Figure 18.8**. Also in Chapter 18, a description of topologically associated domains has been added, along with an update on the 4D Nucleome Network. In Chapter 19, the topic of emerging viral diseases has been updated extensively and reorganized to clearly differentiate influenza viruses that are emerging from those that cause seasonal flu. Other Chapter 19 updates include

▼ **Figure 18.8** Examples of epigenetic inheritance.



(a) Effects of maternal diet on genetically identical mice.



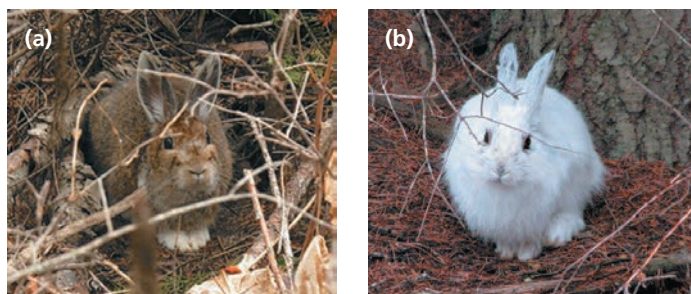
(b) The Dutch Hunger Winter.

information on vaccine programs, mentioning a large measles outbreak in 2019 that correlated with lower vaccination rates in that region. Information has also been added on improvement of treatment regimes for HIV. Chapter 20 has been extensively updated, including addition of two new subsections, “Personal Genome Analysis” and “Personalized Medicine,” with new information on direct-to-consumer genome analysis. Other updates include the first cloning of a primate, stem cell treatment of age-related macular degeneration, CRISPR correction of the sickle-cell disease allele in mice, and a report of gene editing of fertilized human eggs that resulted in live births. Chapter 21 updates include results of the Cancer Genome Atlas Project, a newly discovered function of retrotransposon transcription, and new information on the *FOXP2* gene.

Unit 4 MECHANISMS OF EVOLUTION

The revision of Unit 4 uses an evidence-based approach to strengthen how we help students understand key evolutionary concepts. For example, new text in Concept 24.3 describes how hybrids can become reproductively isolated from both parent species, leading to the formation of a new species. Evidence supporting this new material comes from a 2018 study on the descendants of hybrids between two species of Galápagos finches and provides an example of how scientists can observe the formation of a new species in nature. In Concept 25.2, the discussion of fossils as a form of scientific evidence is supported by a new figure (Figure 25.5) that highlights five different types of fossils and how they are formed. The unit also features new material that connects evolutionary concepts and societal issues. For example, in Chapter 23, new text and a new figure (Figure 23.19) describe how some snowshoe hare populations have not adapted to ongoing climate change, causing them to be poorly camouflaged in early winter and leading to increased mortality. Additional changes include a new section of text in Chapter 22 and a figure (Figure 22.22) describing biogeographical evidence for evolution in a group of freshwater fishes that cannot survive in salt water, yet live in regions separated by wide stretches of ocean. In Chapter 25, a new figure (Figure 25.11) provides fossil evidence of an enormous change in the evolutionary history of life: the first appearance of large, multicellular eukaryotes.

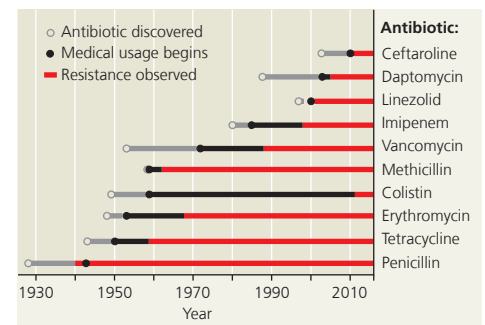
▼ **Figure 23.19** Lack of variation in a population can limit adaptation.



Unit 5 THE EVOLUTIONARY HISTORY OF BIOLOGICAL DIVERSITY

In keeping with our goal of developing students’ skills in interpreting visual representations in biology, we have added a new Visualizing Figure, Figure 32.8, “Visualizing Animal Body Symmetry and Axes.” New Visual Skills Questions provide practice on topics such as interpreting phylogenetic trees and using graphs to infer how rapidly antibiotic resistance evolves in bacteria. Chapter 31 has been significantly revised to account for new fossil discoveries and updates to the phylogenetic tree of fungi (Figure 31.10). Chapter 34 has been updated with recent genomic data and fossil discoveries indicating that Neanderthals and Denisovans are more closely related to each other than to humans and that they interbred with each other (and with humans), including two new figures (Figures 34.51 and 34.52b). In Chapter 29, a new figure (Figure 29.1) provides a visual overview of major steps in the colonization of land by plants, and revisions to text in Concept 29.1 strengthen our description of derived traits of plants that facilitated life on land. Chapter 27 includes a new section of text that describes the rise of antibiotic resistance and multidrug resistance and discusses novel approaches in the search for new antibiotics. This new material is supported by two new figures, Figure 27.22 and Figure 27.23. Other updates include the revision of many phylogenies to reflect recent phylogenomic data; a new Inquiry Figure (Figure 28.26) on the root of the eukaryotic tree; and new text describing the 2017 discovery of 315,000-year-old fossils of a hominin that had facial features like those of humans, while the back of its skull was elongated, as in earlier species.

► **Figure 27.22**
The rise of antibiotic resistance.



Unit 6 PLANT FORM AND FUNCTION

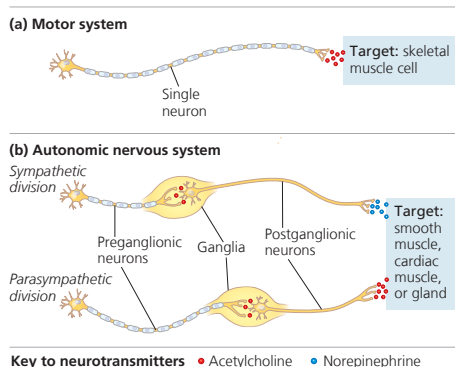
In Chapter 35, greater emphasis is placed on how structure fits function in vascular plants by way of a new Visual Overview. In Chapter 36, a new Visual Skills Question provides a quantitative exercise in estimating stomatal density. Chapter 37 begins with an emphasis on the importance of crop fertilization in feeding the world. To increase student engagement, renewed emphasis is placed on the link between the nutrition of plants and the nutrition of the organisms, including humans, that feed on them. Table 37.1 concerning plant essential elements has been

expanded to include micronutrients as well as macronutrients. In Concept 37.2, a new subsection titled “Global Climate Change and Food Quality” discusses new evidence that global climate change may be negatively impacting the nutritional mineral content of crops. In Chapter 38, the discussion of genetic engineering and agriculture has been enhanced by a discussion of biofortification and by updates concerning “Golden Rice.” Chapter 39 includes new updates on the location of the IAA receptor in plant cells and the role of abscisic acid in bud dormancy. The introduction to Concept 39.2 has been revised to emphasize that plants use many classes of chemicals in addition to the classic hormones to communicate information.

Unit 7 ANIMAL FORM AND FUNCTION

The Unit 7 revisions feature pedagogical innovations coupled with updates for currency. A striking new underwater image of Emperor penguins (Figure 40.1) opens the unit and highlights the contributions of form, function, and behavior to homeostasis in general as well as to the specific topic of thermoregulation. The artwork used to introduce and explore homeostasis throughout the unit (Figures 40.8, 40.17, 41.23, 42.28, 44.19, 44.21, and 45.18) has been improved and refined to provide a clear and consistent presentation of the role of perturbation in triggering a response. In Chapter 43, the introduction of the adaptive immune response has been shifted to later in the chapter, allowing students to build on the features of innate immunity before tackling the more demanding topic of the adaptive response. In Chapter 46, a new section of text in Concept 46.4 provides a clear and current introduction to “Biological Sex, Gender Identity, and Sexual Orientation in Human Sexuality.” In Chapter 48, the structural overview of neurons is now completed before the introduction of information processing. A new illustration, **Figure 49.8**, provides a concise visual comparison of sympathetic and parasympathetic neurons with each other and with motor neurons of the CNS. In addition, in-depth consideration of glia is now provided in Concept 49.1, where it is more logically integrated into the overview of nervous systems. At the end of the unit, an eye-catching photograph of the male frigatebird’s courtship display (Figure 51.1) introduces the topic of animal behavior. Among the content updates that enhance currency and student engagement throughout the unit are discussions of phage

► **Figure 49.8**
Comparison of pathways in the motor and autonomic nervous systems.

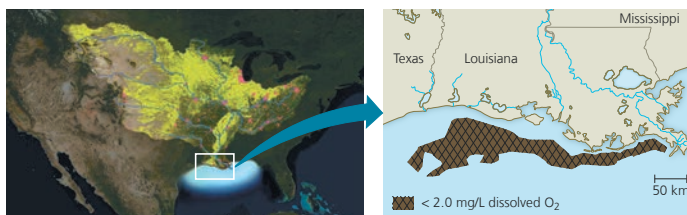


therapy and fecal transplantation, state-of-the-art treatments that both rely on microbiome data, and chronic traumatic encephalopathy (CTE), as well as the latest findings on dinosaur locomotion (Concept 40.1), the awarding of a Nobel Prize in 2017 in the field of circadian rhythms (Concept 40.2), and reference to the ongoing public health crisis of opioid addiction in the context of considering the brain’s reward system (Concept 49.5).

Unit 8 ECOLOGY

Complementary goals of the Unit 8 revision were to strengthen our coverage of core concepts while also increasing our coverage of how human actions affect ecological communities. Revisions include a new section of text and a new figure (Figure 52.7) on how plants (and deforestation) can affect the local or regional climate; a new section of text in Concept 55.1 that summarizes how ecosystems work; new text and a new figure (Figure 52.25) illustrating how rapid evolution can cause rapid ecological change; new material in Concept 55.2 on eutrophication and how it can cause the formation of large “dead zones” in aquatic ecosystems; and new text and a new figure (Figure 54.22) on how the abundance of organisms at each trophic level can be controlled by bottom-up or top-down control. A new figure (**Figure 56.23**) shows the extent of the record-breaking 2017 dead zone in the Gulf of Mexico and the watershed that contributes to its nutrient load. In addition, Concept 56.1 includes a new section that describes attempts to use cloning to resurrect species lost to extinction, while Concept 56.4 includes a new section of text and two new figures (Figure 56.27 and 56.28) on plastic waste, a major and growing environmental problem. In keeping with our book-wide goal of expanding our coverage of climate change, Chapter 56 has a new Scientific Skills Exercise in which students interpret changes in atmospheric CO₂ concentrations. Chapter 55 describes how climate warming is causing large regions of tundra in Alaska to release more CO₂ than they absorb (thereby contributing to further climate warming); a new figure (Figure 56.32) describes human and natural factors that contribute to rising global temperatures; and a new section of text in Concept 56.4 describes how global climate change models are developed and why they are valuable.

▼ **Figure 56.23** A dead zone arising from nitrogen pollution in the Mississippi basin.



Skills Exercises

Scientific Skills Exercises

- 1 Interpreting a Pair of Bar Graphs 23
- 2 Calibrating a Standard Radioactive Isotope Decay Curve and Interpreting Data 33
- 3 Interpreting a Scatter Plot with a Regression Line 54
- 4 Working with Moles and Molar Ratios 58
- 5 Analyzing Polypeptide Sequence Data 89
- 6 Using a Scale Bar to Calculate Volume and Surface Area of a Cell 99
- 7 Interpreting a Scatter Plot with Two Sets of Data 136
- 8 Making a Line Graph and Calculating a Slope 157
- 9 Making a Bar Graph and Evaluating a Hypothesis 179
- 10 Making Scatter Plots with Regression Lines 205
- 11 Using Experiments to Test a Model*
- 12 Interpreting Histograms 250
- 13 Making a Line Graph and Converting Between Units of Data 264
- 14 Making a Histogram and Analyzing a Distribution Pattern 283
- 15 Using the Chi-Square (χ^2) Test 304
- 16 Working with Data in a Table 318
- 17 Interpreting a Sequence Logo 351
- 18 Analyzing DNA Deletion Experiments 376
- 19 Analyzing a Sequence-Based Phylogenetic Tree to Understand Viral Evolution 411
- 20 Analyzing Quantitative and Spatial Gene Expression Data*
- 21 Reading an Amino Acid Sequence Identity Table 458
- 22 Making and Testing Predictions 483
- 23 Using the Hardy-Weinberg Equation to Interpret Data and Make Predictions 493
- 24 Identifying Independent and Dependent Variables, Making a Scatter Plot, and Interpreting Data 513
- 25 Estimating Quantitative Data from a Graph and Developing Hypotheses 538
- 26 Using Protein Sequence Data to Test an Evolutionary Hypothesis 570
- 27 Calculating and Interpreting Means and Standard Errors 590
Making a Bar Graph and Interpreting the Data*
- 28 Interpreting Comparisons of Genetic Sequences 595
- 29 Making Bar Graphs and Interpreting Data 628
- 30 Using Natural Logarithms to Interpret Data 639
- 31 Interpreting Genomic Data and Generating Hypotheses 657
Synthesizing Information from Multiple Data Sets*
- 32 Calculating and Interpreting Correlation Coefficients 678

*Available only in Mastering Biology. All other Scientific Skills Exercises are in the print book, eText, and Mastering Biology.

- 33 Understanding Experimental Design and Interpreting Data 700
- 34 Determining the Equation of a Regression Line 751
- 35 Using Bar Graphs to Interpret Data 762
- 36 Calculating and Interpreting Temperature Coefficients 790
- 37 Making Observations 812
- 38 Using Positive and Negative Correlations to Interpret Data 834
- 39 Interpreting Experimental Results from a Bar Graph 864
- 40 Interpreting Pie Charts 892
- 41 Interpreting Data from an Experiment with Genetic Mutants 918
- 42 Making and Interpreting Histograms 938
- 43 Comparing Two Variables on a Common x-Axis 972
- 44 Describing and Interpreting Quantitative Data 981
- 45 Designing a Controlled Experiment 1014
- 46 Making Inferences and Designing an Experiment 1030
- 47 Interpreting a Change in Slope 1049
- 48 Interpreting Data Values Expressed in Scientific Notation 1082
- 49 Designing an Experiment using Genetic Mutants 1095
- 50 Interpreting a Graph with Log Scales 1136
- 51 Testing a Hypothesis with a Quantitative Model 1150
- 52 Making a Bar Graph and a Line Graph to Interpret Data 1186
- 53 Using the Logistic Equation to Model Population Growth 1200
- 54 Making a Bar Graph and a Scatter Plot 1217
- 55 Interpreting Quantitative Data 1247
- 56 Graphing Data and Evaluating Evidence 1279

Problem-Solving Exercises

- 5 Are you a victim of fish fraud? 89
- 11 Can a skin wound turn deadly? 214
- 17 Are insulin mutations the cause of three infants' neonatal diabetes? 359
- 24 Is hybridization promoting insecticide resistance in mosquitoes that transmit malaria? 518
- 34 Can declining amphibian populations be saved by a vaccine? 733
- 39 How will climate change affect crop productivity? 863
- 45 Is thyroid regulation normal in this patient? 1010
- 55 Can an insect outbreak threaten a forest's ability to absorb CO_2 from the atmosphere? 1245

Featured Figures

Visualizing Figures

- 5.16 Visualizing Proteins 29
- 6.32 Visualizing the Scale of the Molecular Machinery in a Cell 122
- 16.7 Visualizing DNA 319
- 25.8 Visualizing the Scale of Geologic Time 532
- 26.5 Visualizing Phylogenetic Relationships 556
- 32.8 Visualizing Animal Body Symmetry and Axes 680
- 35.11 Visualizing Primary and Secondary Growth 767
- 47.8 Visualizing Gastrulation 1050
- 55.13 Visualizing Biogeochemical Cycles 1249

Figure 5.16 VISUALIZING PROTEINS

Proteins can be represented in different ways, depending on the goal of the illustration.

Structural Models
Using data from structural studies of proteins, computers can generate various types of models. Each model emphasizes a different aspect of the protein's structure, but no model can show what a protein actually looks like. These three models depict lysozyme, a protein in tears and saliva that helps prevent infection by binding to target molecules on bacteria.

Space-filling model: Emphasizes the overall globular shape. Shows all the atoms of the protein (except hydrogen), which are color-coded: gray = carbon, red = oxygen, blue = nitrogen, and yellow = sulfur.

Ribbon model: Shows only the polypeptide backbone, emphasizing how it folds and coils to form a 3-D shape. In this case, disulfide bridges (yellow lines) by double bridge (yellow lines).

Wireframe model (blue): Shows the polypeptide backbone with side chains extending from it. A ribbon model (purple) is superimposed on the wireframe model. The bacterial target molecule (yellow) is bound.

7. In which model is it easiest to follow the polypeptide backbone?

Instructors: The tutorial "Molecular Model: Lysozyme," in which students rotate 3-D models of lysozyme, can be assigned in **Mastering Biology**.

Simplified Diagrams
It isn't always necessary to use a detailed computer model; simplified diagrams are useful when the focus of the figure is on the function of the protein, not the structure.

Instructors: Additional questions related to this Visualizing Figure can be assigned in **Mastering Biology**.

1. A transparent shape is drawn around the contours of a ribbon model of the protein rhodopsin, showing the shape of the molecule as well as some internal details.

2. Draw a simple version of lysozyme that shows its overall shape, based on the molecular models in the top section of the figure.

3. Why is it unnecessary to show the actual shape of insulin here?

Pancreas cell secreting insulin

Make Connections Figures

- 5.26 Contributions of Genomics and Proteomics to Biology 88
- 10.22 The Working Cell 208
- 18.27 Genomics, Cell Signaling, and Cancer 392
- 23.18 The Sickle-Cell Allele 502
- 33.8 Maximizing Surface Area 695
- 37.9 Mutualism Across Kingdoms and Domains 813
- 39.27 Levels of Plant Defenses Against Herbivores 868
- 40.23 Life Challenges and Solutions in Plants and Animals 894
- 44.17 Ion Movement and Gradients 993
- 55.19 The Working Ecosystem 1256
- 56.31 Climate Change Has Effects at All Levels of Biological Organization 1280

Exploring Figures

- 1.3 Levels of Biological Organization 4
- 5.18 Levels of Protein Structure 80
- 6.3 Microscopy 95
- 6.8 Eukaryotic Cells 100
- 6.30 Cell Junctions in Animal Tissues 120

- 7.21 Endocytosis in Animal Cells 140
- 11.8 Cell-Surface Transmembrane Receptors 218
- 12.7 Mitosis in an Animal Cell 238
- 13.8 Meiosis in an Animal Cell 260
- 16.23 Chromatin Packing in a Eukaryotic Chromosome 330
- 24.3 Reproductive Barriers 508
- 25.7 The Origin of Mammals 531
- 27.17 Bacterial Diversity 584
- 28.5 Protistan Diversity 598
- 29.5 Alternation of Generations 620
- 29.13 Bryophyte Diversity 626
- 29.19 Seedless Vascular Plant Diversity 632
- 30.7 Gymnosperm Diversity 642
- 30.17 Angiosperm Diversity 650
- 33.42 Insect Diversity 712
- 34.42 Mammalian Diversity 745
- 35.10 Examples of Differentiated Plant Cells 764
- 41.5 Four Main Feeding Mechanisms of Animals 903
- 44.12 The Mammalian Excretory System 986
- 46.11 Human Gametogenesis 1028
- 49.11 The Organization of the Human Brain 1092
- 50.10 The Structure of the Human Ear 1113
- 50.17 The Structure of the Human Eye 1118
- 53.17 Mechanisms of Density-Dependent Regulation 1204
- 55.14 Water and Nutrient Cycling 1250
- 55.17 Restoration Ecology Worldwide 1254

Inquiry Figures

- 1.25 Does camouflage affect predation rates on two populations of mice? 21
- 4.2 Can organic molecules form under conditions estimated to simulate those on the early Earth? 57
- 7.4 Do membrane proteins move? 128
- [†]10.9 Which wavelengths of light are most effective in driving photosynthesis? 194
- 12.9 At which end do kinetochore microtubules shorten during anaphase? 241
- 12.14 Do molecular signals in the cytoplasm regulate the cell cycle? 245
- 14.3 When F₁ hybrid pea plants self- or cross-pollinate, which traits appear in the F₂ generation? 271
- 14.8 Do the alleles for one character segregate into gametes dependently or independently of the alleles for a different character? 276
- [†]15.3 In a cross between a wild-type female fruit fly and a mutant white-eyed male, what color eyes will the F₁ and F₂ offspring have? 296

- 15.9** How does linkage between two genes affect inheritance of characters? 301
- 16.2** Can a genetic trait be transferred between different bacterial strains? 315
- 16.4** Is protein or DNA the genetic material of phage T2? 316
- *† 16.12** Does DNA replication follow the conservative, semiconservative, or dispersive model? 322
- 17.3** Do individual genes specify the enzymes that function in a biochemical pathway? 338
- 18.22** Could Bicoid be a morphogen that determines the anterior end of a fruit fly? 387
- 19.2** What causes tobacco mosaic disease? 399
- 20.16** Can the nucleus from a differentiated animal cell direct development of an organism? 429
- 20.21** Can a fully differentiated human cell be “deprogrammed” to become a stem cell? 432
- 21.18** What is the function of a gene (*FOXP2*) that may be involved in language acquisition? 462
- 22.13** Can a change in a population’s food source result in evolution by natural selection? 477
- *23.16** Do females select mates based on traits indicative of “good genes”? 500
- 24.7** Can divergence of allopatric populations lead to reproductive isolation? 512
- 24.12** Does sexual selection in cichlids result in reproductive isolation? 515
- 24.19** How does hybridization lead to speciation in sunflowers? 521
- 25.27** What causes the loss of spines in lake stickleback fish? 546
- 26.6** What is the species identity of food being sold as whale meat? 557
- 28.26** What is the root of the eukaryotic tree? 612
- 29.14** Can bryophytes reduce the rate at which key nutrients are lost from soils? 627
- 31.22** Do fungal endophytes benefit a woody plant? 667
- 33.29** Did the arthropod body plan result from new *Hox* genes? 706
- 36.18** Does phloem sap contain more sugar near sources than near sinks? 801
- 37.10** How variable are the compositions of bacterial communities inside and outside of roots? 814
- 39.5** What part of a grass coleoptile senses light, and how is the signal transmitted? 847
- 39.6** What causes polar movement of auxin from shoot tip to base? 848
- 39.16** How does the order of red and far-red illumination affect seed germination? 857
- 40.16** How does a Burmese python generate heat while incubating eggs? 888
- 40.22** What happens to the circadian clock during hibernation? 893
- *41.4** Can diet influence the frequency of neural tube defects? 902
- 42.25** What causes respiratory distress syndrome? 944
- 44.20** Can aquaporin mutations cause diabetes? 995
- 46.8** Why is sperm usage biased when female fruit flies mate twice? 1024
- †47.3** Does the distribution of Ca^{2+} in an egg correlate with formation of the fertilization envelope? 1045
- 47.23** How does distribution of the gray crescent affect the developmental potential of the first two daughter cells? 1061
- 47.24** Can the dorsal lip of the blastopore induce cells in another part of the amphibian embryo to change their developmental fate? 1062
- 47.26** What role does the zone of polarizing activity (ZPA) play in limb pattern formation in vertebrates? 1063
- 51.8** Does a digger wasp use landmarks to find her nest? 1145
- 51.24** Are differences in migratory orientation within a species genetically determined? 1157
- 53.13** How does caring for offspring affect parental survival in kestrels? 1201
- †54.3** Can a species’ niche be influenced by competition? 1216
- 54.20** Is *Pisaster ochraceus* a keystone species? 1226
- 55.6** Which nutrient limits phytoplankton production along the coast of Long Island? 1243
- 55.12** How does temperature affect litter decomposition in an ecosystem? 1248
- *56.12** What caused the drastic decline of the Illinois greater prairie chicken population? 1267

Research Method Figures

- 5.21** X-Ray Crystallography 83
- 6.4** Cell Fractionation 96
- 10.8** Determining an Absorption Spectrum 193
- 13.3** Preparing a Karyotype 256
- 14.2** Crossing Pea Plants 270
- 14.7** The Testcross 275
- 15.11** Constructing a Linkage Map 305
- 20.3** Sequencing by Synthesis: Next-Generation Sequencing 417
- 20.7** The Polymerase Chain Reaction (PCR) 421
- 20.11** RT-PCR Analysis of the Expression of Single Genes 425
- 26.15** Applying Parsimony to a Problem in Molecular Systematics 563
- 35.21** Using Dendrochronology to Study Climate 773
- 37.7** Hydroponic Culture 810
- 48.6** Intracellular Recording 1072
- 53.2** Determining Population Size Using the Mark-Recapture Method 1191
- 54.14** Determining Microbial Diversity Using Molecular Tools 1223

*The Inquiry Figure, original research paper, and a worksheet to guide you through the paper are provided in *Inquiry in Action: Interpreting Scientific Papers*, Fourth Edition.

†A related Experimental Inquiry Tutorial can be assigned in Mastering Biology.

Student and Lab Supplements

For Students

NEW! *Active Reading Guides, Twelfth Edition*

by Fred and Theresa Holtzclaw, The Webb School of Knoxville

These worksheets provide students with self-assessment activities to complete as they read each chapter. Students can download the Active Reading Guides from the Mastering Biology Study Area.

Study Guide, Eleventh Edition

by Martha R. Taylor, Ithaca, New York, and Michael Pollock, Mount Royal University

978-0-134-44377-5/0-134-44377-2

This popular study aid provides concept maps, chapter summaries, word roots, and a variety of interactive activities including multiple-choice, short-answer essay, art labeling, and graph interpretation questions.

Study Card, Eleventh Edition

978-0-134-48648-2/0-134-48648-X

This quick-reference card provides students with an overview of the entire field of biology, helping them see the connections between topics.

*Inquiry in Action: Interpreting Scientific Papers, Fourth Edition**

by Ruth V. Buskirk, University of Texas at Austin, and Christopher M. Gillen, Kenyon College

978-0-134-47861-6/0-134-47861-4

This guide helps students learn how to read and understand primary research articles. Part A presents complete articles accompanied by questions that help students analyze the article. Related Inquiry Figures are included in the supplement. Part B covers every part of a research paper, explaining the aim of the sections and how the paper works as a whole.

*Practicing Biology: A Student Workbook, Sixth Edition**

by Jean Heitz and Cynthia Giffen, University of Wisconsin, Madison

978-0-134-48603-1/0-134-48603-X

This workbook offers a variety of activities to suit different learning styles. Activities such as modeling and concept mapping allow students

to visualize and understand biological processes. Other activities focus on basic skills, such as reading and drawing graphs.

*Biological Inquiry: A Workbook of Investigative Cases, Fifth Edition**

by Margaret Waterman, Southeast Missouri State University, and Ethel Stanley, BioQUEST Curriculum Consortium and Beloit College

978-0-134-48646-8/0-134-48646-3

This workbook offers ten investigative cases. Each case study requires students to synthesize information from multiple chapters of the text and apply that knowledge to a real-world scenario as they pose hypotheses, gather new information, analyze evidence, graph data, and draw conclusions. A link to a student website is in the Study Area in Mastering Biology.

Spanish Glossary for Biology

By Laura P. Zanella, University of California, Riverside 978-0-32183498-0/0-321-83498-4

Into the Jungle: Great Adventures in the Search for Evolution

by Sean B. Carroll, University of Wisconsin, Madison

978-0-32155671-4/0-321-55671-2

Get Ready for Biology

by Lori K. Garrett, Parkland College

978-0-32150057-1/0-321-50057-1

A Short Guide to Writing About Biology, Ninth Edition

by Jan A. Pechenik, Tufts University

978-0-13414373-6/0-134-14373-6

An Introduction to Chemistry for Biology Students, Ninth Edition

by George I. Sackheim, University of Illinois, Chicago

978-0-805-39571-6/0-805-39571-7

* An Instructor Guide is available for downloading through the Instructor Resources area of Mastering Biology.

For Lab

Investigating Biology Laboratory Manual, Ninth Edition

by Judith Giles Morgan, Emory University, and M. Eloise Brown Carter, Oxford College of Emory University

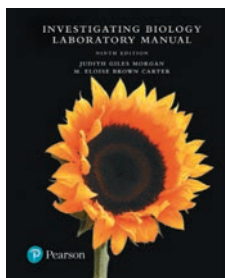
978-0-13447346-8/0-134-47346-9

With its distinctive investigative approach to learning, this best-selling laboratory manual is now more engaging than ever, with full-color art and photos throughout. The lab manual encourages students to participate in the process of science and develop creative and critical-reasoning skills.

Annotated Instructor's Edition for Investigating Biology Laboratory Manual, Ninth Edition

978-0-13451922-7/0-134-51922-1

This Annotated Instructor's Edition features teaching information including margin notes with suggestions for lab procedures and answers to questions from the Student Edition. Also included is a detailed Teaching Plan at the end of each lab with specific suggestions for organizing labs, including estimated time allotments for each part



of the lab and suggestions for encouraging independent thinking and collaborative discussions.

Preparation Guide for Investigating Biology, Ninth Edition

978-013451801-5/0-134-51801-2

This guide contains materials lists, suggested vendors, instructions for preparing solutions and constructing materials, schedules for planning advance preparation, and more. It is available for downloading through the Instructor Resources area of Mastering Biology.

Pearson Collections Custom Library

This library gives instructors the power to create custom lab manuals using Pearson content as well as original materials. Learn more at www.pearsonhighered.com/collections.

NEW! Mastering Biology LabBench

The LabBench pre-labs feature 13 online tutorials in Mastering Biology that will both prepare students for their lab work and reinforce key biological principles.

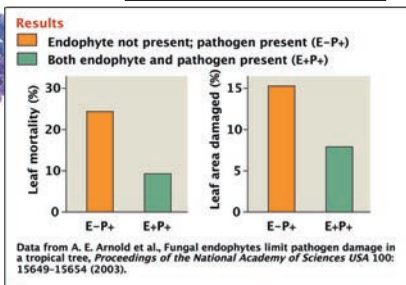
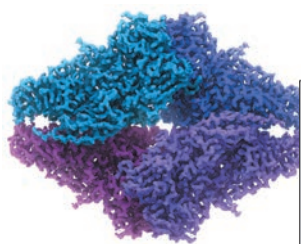
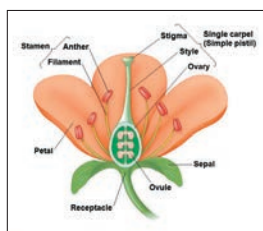
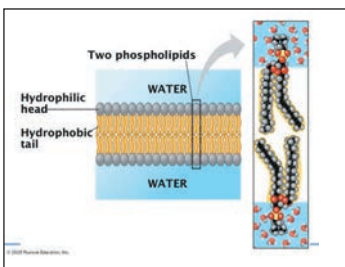
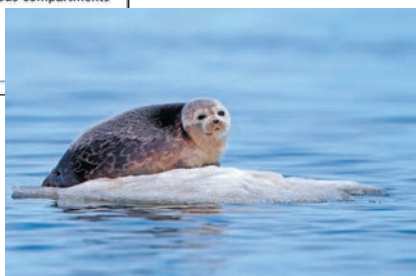
Instructor Resources

The Instructor Resources Area of Mastering Biology

- **5 NEW! Ready-to-Go Teaching Modules** help instructors efficiently make use of the available teaching tools for the toughest topics. Before-class assignments, in-class activities, and after-class assignments are provided for ease of use. Instructors can incorporate active learning into their course with the suggested activity ideas and clicker questions or Learning Catalytics Questions. A total of 15 modules are now available.
- **Lecture Presentations in PowerPoint®** for each chapter with lecture notes, editable figures (art and photos with enlarged, customizable labels), tables, and links to animations and videos:

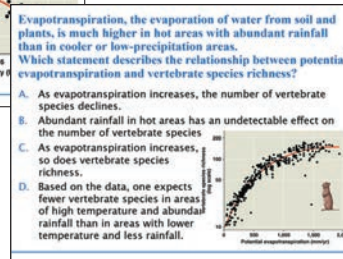
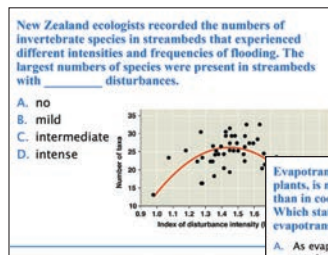
Concept 7.1: Cellular membranes are fluid mosaics of lipids and proteins

- Phospholipids are the most abundant lipid in most membranes
- Phospholipids are **amphipathic** molecules, containing hydrophobic and hydrophilic regions
- A phospholipid bilayer can exist as a stable boundary between two aqueous compartments



- **Accessible Lecture Presentations in PowerPoint** with alt text for every image; students can access alt text with a screen reader if needed
- **Editable Images in PowerPoint** (all art and photos from the text) and all tables from the text in PowerPoint with enlarged, customizable labels
- **Labeled and Unlabeled JPEG Images**, including art, photos from the text, and extra photos

- **Clicker Questions in PowerPoint**, which can be used to stimulate effective classroom discussions (for use with or without clickers):



- **EXPANDED! 500 Instructor Animations and Videos**, including BioFlix 3-D Animations, HHMI BioInteractive Animations and Videos, BBC Videos, and much more
- **Test Bank** questions in TestGen® software and Microsoft® Word. This extensively revised resource contains over 4,500 questions, including scenario-based questions and art, graph, and data interpretation questions. **NEW!** Every image in the Test Bank has alt text, which students can access with a screen reader if needed.
- **NEW! Statistics Worksheets for Biology**
- **Instructor Answers** to Scientific Skills Exercises, Problem-Solving Exercises, Interpret the Data Questions, and Essay Questions; includes rubric and tips for grading short-answer essays
- **Instructor Guides for Supplements:** Instructor Guide for *Active Reading Guides*; Instructor Guide for *Practicing Biology: A Student Workbook*; Instructor Guide for *Biological Inquiry: A Workbook of Investigative Cases*; Answer Key for *Inquiry in Action: Interpreting Scientific Papers*; *Investigating Biology Lab Prep Guide*; and *Investigating Biology Lab Data Tables*

Learning Catalytics™

Learning Catalytics allows students to use their smartphone, tablet, or laptop to respond to questions in class. For more information, visit learningcatalytics.com.

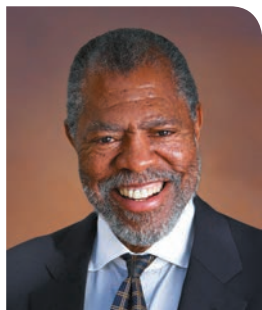


Learning Management Systems

Integration with various learning management systems is available for Mastering Biology. Contact your sales representative for details.

Interviews

Unit 1 THE CHEMISTRY OF LIFE 27



Kenneth Olden

National Center for
Environmental Assessment

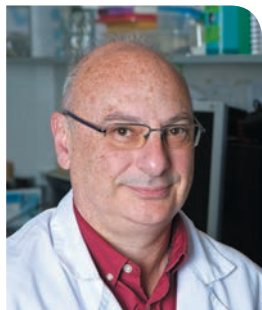
Unit 2 THE CELL 92



Diana Bautista

University of California,
Berkeley

Unit 3 GENETICS 253



Francisco Mojica

University of Alicante,
Spain

Unit 4 MECHANISMS OF EVOLUTION 467



Cassandra Extavour

Harvard University

Unit 5 THE EVOLUTIONARY HISTORY OF BIOLOGICAL DIVERSITY 552



Penny Chisholm

Massachusetts Institute of
Technology

Unit 6 PLANT FORM AND FUNCTION 757



Dennis Gonsalves

Agricultural Research
Center, Hilo, Hawaii

Unit 7 ANIMAL FORM AND FUNCTION 872



Steffanie Strathdee

University of California,
San Diego

Unit 8 ECOLOGY 1163



Chelsea Rochman

University of Toronto

Acknowledgments

The authors wish to express their gratitude to the global community of instructors, researchers, students, and publishing professionals who have contributed to the Twelfth Edition of *Campbell Biology*.

As authors of this text, we are mindful of the daunting challenge of keeping up to date in all areas of our rapidly expanding subject. We are grateful to the many scientists who helped shape this text by discussing their research fields with us, answering specific questions in their areas of expertise, and sharing their ideas about biology education. We are especially grateful to the following, listed alphabetically: Graham Alexander, Elizabeth Atkinson, Kristian Axelsen, Ron Bassar, Christopher Benz, David Booth, George Brooks, Abby Dernberg, Jean DeSaix, Alex Engel, Rachel Kramer Green, Fred Holtzclaw, Theresa Holtzclaw, Tim James, Kathy Jones, Azarias Karamanlidis, Gary Karpen, Joe Montoya, Laurie Nemzer, Kevin Peterson, T. K. Reddy, David Reznick, Thomas Schneider, Alastair Simpson, Martin Smith, Steven Swoap, and John Taylor. In addition, the biologists listed on pages xxviii–xxxi provided detailed reviews, helping us ensure the text’s scientific accuracy and improve its pedagogical effectiveness. Thanks also to Mary Camuso and Ann Sinclair for contributing a creative Study Tip for their fellow students.

Thanks also to the other professors and students, from all over the world, who contacted the authors directly with useful suggestions. We alone bear the responsibility for any errors that remain, but the dedication of our consultants, reviewers, and other correspondents makes us confident in the accuracy and effectiveness of this text.

Interviews with prominent scientists have been a hallmark of *Campbell Biology* since its inception, and conducting these interviews was again one of the great pleasures of revising the book. To open the eight units of this edition, we are proud to include interviews with Kenneth Olden, Diana Bautista, Francisco Mojica, Cassandra Extavour, Penny Chisholm, Dennis Gonsalves, Steffanie Strathdee, and Chelsea Rochman.

Mastering Biology and the other electronic accompaniments for this text are invaluable teaching and learning aids. We are grateful to the contributors for the Ready-to-Go Teaching Modules: Chad Brassil, Ruth Buskirk, Eileen Gregory, Angela Hodgson, Molly Jacobs, Bridgette Kirkpatrick, Maureen Leupold, Jennifer Metzler, Karen Resendes, Justin Shaffer, Allison Silveus, Jered Studinski, Cynthia Surmacz, Sara Tallarovic, and Carole Twichell. We would also like to extend our sincere appreciation to Carolyn Wetzel for her hard work on the Figure Walkthroughs. And our gratitude goes to Bryan Jennings and Roberta Batorsky for their work on the Reading Questions. Thanks also to Ann Brokaw and Bob Cooper for their contributions to the AAAS Science in the Classroom activities; we also appreciate the support of Beth Reudi, Shelby Lake, and Lydia Kaprelian from AAAS.

The value of *Campbell Biology* as a learning tool is greatly enhanced by the supplementary materials that have been created for instructors and students. We recognize that the dedicated authors of these materials are essentially writing mini (and not so mini) books. We appreciate the hard work and creativity of all the authors listed, with their creations, on pages xxiv–xxv. We are also grateful to Kathleen Fitzpatrick and Nicole Tunbridge (PowerPoint® Lecture Presentations); Roberta Batorsky, Douglas Darnowski, James Langeland, and David Knochel (Clicker Questions); Sonish Azam, Ford Lux, Karen Bernd, Janet Lanza, Chris Romero, Marshall Sundberg, Justin Shaffer, Ed Zalisko, and David Knochel (Test Bank).

Campbell Biology results from an unusually strong synergy between a team of scientists and a team of publishing professionals.

Our editorial team at Pearson Education again demonstrated unmatched talents, commitment, and pedagogical insights. Josh Frost, our Manager of Higher Ed Global Content Strategy for Life Sciences, brought publishing savvy, intelligence, and a much-appreciated

level head to leading the whole team. The clarity and effectiveness of every page owe much to our extraordinary Supervising Editors Beth Winickoff and Pat Burner, who worked with a top-notch team of Senior Developmental Editors in John Burner, Mary Ann Murray, Hilair Chism, Andrew Recher, and Mary Hill. Our unsurpassed Director of Content Development Ginnie Simone Jutson and Courseware Portfolio Management Director Beth Wilbur were indispensable in moving the project in the right direction. We also want to thank Robin Heyden for organizing the annual Biology Leadership Conferences and keeping us in touch with the world of AP Biology. We also extend our thanks to Ashley Fallon, Editorial Assistant, Chelsea Noack, Associate Content Analyst, and Rebecca Berardy Schwartz, Product Manager.

You would not have this beautiful text if not for the work of the production team: Director, Content Production & Digital Studio Erin Gregg; Managing Producer Michael Early; Senior Content Producer Lori Newman; Photo Researcher Maureen Spuhler; Copy Editor Joanna Dinsmore; Proofreader Pete Shanks; Rights & Permissions Manager Ben Ferrini; Rights & Permissions Project Manager Matt Perry; Senior Project Manager Margaret McConnell and the rest of the staff at Integra Software Services, Inc.; Art Production Manager Rebecca Marshall, Artist Kitty Auble, and the rest of the staff at Lachina Creative; Design Manager Mark Ong; Text and Cover Designer Jeff Puda; and Manufacturing Buyer Stacey Weinberger. We also thank those who worked on the text’s supplements: Project Manager Shiny Rajesh and her team at Integra Software Services.

For creating the wonderful package of electronic media that accompanies the text, we are grateful to Senior Content Developer Sarah Jensen; Content Producers Kaitlin Smith and Ashley Gordon; Director, Production & Digital Studio Katie Foley; Director, Production & Digital Studio Laura Tommasi; Supervising Media Producer Tod Regan; Specialist, Instructional Design and Development Sarah Young-Dualan; Digital Program Manager, Science, Caroline Ayres; Project Manager Katie Cook; Media Producer Ziki Dekel; Manager, Creative Technology Greg Davis; and Senior Learning Tools Strategist Kassi Foley.

For their important roles in marketing the text and media, we thank Alysun Estes, Kelly Galli, Jane Campbell, Brad Parkins, and Stacey Abraham. For their enthusiasm, encouragement, and support, we are grateful to Jeanne Zalesky, Director, Global Higher Ed Content Management and Strategy, Science & Health Sciences; Michael Gillespie, Director, Higher Ed Product Management, Life Sciences; Adam Jaworski, VP Product Management Higher Ed, Science; and Paul Corey, SVP Global Content Strategy, Higher Ed.

The Pearson sales team, which represents *Campbell Biology* on campus, is an essential link to the users of the text. They tell us what you like and don’t like about the text, communicate the features of the text, and provide prompt service. We thank them for their hard work and professionalism. For representing our text to our international audience, we thank our sales and marketing partners throughout the world. They are all strong allies in biology education.

Finally, we wish to thank our families and friends for their encouragement and patience throughout this long project. Our special thanks to Lily and Alex (L.A.U.); Debra and Hannah (M.L.C.); Aaron, Sophie, Noah, and Gabriele (S.A.W.); Natalie (P.V.M.); and Jim, Abby, Dan, and Emily (R.B.O). Thanks to Jane Reece, now retired, for her generosity and thoughtfulness throughout her many years as a *Campbell* author. And, as always, thanks to Rochelle, Allison, Jason, McKay, and Gus.

Lisa A. Urry, Michael L. Cain, Steven A. Wasserman,
Peter V. Minorsky, and Rebecca B. Orr

Twelfth Edition Reviewers

Sheena Abernathy, *College of the Mainland*; James Arnone, *William Paterson University*; Josh Auld, *West Chester University*; Gemma Bartha, *Springfield College*; Louise Beard, *University of Essex*; Marin Beaupre, *Massasoit Community College*; Kevin Bennett, *University of Hawai'i*; Kelsie Bernot, *North Carolina A&T State University*; Christine Bezotte, *Elmira College*; Chris Bloch, *Bridgewater State University*; Aiwei Borengasser, *University of Arkansas – Pulaski Tech*; Robert Borgon, *University of Central Florida*; Nicole Bournias-Vardiabasis, *California State University, San Bernardino*; George Brooks, *University of California, Berkeley*; Michael Buoni, *Delaware Technical Community College*; Kelcey Burriss, *Union High School*; Elena Caines, *Broward College*; Mickael Cariveau, *Mount Olive College*; Billy Carver, *Lees-McRae College*; Anne Casper, *Eastern Michigan University*; Bruce Chase, *University of Nebraska, Omaha*; Amanda Chau, *Blinn College*; Katie Clark, *University of California, Riverside*; Catharina Coenen, *Allegheny College*; Curt Coffman, *Vincennes University*; Juliet Collins, *University of Wisconsin, Madison*; Bob Cooper, *Pennsbury High School*; Robin Cotter, *Phoenix College*; Marilyn Cruz-Alvarez, *Florida Gulf Coast University*; Noelle Cutter, *Molloy College*; Deborah Dardis, *Southeastern Louisiana University*; Farahad Dastoor, *University of Maine, Orono*; Andrew David, *Clarkson University*; Jeremiah Davie, *D'Youville College*; Brian Deis, *University of Hawai'i Jean DeSaix, University of North Carolina at Chapel Hill*; Kelly Dubois, *Calvin College*; Cynthia Eayre, *Fresno City College*; Arri Eisen, *Emory University*; Lisa Elfring, *University of Arizona*; Kurt Elliott, *Northwest Vista College*; Ana Esther Escandon, *Los Angeles Harbor College*; Linda Fergusson-Kolmes, *Portland Community College*; April Fong, *Portland Community College*; Robert Fowler, *San Jose State University*; Brittany Gasper, *Florida Southern College*; Carri Gerber, *The Ohio State University*; Marina Gerson, *California State University, Stanislaus*; Brian Gibbens, *University of Minnesota*; Sara Gremillion, *Georgia Southern University*; Ron Gross, *Community College of Allegheny County*; Melissa Gutierrez, *University of Southern Mississippi*; Gokhan Hacisalihoglu, *Florida A&M University*; Monica Hall-Woods, *St. Charles Community College*; Catherine Hartkorn, *New Mexico State University*; Valerie Haywood, *Case Western Reserve University*; Maryann Herman, *St. John Fisher College*; Alexander Heyl, *Adelphi University*; Laura Hill, *University of Vermont*; Anne-Marie Hoskinson, *South Dakota State University*; Katrina Ilves, *Pace University*; James Jacob, *Tompkins Cortland Community College*; Darrel James, *Fred C. Beyer High School*; Jerry Johnson, *Corban University*; Greg Jones, *Santa Fe College*; Kathryn Jones, *Howard Community College*; Seth Jones, *University of Kentucky*; Steven Karafit, *University of Central Arkansas*; Lori Kayes, *Oregon State University*; Ben Kolber, *Duquesne University*; Catherine Konopka, *John Carroll University*; Bill Kroll, *Loyola University, Chicago*; MaryLynne LaMantia, *Golden West College*; Neil Lamb, *HudsonAlpha Institute for Biotechnology*; Michelle LaPorte, *St. Louis Community College*; Neil Lax, *Duquesne University*; John Lepri, *Carrboro High School*; Jani Lewis, *State University of New York at Geneseo*; Eddie Lunsford, *Southwestern Community College*; Alyssa MacDonald, *Leeward Community College*; Charles Mallery, *University of Miami*; Marlee Marsh, *Columbia College*; Nicole McDaniels, *Herkimer College*; Mike Meighan, *University of California, Berkeley*; Jennifer Metzler, *Ball State University*; Grace Ju Miller, *Indiana Wesleyan University*; Terry Miller, *Central Carolina Community College*; Shamone Mizenmayer, *Central High School*; Cam Muir, *University of Hawai'i at Hilo*; Heather Murdock, *San Francisco State University*; Madhavan Narayanan, *Mercy College*; Jennifer Nauen, *University of Delaware*; Karen Neal, *J. Sargeant Reynolds Community College, Richmond*; Leonore Neary, *Joliet Junior College*; Shanna Nifoussi, *University of Superior*; Jennifer Ortiz, *North Hills School District*; Fernanda Oyarzun, *Universidad Católica de la Santísima Concepción, Chile*; Stephanie Pandolfi, *Wayne State University*; John Plunket, *Horry-Georgetown Technical College*; Elena Pravosudova, *University of Nevada, Reno*; Pushpa Ramakrishna, *Chandler-Gilbert Community College*; Sami Raut, *University of Alabama, Birmingham*; Robert Reavis, *Glendale Community College*; Linda Rehfuess, *Bucks County Community College*; Deborah Rhoden, *Snead State Community College*; Linda Richardson, *Blinn College*; Brian Ring, *Valdosta State University*; Rob Ruliffson, *Minneapolis Community and Technical College*; Judy Schoonmaker, *Colorado School of Mines*; David Schultz, *University of Louisville*; David Schwartz, *Houston Community College*; Duane Sears, *University of California, Santa Barbara*; J. Michael Sellers, *University of Southern Mississippi*; Pramila Sen, *Houston Community College*; Jyotsna Sharma, *University of Texas San Antonio*; Joan Sharp, *Simon Fraser University*; Marcia Shofner, *University of Maryland, College Park*; Linda Sigismondi, *University of Rio Grande*; Davida Smyth, *Mercy College*; Helen Snodgrass, *YES Prep North Forest*; Ayodotun Sodipe, *Texas Southern University*; Kathy Sparace, *Tri-County Technical College*; Patricia Steinke, *San Jacinto College Central*; Elizabeth Sudduth, *Georgia Gwinnett College*; Aaron Sullivan, *Houghton College*; Yvonne Sun, *University of Dayton*; Andrea Swei, *San Francisco State University*; Greg Thurmon, *Central Methodist University*; Stephanie Toering-Peters, *Wartburg College*; Monica Togna, *Drexel University*; Gail Tompkins, *Wake Technical Community College*; Tara Turley-Stoulig, *Southeastern Louisiana University*; Bishnu Twanabasu, *Weatherford College*; Erin Ventresca, *Albright College*; Wei Wan, *Texas A&M University*; Alan Wasmoen, *Metropolitan Community College, Nebraska*; Fred Wasserman, *Boston University*; Vicki Watson, *University of Montana*; Bill Wesley, *Mars Area High School*; Clay White, *Lone Star College*; Lisa Whitenack, *Allegheny College*; Larry Wimmers, *Towson University*; Heather Woodson, *Gaston College*; Shelly Wu, *Texas Christian University*; Mary Wuerth, *Tamalpais High School*; John Yoder, *University of Alabama*; Alyson Zeamer, *University of Texas San Antonio*.

Reviewers of Previous Editions

Steve Abedon, *Ohio State University*; Kenneth Able, *State University of New York, Albany*; Thomas Adams, *Michigan State University*; Martin Adamson, *University of British Columbia*; Dominique Adriaens, *Ghent University*; Ann Aguanno, *Marymount Manhattan College*; Shylaja Akkaraju, *Bronx Community College of CUNY*; Marc Albrecht, *University of Nebraska*; John Alcock, *Arizona State University*; Eric Alcorn, *Acadia University*; George R. Aliaga, *Tarrant County College*; Philip Allman, *Florida Gulf Coast College*; Rodney Allrich, *Purdue University*; Richard Almon, *State University of New York, Buffalo*; Bonnie Amos, *Angelo State University*; Katherine Anderson, *University of California, Berkeley*; Richard J. Andren, *Montgomery County Community College*; Estry Ang, *University of Pittsburgh, Greensburg*; Jeff Appling, *Clemson University*; J. David Archibald, *San Diego State University*; David Armstrong, *University of Colorado, Boulder*; Howard J. Arnott, *University of Texas, Arlington*; Mary Ashley, *University of Illinois, Chicago*; Angela S. Aspbury, *Texas State University*; Robert Atherton, *University of Wyoming*; Karl Aufderheide, *Texas A&M University*; Leigh Auleb, *San Francisco State University*; Terry Austin, *Temple College*; P. Stephen Baenziger, *University of Nebraska*; Brian Bagatto, *University of Akron*; Ellen Baker, *Santa Monica College*; Katherine Baker, *Millersville University*; Virginia Baker, *Chipola College*; Teri Balsler, *University of Wisconsin, Madison*; William Barklow, *Framingham State College*; Susan Barman, *Michigan State University*; Steven Barnhart, *Santa Rosa Junior College*; Jim Barron, *Montana State University Billings*; Andrew Barton, *University of Maine Farmington*; Rebecca A. Bartow, *Western Kentucky University*; Ron Basmajian, *Merced College*; David Bass, *University of Central Oklahoma*; Stephen Bauer, *Belmont Abbey College*; Bonnie Baxter, *Westminster College*; Tim Beagley, *Salt Lake Community College*; Margaret E. Beard, *College of the Holy Cross*; Tom Beatty, *University of British Columbia*; Chris Beck, *Emory University*; Wayne Becker, *University of Wisconsin, Madison*; Patricia Bedinger, *Colorado State University*; Jane Beiswenger, *University of Wyoming*; Anne Bekoff, *University of Colorado, Boulder*; Marc Bekoff, *University of Colorado, Boulder*; Tania Beliz, *College of San Mateo*; Adrienne Bendich, *Hoffman-La Roche, Inc.*; Marilee Benore, *University of Michigan, Dearborn*; Barbara Bentley, *State University of New York, Stony Brook*; Darwin Berg, *University of California, San Diego*; Werner Bergen, *Michigan State University*; Gerald Bergstrom, *University of Wisconsin, Milwaukee*; Anna W. Berkovitz, *Purdue University*; Aimee Bernard, *University of Colorado Denver*; Dorothy Berner, *Temple University*; Annalisa Berta, *San Diego State University*; Paulette Bierzychudek, *Pomona College*; Charles Biggers, *Memphis State University*; Teresa Bilinski, *St. Edward's University*; Kenneth Birnbaum, *New York University*; Sarah Bissonnette, *University of California, Berkeley*; Catherine Black, *Idaho State University*; Michael W. Black, *California Polytechnic State University, San Luis Obispo*; William Blaker, *Furman University*; Robert Blanchard, *University of New Hampshire*; Andrew R. Blaustein, *Oregon State University*; Judy Bluemer, *Morton College*; Edward Blumenthal, *Marquette University*; Robert Blystone, *Trinity University*; Robert Boley, *University of Texas, Arlington*; Jason E. Bond, *East Carolina University*; Eric Bonde, *University of Colorado, Boulder*; Cornelius Bondzi, *Hampton University*; Richard Boohar, *University of Nebraska, Omaha*; Carey L. Booth, *Reed College*; Allan Bornstein, *Southeast Missouri State University*; David Bos, *Purdue University*; Oliver Bossdorf, *State University of New York, Stony Brook*; James L. Botsford, *New Mexico State University*; Lisa Boucher, *University of Nebraska, Omaha*; Jeffery Bowen, *Bridgewater State University*; J. Michael Bowes, *Humboldt State University*; Richard Bowker, *Alma College*; Robert Bowker, *Glendale Community College, Arizona*; Scott Bowling, *Auburn University*; Barbara Bowman, *Mills College*; Barry Bowman, *University of California, Santa Cruz*; Deric Bownds, *University of Wisconsin, Madison*; Robert Boyd, *Auburn University*; Sunny Boyd, *University of Notre Dame*; Jerry Brand, *University of Texas, Austin*; Edward Braun, *Iowa State University*; Theodore A. Bremner, *Howard University*; James Brenneman, *University of Evansville*; Charles H. Brenner, *Berkeley, California*; Lawrence Brewer, *University of Kentucky*; Donald P. Briskin, *University of Illinois, Urbana*; Paul Broady, *University of Canterbury*; Chad Brommer, *Emory University*; Judith L. Bronstein, *University of Arizona*; David Broussard, *Lycoming College*; Danny Brower, *University of Arizona*; Carole Browne, *Wake Forest University*; Beverly Brown, *Nazareth College*; Mark Browning, *Purdue University*; David Bruck, *San Jose State University*; Robb T. Brumfield, *Louisiana State University*; Herbert Bruneau, *Oklahoma State University*; Gary Brusca, *Humboldt State University*; Richard C. Brusca, *University of Arizona, Arizona-Sonora Desert Museum*; Alan H. Brush, *University of Connecticut, Storrs*; Howard Buhse, *University of Illinois, Chicago*; Arthur Buikema, *Virginia Tech*; Beth Burch, *Huntington University*; Tessa Burch, *University of Tennessee*; Al Burchsted, *College of Staten Island*; Warren Burggren, *University of North Texas*; Meg Burke, *University of North Dakota*; Edwin Burling, *De Anza College*; Dale Burnside, *Lenoir-Rhyne University*; William Busa, *Johns Hopkins University*; Jorge Busciglio, *University of California, Irvine*; John Bushnell, *University of Colorado*; Linda Butler, *University of Texas, Austin*; David Byres, *Florida Community College, Jacksonville*; Patrick Cafferty, *Emory University*; Guy A. Caldwell, *University of Alabama*; Jane Caldwell, *West Virginia University*; Kim A. Caldwell, *University of Alabama*; Ragan Callaway, *The University of Montana*; Kenneth M. Cameron, *University of Wisconsin, Madison*; R. Andrew Cameron, *California Institute of Technology*; Alison Campbell, *University of Waikato*; Iain Campbell, *University of Pittsburgh*; Michael Campbell, *Penn State University*; Patrick Canary, *Northland Pioneer College*; W. Zacheus Cande, *University of California, Berkeley*; Deborah Canington, *University of California, Davis*; Robert E. Cannon, *University of North Carolina, Greensboro*; Frank Cantelmo, *St. John's University*; John Capeheart, *University of Houston, Downtown*; Gregory Capelli, *College of William and Mary*; Cheryl Keller Capone, *Pennsylvania State University*;

Richard Cardullo, *University of California, Riverside*; Nina Caris, *Texas A&M University*; Mickael Cariveau, *Mount Olive College*; Jeffrey Carmichael, *University of North Dakota*; Robert Carroll, *East Carolina University*; Laura L. Carruth, *Georgia State University*; J. Aaron Cassill, *University of Texas, San Antonio*; Karen I. Champ, *Central Florida Community College*; David Champlin, *University of Southern Maine*; Brad Chandler, *Palo Alto College*; Wei-Jen Chang, *Hamilton College*; Bruce Chase, *University of Nebraska, Omaha*; P. Bryant Chase, *Florida State University*; Doug Cheeseman, *De Anza College*; Shepley Chen, *University of Illinois, Chicago*; Giovina Chinchar, *Tougaloo College*; Joseph P. Chinnici, *Virginia Commonwealth University*; Jung H. Choi, *Georgia Institute of Technology*; Steve Christensen, *Brigham Young University, Idaho*; Geoffrey Church, *Fairfield University*; Henry Claman, *University of Colorado Health Science Center*; Anne Clark, *Binghamton University*; Greg Clark, *University of Texas*; Patricia J. Clark, *Indiana University-Purdue University, Indianapolis*; Ross C. Clark, *Eastern Kentucky University*; Lynwood Clemens, *Michigan State University*; Janice J. Clymer, *San Diego Mesa College*; Reggie Cobb, *Nashville Community College*; William P. Coffman, *University of Pittsburgh*; Austin Randy Cohen, *California State University, Northridge*; Bill Cohen, *University of Kentucky*; J. John Cohen, *University of Colorado Health Science Center*; James T. Colbert, *Iowa State University*; Sean Coleman, *University of the Ozarks*; Jan Colpaert, *Hasselt University*; Robert Colvin, *Ohio University*; Jay Comeaux, *McNeese State University*; David Cone, *Saint Mary's University*; Erin Connolly, *University of South Carolina*; Elizabeth Connor, *University of Massachusetts*; Joanne Conover, *University of Connecticut*; Ron Cooper, *University of California, Los Angeles*; Gregory Copenhaver, *University of North Carolina, Chapel Hill*; John Corliss, *University of Maryland*; James T. Costa, *Western Carolina University*; Stuart J. Coward, *University of Georgia*; Charles Creutz, *University of Toledo*; Bruce Criley, *Illinois Wesleyan University*; Norma Criley, *Illinois Wesleyan University*; Joe W. Crim, *University of Georgia*; Greg Crowther, *University of Washington*; Karen Curto, *University of Pittsburgh*; William Cushwa, *Clark College*; Anne Cusic, *University of Alabama, Birmingham*; Richard Cyr, *Pennsylvania State University*; Curtis Daehler, *University of Hawaii at Manoa*; Marymegan Daly, *The Ohio State University*; W. Marshall Darley, *University of Georgia*; Douglas Darnowski, *Indiana University Southeast*; Cynthia Dassler, *The Ohio State University*; Shannon Datwyler, *California State University, Sacramento*; Marianne Dauwalder, *University of Texas, Austin*; Larry Davenport, *Samford University*; Bonnie J. Davis, *San Francisco State University*; Jerry Davis, *University of Wisconsin, La Crosse*; Michael A. Davis, *Central Connecticut State University*; Thomas Davis, *University of New Hampshire*; Melissa Deadmond, *Truckee Meadows Community College*; John Dearn, *University of Canberra*; Maria E. de Bellard, *California State University, Northridge*; Teresa DeGolier, *Bethel College*; James Dekloe, *University of California, Santa Cruz*; Eugene Delay, *University of Vermont*; Patricia A. DeLeon, *University of Delaware*; Veronique Delesalle, *Gettysburg College*; T. Delevoryas, *University of Texas, Austin*; Roger Del Moral, *University of Washington*; Charles F. Delwiche, *University of Maryland*; Diane C. DeNagel, *Northwestern University*; William L. Dentler, *University of Kansas*; Jennifer Derkits, *J. Sergeant Reynolds Community College*; Daniel DerVartanian, *University of Georgia*; Jean DeSaix, *University of North Carolina, Chapel Hill*; Janet De Souza-Hart, *Massachusetts College of Pharmacy & Health Sciences*; Biao Ding, *Ohio State University*; Michael Dini, *Texas Tech University*; Kevin Dixon, *Florida State University*; Andrew Dobson, *Princeton University*; Stanley Dodson, *University of Wisconsin, Madison*; Jason Douglas, *Angelina College*; Mark Drapeau, *University of California, Irvine*; John Drees, *Temple University School of Medicine*; Charles Drewes, *Iowa State University*; Marvin Druger, *Syracuse University*; Gary Dudley, *University of Georgia*; David Dunbar, *Cabrini College*; Susan Dunford, *University of Cincinnati*; Kathryn A. Durham, *Lorain Community College*; Betsey Dyer, *Wheaton College*; Robert Eaton, *University of Colorado*; Robert S. Edgar, *University of California, Santa Cruz*; Anna Edlund, *Lafayette College*; Douglas J. Eernisse, *California State University, Fullerton*; Betty J. Eidemiller, *Lamar University*; Brad Elder, *Doane College*; Curt Elderkin, *College of New Jersey*; William D. Eldred, *Boston University*; Michelle Elekonich, *University of Nevada, Las Vegas*; George Ellmore, *Tufts University*; Mary Ellard-Ivey, *Pacific Lutheran University*; Kurt Elliott, *North West Vista College*; Norman Ellstrand, *University of California, Riverside*; Johnny El-Rady, *University of South Florida*; Bert Ely, *University of South Carolina*; Dennis Emery, *Iowa State University*; John Endler, *University of California, Santa Barbara*; Rob Erdman, *Florida Gulf Coast College*; Dale Erskine, *Lebanon Valley College*; Margaret T. Erskine, *Lansing Community College*; Susan Erster, *Stony Brook University*; Gerald Esch, *Wake Forest University*; Frederick B. Essig, *University of South Florida*; Mary Eubanks, *Duke University*; David Evans, *University of Florida*; Robert C. Evans, *Rutgers University, Camden*; Sharon Eversman, *Montana State University*; Olukemi Fadayomi, *Ferris State University*; Lincoln Fairchild, *Ohio State University*; Peter Fajer, *Florida State University*; Bruce Fall, *University of Minnesota*; Sam Fan, *Bradley University*; Lynn Fancher, *College of DuPage*; Ellen H. Fanning, *Vanderbilt University*; Paul Farnsworth, *University of New Mexico*; Larry Farrell, *Idaho State University*; Jerry F. Feldman, *University of California, Santa Cruz*; Lewis Feldman, *University of California, Berkeley*; Myriam Alhadef Feldman, *Cascadia Community College*; Eugene Fenster, *Longview Community College*; Linda Fergusson-Kolmes, *Portland Community College, Sylvania Campus*; Russell Fernald, *University of Oregon*; Danilo Fernando, *SUNY College of Environmental Science and Forestry, Syracuse*; Rebecca Ferrell, *Metropolitan State College of Denver*; Christina Fieber, *Horry-Georgetown Technical College*; Melissa Fierke, *SUNY College of Environmental Science and Forestry*; Kim Finer, *Kent State University*; Milton Fingerman, *Tulane University*; Barbara Finney, *Regis College*; Teresa Fischer, *Indian River Community College*; Frank Fish, *West Chester University*; David Fisher, *University of Hawaii, Manoa*; Jonathan S. Fisher, *St. Louis University*; Steven Fisher, *University of California, Santa Barbara*; David Fitch, *New York University*; Kirk Fitzhugh, *Natural History Museum of Los Angeles County*; Lloyd Fitzpatrick, *University of North Texas*; William Fixsen, *Harvard University*; T. Fleming, *Bradley University*; Abraham Flexer, *Manuscript Consultant, Boulder, Colorado*; Mark Flood, *Fairmont State University*; Margaret Folsom, *Methodist College*; Kerry Foresman, *University of Montana*; Norma Fowler, *University of Texas, Austin*; Robert G. Fowler,

San Jose State University; David Fox, *University of Tennessee, Knoxville*; Carl Frankel, *Pennsylvania State University, Hazleton*; Stewart Frankel, *University of Hartford*; Robert Franklin, *College of Charleston*; James Franzen, *University of Pittsburgh*; Art Fredeen, *University of Northern British Columbia*; Kim Fredericks, *Viterbo University*; Bill Freedman, *Dalhousie University*; Matt Friedman, *University of Chicago*; Otto Friesen, *University of Virginia*; Frank Frisch, *Chapman University*; Virginia Fry, *Monterey Peninsula College*; Bernard Frye, *University of Texas, Arlington*; Jed Fuhrman, *University of Southern California*; Alice Fulton, *University of Iowa*; Chandler Fulton, *Brandeis University*; Sara Fultz, *Stanford University*; Berdell Funke, *North Dakota State University*; Anne Funkhouser, *University of the Pacific*; Zofia E. Gagnon, *Marist College*; Michael Gaines, *University of Miami*; Cynthia M. Galloway, *Texas A&M University, Kingsville*; Arthur W. Galston, *Yale University*; Stephen Gammie, *University of Wisconsin, Madison*; Carl Gans, *University of Michigan*; John Gapter, *University of Northern Colorado*; Andrea Gargas, *University of Wisconsin, Madison*; Lauren Garner, *California Polytechnic State University, San Luis Obispo*; Reginald Garrett, *University of Virginia*; Craig Gatto, *Illinois State University*; Kristen Genet, *Anoka Ramsey Community College*; Patricia Gensel, *University of North Carolina*; Chris George, *California Polytechnic State University, San Luis Obispo*; Robert George, *University of Wyoming*; J. Whitfield Gibbons, *University of Georgia*; J. Phil Gibson, *University of Oklahoma*; Frank Gilliam, *Marshall University*; Eric Gillock, *Fort Hayes State University*; Simon Gilroy, *University of Wisconsin, Madison*; Edwin Ginés-Candelaria, *Miami Dade College*; Alan D. Gishlick, *Gustavus Adolphus College*; Todd Gleeson, *University of Colorado*; Jessica Gleffe, *University of California, Irvine*; John Glendinning, *Barnard College*; David Glenn-Lewin, *Wichita State University*; William Glider, *University of Nebraska*; Tricia Glidewell, *Marist School*; Elizabeth A. Godrick, *Boston University*; Jim Goetze, *Laredo Community College*; Lynda Goff, *University of California, Santa Cruz*; Elliott Goldstein, *Arizona State University*; Paul Goldstein, *University of Texas, El Paso*; Sandra Gollnick, *State University of New York, Buffalo*; Roy Golsteyn, *University of Lethbridge*; Anne Good, *University of California, Berkeley*; Judith Goodenough, *University of Massachusetts, Amherst*; Wayne Goodey, *University of British Columbia*; Barbara E. Goodman, *University of South Dakota*; Robert Goodman, *University of Wisconsin, Madison*; Ester Goudsmit, *Oakland University*; Linda Graham, *University of Wisconsin, Madison*; Robert Grammer, *Belmont University*; Joseph Graves, *Arizona State University*; Eileen Gregory, *Rollins College*; Phyllis Griffard, *University of Houston, Downtown*; A. J. E. Griffiths, *University of British Columbia*; Bradley Griggs, *Piedmont Technical College*; William Grimes, *University of Arizona*; David Grise, *Texas A&M University, Corpus Christi*; Mark Gromko, *Bowling Green State University*; Serine Gropper, *Auburn University*; Katherine L. Gross, *Ohio State University*; Gary Gussin, *University of Iowa*; Edward Gruber, *Temple University*; Carla Guthridge, *Cameron University*; Mark Guyer, *National Human Genome Research Institute*; Ruth Levy Guyer, *Bethesda, Maryland*; Carla Haas, *Pennsylvania State University*; R. Wayne Habermehl, *Montgomery County Community College*; Pryce Pete Haddix, *Auburn University*; Mac Hadley, *University of Arizona*; Joel Hagen, *Radford University*; Jack P. Hailman, *University of Wisconsin*; Leah Haimo, *University of California, Riverside*; Ken Halanych, *Auburn University*; Jody Hall, *Brown University*; Heather Hallen-Adams, *University of Nebraska, Lincoln*; Douglas Hallett, *Northern Arizona University*; Rebecca Halyard, *Clayton State College*; Devney Hamilton, *Stanford University* (student); E. William Hamilton, *Washington and Lee University*; Matthew B. Hamilton, *Georgetown University*; Sam Hammer, *Boston University*; Penny Hanchey-Bauer, *Colorado State University*; William F. Hanna, *Massasoit Community College*; Dennis Haney, *Furman University*; Laszlo Hanzely, *Northern Illinois University*; Jeff Hardin, *University of Wisconsin, Madison*; Jean Hardwick, *Ithaca College*; Luke Harmon, *University of Idaho*; Lisa Harper, *University of California, Berkeley*; Deborah Harris, *Case Western Reserve University*; Jeanne M. Harris, *University of Vermont*; Richard Harrison, *Cornell University*; Stephanie Harvey, *Georgia Southwestern State University*; Carla Hass, *Pennsylvania State University*; Chris Haufler, *University of Kansas*; Bernard A. Hauser, *University of Florida*; Chris Haynes, *Shelton State Community College*; Evan B. Hazard, *Bemidji State University* (emeritus); H. D. Heath, *California State University, East Bay*; George Hechtel, *State University of New York, Stony Brook*; S. Blair Hedges, *Pennsylvania State University*; Brian Hedlund, *University of Nevada, Las Vegas*; David Heins, *Tulane University*; Jean Heitz, *University of Wisconsin, Madison*; Andreas Hejnol, *Sars International Centre for Marine Molecular Biology*; John D. Helmann, *Cornell University*; Colin Henderson, *University of Montana*; Susan Hengeveld, *Indiana University*; Michelle Henricks, *University of California, Los Angeles*; Carol Henry, *Chicago State University*; Frank Heppner, *University of Rhode Island*; Albert Herrera, *University of Southern California*; Scott Herrick, *Missouri Western State College*; Ira Herskowitz, *University of California, San Francisco*; Paul E. Hertz, *Barnard College*; Chris Hess, *Butler University*; David Hibbett, *Clark University*; R. James Hickey, *Miami University*; Karen Hicks, *Kenyon College*; Kendra Hill, *San Diego State University*; William Hillenius, *College of Charleston*; Kenneth Hillers, *California Polytechnic State University, San Luis Obispo*; Ralph Hinegardner, *University of California, Santa Cruz*; William Hines, *Foothill College*; Robert Hinrichsen, *Indiana University of Pennsylvania*; Helmut Hirsch, *State University of New York, Albany*; Tuan-hua David Ho, *Washington University*; Carl Hoagstrom, *Ohio Northern University*; Elizabeth Hobson, *New Mexico State University*; Jason Hodin, *Stanford University*; James Hoffman, *University of Vermont*; A. Scott Holaday, *Texas Tech University*; Mark Holbrook, *University of Iowa*; N. Michele Holbrook, *Harvard University*; James Holland, *Indiana State University, Bloomington*; Charles Holliday, *Lafayette College*; Lubbock Karl Hoole, *Idaho State University*; Alan R. Holyoak, *Brigham Young University, Idaho*; Laura Hoopes, *Occidental College*; Nancy Hopkins, *Massachusetts Institute of Technology*; Sandra Horikami, *Daytona Beach Community College*; Kathy Hornberger, *Widener University*; Pius F. Horner, *San Bernardino Valley College*; Becky Houck, *University of Portland*; Margaret Houk, *Ripon College*; Laura Houston, *Northeast Lakeview College*; Daniel J. Howard, *New Mexico State University*; Ronald R. Hoy, *Cornell University*; Sandra Hsu, *Skyline College*; Sara Huang, *Los Angeles Valley College*; Cristin Hulslander, *University of Oregon*; Donald Humphrey, *Emory University School of Medicine*;

Catherine Hurlbut, *Florida State College, Jacksonville*; Diane Husic, *Moravian College*; Robert J. Huskey, *University of Virginia*; Steven Hutcheson, *University of Maryland, College Park*; Linda L. Hyde, *Gordon College*; Bradley Hyman, *University of California, Riverside*; Jeffrey Ihara, *Mira Costa College*; Mark Iked, *San Bernardino Valley College*; Cheryl Ingram-Smith, *Clemson University*; Erin Irish, *University of Iowa*; Sally Irwin, *University of Hawaii, Maui College*; Harry Itagaki, *Kenyon College*; Alice Jacklet, *State University of New York, Albany*; John Jackson, *North Hennepin Community College*; Thomas Jacobs, *University of Illinois*; Kathy Jacobson, *Grinnell College*; Mark Jaffe, *Nova Southeastern University*; John C. Jahoda, *Bridgewater State College*; Douglas Jensen, *Converse College*; Jamie Jensen, *Brigham Young University*; Dan Johnson, *East Tennessee State University*; Lance Johnson, *Midland Lutheran College*; Lee Johnson, *The Ohio State University*; Randall Johnson, *University of California, San Diego*; Roishene Johnson, *Bossier Parish Community College*; Stephen Johnson, *William Penn University*; Wayne Johnson, *Ohio State University*; Kenneth C. Jones, *California State University, Northridge*; Russell Jones, *University of California, Berkeley*; Cheryl Jorcyk, *Boise State University*; Chad Jordan, *North Carolina State University*; Ann Jorgensen, *University of Hawaii*; Alan Journet, *Southeast Missouri State University*; Walter Judd, *University of Florida*; Ari Jumpponen, *Kansas State University*; Thomas W. Jurik, *Iowa State University*; Caroline M. Kane, *University of California, Berkeley*; Doug Kane, *Defiance College*; Thomas C. Kane, *University of Cincinnati*; The-Hui Kao, *Pennsylvania State University*; Tamos Kapros, *University of Missouri*; Kasey Karen, *Georgia College & State University*; E. L. Karlstrom, *University of Puget Sound*; David Kass, *Eastern Michigan University*; Jennifer Katcher, *Pima Community College*; Laura A. Katz, *Smith College*; Judy Kaufman, *Monroe Community College*; Maureen Kearney, *Field Museum of Natural History*; Eric G. Keeling, *Cary Institute of Ecosystem Studies*; Patrick Keeling, *University of British Columbia*; Thomas Keller, *Florida State University*; Elizabeth A. Kellogg, *University of Missouri, St. Louis*; Paul Kenrick, *Natural History Museum, London*; Norm Kenkel, *University of Manitoba*; Chris Kennedy, *Simon Fraser University*; George Khoury, *National Cancer Institute*; Stephen T. Kilpatrick, *University of Pittsburgh at Johnstown*; Rebecca T. Kimball, *University of Florida*; Shannon King, *North Dakota State University*; Mark Kirk, *University of Missouri, Columbia*; Robert Kitchin, *University of Wyoming*; Hillar Klandorf, *West Virginia University*; Attila O. Klein, *Brandeis University*; Karen M. Klein, *Northampton Community College*; Daniel Klionsky, *University of Michigan*; Mark Knauss, *Georgia Highlands College*; Janice Knepper, *Villanova University*; Charles Knight, *California Polytechnic State University*; Jennifer Knight, *University of Colorado*; Ned Knight, *Linfield College*; Roger Koeppe, *University of Arkansas*; David Kohl, *University of California, Santa Barbara*; Greg Kopf, *University of Pennsylvania School of Medicine*; Thomas Koppenheffer, *Trinity University*; Peter Kourtev, *Central Michigan University*; Margareta Krabbe, *Uppsala University*; Jacob Krans, *Western New England University*; Anselm Kratochwil, *Universität Osnabrück*; Eliot Krause, *Seton Hall University*; Deborah M. Kristan, *California State University, San Marcos*; Steven Kristoff, *Ivy Tech Community College*; Dubeer Kroening, *University of Wisconsin*; William Kroll, *Loyola University, Chicago*; Janis Kuby, *San Francisco State University*; Barbara Kuemerle, *Case Western Reserve University*; Justin P. Kumar, *Indiana University*; Rukmani Kuppuswami, *Laredo Community College*; David Kurijaka, *Ohio University*; Lee Kurtz, *Georgia Gwinnett College*; Michael P. Labare, *United States Military Academy, West Point*; Marc-André Lachance, *University of Western Ontario*; J. A. Lackey, *State University of New York, Oswego*; Elaine Lai, *Brandeis University*; Mohamed Lakrim, *Kingsborough Community College*; Ellen Lamb, *University of North Carolina, Greensboro*; William Lambert, *College of St Benedict and St John's University*; William L'Amoreaux, *College of Staten Island*; Lynn Lamoreux, *Texas A&M University*; Carmine A. Lanciani, *University of Florida*; Kenneth Lang, *Humboldt State University*; Jim Langland, *Kalamazoo College*; Dominic Lannutti, *El Paso Community College*; Allan Larson, *Washington University*; Grace Lasker, *Lake Washington Institute of Technology*; John Latto, *University of California, Santa Barbara*; Diane K. Lavett, *State University of New York, Cortland, and Emory University*; Charles Leavell, *Fullerton College*; C. S. Lee, *University of Texas*; Daewoo Lee, *Ohio University*; Tali D. Lee, *University of Wisconsin, Eau Claire*; Hugh Lefcort, *Gonzaga University*; Robert Leonard, *University of California, Riverside*; Michael R. Leonardo, *Coe College*; John Lepri, *University of North Carolina, Greensboro*; Donald Levin, *University of Texas, Austin*; Joseph Levine, *Boston College*; Mike Levine, *University of California, Berkeley*; Alcinda Lewis, *University of Colorado, Boulder*; Bill Lewis, *Shoreline Community College*; Jani Lewis, *State University of New York*; John Lewis, *Loma Linda University*; Lorraine Lica, *California State University, East Bay*; Harvey Liftin, *Broward Community College*; Harvey Lillywhite, *University of Florida, Gainesville*; Graeme Lindbeck, *Valencia Community College*; Clark Lindgren, *Grinnell College*; Eric W. Linton, *Central Michigan University*; Diana Lipscomb, *George Washington University*; Christopher Little, *The University of Texas, Pan American*; Kevin D. Livingstone, *Trinity University*; Andrea Lloyd, *Middlebury College*; Tatyana Lobova, *Old Dominion University*; Sam Loker, *University of New Mexico*; David Longstreth, *Louisiana State University*; Christopher A. Loretz, *State University of New York, Buffalo*; Donald Lovett, *College of New Jersey*; Jane Lubchenko, *Oregon State University*; Douglas B. Luckie, *Michigan State University*; Hannah Lui, *University of California, Irvine*; Margaret A. Lynch, *Tufts University*; Steven Lynch, *Louisiana State University, Shreveport*; Lisa Lyons, *Florida State University*; Richard Machemer Jr., *St. John Fisher College*; Elizabeth Machunis-Masuoka, *University of Virginia*; James MacMahon, *Utah State University*; Nancy Magill, *Indiana University*; Christine R. Maher, *University of Southern Maine*; Linda Maier, *University of Alabama, Huntsville*; Jose Maldonado, *El Paso Community College*; Richard Malkin, *University of California, Berkeley*; Charles Mallery, *University of Miami*; Keith Malmos, *Valencia Community College, East Campus*; Cindy Malone, *California State University, Northridge*; Mark Maloney, *University of South Mississippi*; Carol Mapes, *Kutztown University of Pennsylvania*; William Margolin, *University of Texas Medical School*; Lynn Margulis, *Boston University*; Julia Marrs, *Barnard College* (student); Kathleen A. Marrs, *Indiana University-Purdue University, Indianapolis*; Edith Marsh, *Angelo State University*; Diane L. Marshall, *University of New Mexico*; Mary Martin,

Northern Michigan University; Karl Mattox, *Miami University of Ohio*; Joyce Maxwell, *California State University, Northridge*; Jeffrey D. May, *Marshall University*; Mike Mayfield, *Ball State University*; Kamau Mbutia, *Bowling Green State University*; Lee McClenaghan, *San Diego State University*; Richard McCracken, *Purdue University*; Andrew McCubbin, *Washington State University*; Kerry McDonald, *University of Missouri, Columbia*; Tanya McGhee, *Craven Community College*; Jacqueline McLaughlin, *Pennsylvania State University, Lehigh Valley*; Neal McReynolds, *Texas A&M International*; Darcy Medica, *Pennsylvania State University*; Lisa Marie Meffert, *Rice University*; Susan Meiers, *Western Illinois University*; Michael Meighan, *University of California, Berkeley*; Scott Meissner, *Cornell University*; Paul Melchior, *North Hennepin Community College*; Phillip Meneely, *Haverford College*; John Merrill, *Michigan State University*; Brian Metscher, *University of California, Irvine*; Jenny Metzler, *Ball State University*; Ralph Meyer, *University of Cincinnati*; James Mickle, *North Carolina State University*; Jan Mikesell, *Gettysburg College*; Roger Milkman, *University of Iowa*; Grace Miller, *Indiana Wesleyan University*; Helen Miller, *Oklahoma State University*; John Miller, *University of California, Berkeley*; Jonathan Miller, *Edmonds Community College*; Kenneth R. Miller, *Brown University*; Mill Miller, *Wright State University*; Alex Mills, *University of Windsor*; Sarah Milton, *Florida Atlantic University*; Eli Minkoff, *Bates College*; John E. Minnich, *University of Wisconsin, Milwaukee*; Subhash Minocha, *University of New Hampshire*; Michael J. Misamore, *Texas Christian University*; Kenneth Mitchell, *Tulane University School of Medicine*; Ivona Mladenovic, *Simon Fraser University*; Alan Molumby, *University of Illinois, Chicago*; Nicholas Money, *Miami University*; Russell Monson, *University of Colorado, Boulder*; Joseph P. Montoya, *Georgia Institute of Technology*; Frank Moore, *Oregon State University*; Janice Moore, *Colorado State University*; Linda Moore, *Georgia Military College*; Randy Moore, *Wright State University*; William Moore, *Wayne State University*; Carl Moos, *Veterans Administration Hospital, Albany, New York*; Linda Martin Morris, *University of Washington*; Michael Mote, *Temple University*; Alex Motten, *Duke University*; Jeanette Mowery, *Madison Area Technical College*; Deborah Mowshowitz, *Columbia University*; Rita Moyes, *Texas A&M, College Station*; Darrel L. Murray, *University of Illinois, Chicago*; Courtney Murren, *College of Charleston*; John Mutchmor, *Iowa State University*; Elliot Myerowitz, *California Institute of Technology*; Barbara Nash, *Mercy College*; Gavin Naylor, *Iowa State University*; John Neess, *University of Wisconsin, Madison*; Ross Nehm, *Ohio State University*; Tom Neils, *Grand Rapids Community College*; Kimberlyn Nelson, *Pennsylvania State University*; Raymond Neubauer, *University of Texas, Austin*; Todd Newbury, *University of California, Santa Cruz*; James Newcomb, *New England College*; Jacalyn Newman, *University of Pittsburgh*; Harvey Nichols, *University of Colorado, Boulder*; Deborah Nickerson, *University of South Florida*; Bette Nicotri, *University of Washington*; Caroline Niederman, *Tomball College*; Eric Nielsen, *University of Michigan*; Maria Nieto, *California State University, East Bay*; Anders Nilsson, *University of Umeå*; Greg Nishiyama, *College of the Canyons*; Charles R. Noback, *College of Physicians and Surgeons, Columbia University*; Jane Noble-Harvey, *Delaware University*; Mary C. Nolan, *Irvine Valley College*; Kathleen Nolta, *University of Michigan*; Peter Nonacs, *University of California, Los Angeles*; Mohamed A. F. Noor, *Duke University*; Shawn Nordell, *St. Louis University*; Richard S. Norman, *University of Michigan, Dearborn* (emeritus); David O. Norris, *University of Colorado, Boulder*; Steven Norris, *California State University, Channel Islands*; Gretchen North, *Occidental College*; Cynthia Norton, *University of Maine, Augusta*; Steve Norton, *East Carolina University*; Steve Nowicki, *Duke University*; Bette H. Nybakken, *Hartnell College*; Brian O'Conner, *University of Massachusetts, Amherst*; Gerard O'Donovan, *University of North Texas*; Eugene Odum, *University of Georgia*; Mark P. Oemke, *Alma College*; Linda Ogren, *University of California, Santa Cruz*; Patricia O'Hern, *Emory University*; Olabisi Ojo, *Southern University at New Orleans*; Nathan O. Okia, *Auburn University, Montgomery*; Jeanette Oliver, *St. Louis Community College, Florissant Valley*; Gary P. Olivetti, *University of Vermont*; Margaret Olney, *St. Martin's College*; John Olsen, *Rhodes College*; Laura J. Olsen, *University of Michigan*; Sharman O'Neill, *University of California, Davis*; Wan Ooi, *Houston Community College*; Aharon Oren, *The Hebrew University*; John Oross, *University of California, Riverside*; Rebecca Orr, *Collin College*; Catherine Ortega, *Fort Lewis College*; Charissa Osborne, *Butler University*; Gay Ostarello, *Diablo Valley College*; Henry R. Owen, *Eastern Illinois University*; Thomas G. Owens, *Cornell University*; Penny Padgett, *University of North Carolina, Chapel Hill*; Kevin Padian, *University of California, Berkeley*; Dianna Padilla, *State University of New York, Stony Brook*; Anthony T. Paganini, *Michigan State University*; Fatimata Pale, *Thiel College*; Barry Palevitz, *University of Georgia*; Michael A. Palladino, *Monmouth University*; Matt Palmtag, *Florida Gulf Coast University*; Stephanie Pandolfi, *Michigan State University*; Daniel Papaj, *University of Arizona*; Peter Pappas, *County College of Morris*; Nathalie Pardigon, *Institut Pasteur*; Bulah Parker, *North Carolina State University*; Stanton Parmeter, *Chemeketa Community College*; Susan Parrish, *McDaniel College*; Cindy Paszkowski, *University of Alberta*; Robert Patterson, *San Francisco State University*; Ronald Patterson, *Michigan State University*; Crellin Pauling, *San Francisco State University*; Kay Pauling, *Foothill Community College*; Daniel Pavuk, *Bowling Green State University*; Debra Pearce, *Northern Kentucky University*; Patricia Pearson, *Western Kentucky University*; Andrew Pease, *Stevenson University*; Nancy Pelaez, *Purdue University*; Shelley Penrod, *North Harris College*; Imara Y. Perera, *North Carolina State University*; Beverly Perry, *Houston Community College*; Irene Perry, *University of Texas of the Permian Basin*; Roger Persell, *Hunter College*; Eric Peters, *Chicago State University*; Larry Peterson, *University of Guelph*; David Pfennig, *University of North Carolina, Chapel Hill*; Mark Pilgrim, *College of Coastal Georgia*; David S. Pilliod, *California Polytechnic State University, San Luis Obispo*; Vera M. Piper, *Shenandoah University*; Deb Pires, *University of California, Los Angeles*; J. Chris Pires, *University of Missouri, Columbia*; Jarmila Pittermann, *University of California, Santa Cruz*; Bob Pittman, *Michigan State University*; James Platt, *University of Denver*; Martin Poenie, *University of Texas, Austin*; Scott Poethig, *University of Pennsylvania*; Crima Pogge, *San Francisco Community College*; Michael Pollock, *Mount Royal University*; Roberta Pollock, *Occidental College*; Jeffrey Pommerville, *Texas A&M University*; Therese M. Poole, *Georgia State University*; Angela R. Porta, *Kean University*; Jason Porter,

University of the Sciences, Philadelphia; Warren Porter, University of Wisconsin; Daniel Potter, University of California, Davis; Donald Potts, University of California, Santa Cruz; Robert Powell, Avila University; Andy Pratt, University of Canterbury; David Pratt, University of California, Davis; Halina Presley, University of Illinois, Chicago; Eileen Preston, Tarrant Community College Northwest; Mary V. Price, University of California, Riverside; Mitch Price, Pennsylvania State University; Steven Price, Virginia Commonwealth University; Terrell Pritts, University of Arkansas, Little Rock; Rong Sun Pu, Kean University; Rebecca Pyles, East Tennessee State University; Scott Quackenbush, Florida International University; Ralph Quatrano, Oregon State University; Peter Quinby, University of Pittsburgh; Val Raghavan, Ohio State University; Deanna Raineri, University of Illinois, Champaign-Urbana; David Randall, City University Hong Kong; Talitha Rajah, Indiana University Southeast; Charles Ralph, Colorado State University; Pushpa Ramakrishna, Chandler-Gilbert Community College; Thomas Rand, Saint Mary's University; Monica Ranes-Goldberg, University of California, Berkeley; Samiksha Raut, University of Alabama at Birmingham; Robert S. Rawding, Gannon University; Robert H. Reavis, Glendale Community College; Kurt Redborg, Coe College; Ahnya Redman, Pennsylvania State University; Brian Reeder, Morehead State University; Bruce Reid, Kean University; David Reid, Blackburn College; C. Gary Reiness, Lewis & Clark College; Charles Remington, Yale University; Erin Rempala, San Diego Mesa College; David Reznick, University of California, Riverside; Fred Rhoades, Western Washington State University; Douglas Rhoads, University of Arkansas; Eric Ribbens, Western Illinois University; Christina Richards, New York University; Sarah Richart, Azusa Pacific University; Wayne Rickoll, University of Puget Sound; Christopher Riegle, Irvine Valley College; Loren Rieseberg, University of British Columbia; Bruce B. Riley, Texas A&M University; Todd Rimkus, Marymount University; John Rinehart, Eastern Oregon University; Donna Ritch, Pennsylvania State University; Carol Rivin, Oregon State University East; Laurel Roberts, University of Pittsburgh; Diane Robins, University of Michigan; Kenneth Robinson, Purdue University; Thomas Rodella, Merced College; Luis Rodriguez, San Antonio College; Deb Roess, Colorado State University; Heather Roffey, Marianopolis College; Rodney Rogers, Drake University; Suzanne Rogers, Seton Hill University; William Roosenburg, Ohio University; Kara Rosch, Blinn College; Mike Rosenzweig, Virginia Polytechnic Institute and State University; Wayne Rosing, Middle Tennessee State University; Thomas Rost, University of California, Davis; Stephen I. Rothstein, University of California, Santa Barbara; John Ruben, Oregon State University; Albert Ruesink, Indiana University; Patricia Rugaber, College of Coastal Georgia; Scott Russell, University of Oklahoma; Jodi Rymer, College of the Holy Cross; Neil Sabine, Indiana University; Tyson Sacco, Cornell University; Glenn-Peter Saetre, University of Oslo; Rowan F. Sage, University of Toronto; Tammy Lynn Sage, University of Toronto; Sanga Saha, Harold Washington College; Don Sakaguchi, Iowa State University; Walter Sakai, Santa Monica College; Per Salvesen, University of Bergen; Mark F. Sanders, University of California, Davis; Kathleen Sandman, Ohio State University; Davison Sangweme, University of North Georgia; Louis Santiago, University of California, Riverside; Ted Sargent, University of Massachusetts, Amherst; K. Sathasivan, University of Texas, Austin; Gary Saunders, University of New Brunswick; Thomas R. Sawicki, Spartano Community College; Inder Saxena, University of Texas, Austin; Karin Scarpinato, Georgia Southern University; Carl Schaefer, University of Connecticut; Andrew Schaffner, Cal Poly San Luis Obispo; Maynard H. Schaus, Virginia Wesleyan College; Renate Scheibe, University of Osnabrück; Cara Schillington, Eastern Michigan University; David Schimpf, University of Minnesota, Duluth; William H. Schlesinger, Duke University; Mark Schliessel, University of California, Berkeley; Christopher J. Schneider, Boston University; Thomas W. Schoener, University of California, Davis; Robert Schorr, Colorado State University; Patricia M. Schulte, University of British Columbia; Karen S. Schumaker, University of Arizona; Brenda Schumpert, Valencia Community College; David J. Schwartz, Houston Community College; Carrie Schwarz, Western Washington University; Christa Schwintzer, University of Maine; Erik P. Scully, Towson State University; Robert W. Seagull, Hofstra University; Edna Seaman, Northeastern University; Duane Sears, University of California, Santa Barbara; Brent Selinger, University of Lethbridge; Orono Shukdeb Sen, Bethune-Cookman College; Wendy Sera, Seton Hill University; Alison M. Shakarian, Salve Regina University; Timothy E. Shannon, Francis Marion University; Victoria C. Sharpe, Blinn College; Elaine Shea, Loyola College, Maryland; Stephen Sheckler, Virginia Polytechnic Institute and State University; Robin L. Sherman, Nova Southeastern University; Richard Sherwin, University of Pittsburgh; Alison Sherwood, University of Hawaii at Manoa; Lisa Shimeld, Crafton Hills College; James Shinkle, Trinity University; Barbara Shipes, Hampton University; Brian Shmaefsky, Lone Star College; Richard M. Showman, University of South Carolina; Eric Shows, Jones County Junior College; Peter Shugarman, University of Southern California; Alice Shuttey, DeKalb Community College; James Sidie, Ursinus College; Daniel Simberloff, Florida State University; Rebecca Simmons, University of North Dakota; Anne Simon, University of Maryland, College Park; Robert Simons, University of California, Los Angeles; Alastair Simpson, Dalhousie University; Susan Singer, Carleton College; Sedonia Sipes, Southern Illinois University, Carbondale; John Skillman, California State University, San Bernardino; Roger Sloboda, Dartmouth University; John Smarrelli, Le Moyné College; Andrew T. Smith, Arizona State University; Kelly Smith, University of North Florida; Nancy Smith-Huerta, Miami Ohio University; John Smol, Queen's University; Andrew J. Snope, Essex Community College; Mitchell Sogin, Woods Hole Marine Biological Laboratory; Doug Soltis, University of Florida, Gainesville; Julio G. Soto, San Jose State University; Susan Sovonick-Dunford, University of Cincinnati; Rebecca Sperry, Salt Lake Community College; Frederick W. Spiegel, University of Arkansas; Clint Springer, Saint Joseph's University; John Stachowicz, University of California, Davis; Joel Stafstrom, Northern Illinois University; Alam Stam, Capital University; Amanda Starnes, Emory University; Karen Steudel, University of Wisconsin; Barbara Stewart, Swarthmore College; Gail A. Stewart, Camden County College; Cecil Still, Rutgers University, New Brunswick; Margery Stinson, Southwestern College; James Stockand, University of Texas Health

Science Center, San Antonio; John Stolz, California Institute of Technology; Judy Stone, Colby College; Richard D. Storey, Colorado College; Stephen Strand, University of California, Los Angeles; Eric Strauss, University of Massachusetts, Boston; Antony Stretton, University of Wisconsin, Madison; Russell Stullken, Augusta College; Mark Sturtevant, Oakland University, Flint; John Sullivan, Southern Oregon State University; Gerald Summers, University of Missouri; Judith Sumner, Assumption College; Marshall D. Sundberg, Emporia State University; Cynthia Surmacz, Bloomsburg University; Lucinda Swatzell, Southeast Missouri State University; Daryl Sweeney, University of Illinois, Champaign-Urbana; Diane Sweeney, Punahou School; Samuel S. Sweet, University of California, Santa Barbara; Janice Swenson, University of North Florida; Michael A. Sypes, Pennsylvania State University; Lincoln Taiz, University of California, Santa Cruz; David Tam, University of North Texas; Yves Tan, Cabrillo College; Samuel Tarsitano, Southwest Texas State University; David Tauck, Santa Clara University; Emily Taylor, California Polytechnic State University, San Luis Obispo; James Taylor, University of New Hampshire; John W. Taylor, University of California, Berkeley; Kristen Taylor, Salt Lake Community College; Martha R. Taylor, Cornell University; Franklyn Tan Te, Miami Dade College; Thomas Terry, University of Connecticut; Roger Thibault, Bowling Green State University; Kent Thomas, Wichita State University; Rebecca Thomas, College of St. Joseph; William Thomas, Colby-Sawyer College; Cyril Thong, Simon Fraser University; John Thornton, Oklahoma State University; Robert Thornton, University of California, Davis; William Thwaites, Tillamook Bay Community College; Stephen Timme, Pittsburg State University; Mike Toliver, Eureka College; Eric Toolson, University of New Mexico; Leslie Towill, Arizona State University; James Trianello, Boston University; Paul Q. Trombley, Florida State University; Nancy J. Trun, Duquesne University; Constantine Tsoukas, San Diego State University; Marsha Turell, Houston Community College; Victoria Turgeon, Furman University; Robert Tuveson, University of Illinois, Urbana; Maura G. Tyrrell, Stonehill College; Catherine Uekert, Northern Arizona University; Claudia Uhde-Stone, California State University, East Bay; Gordon Uno, University of Oklahoma; Lisa A. Urry, Mills College; Saba Valadkhan, Center for RNA Molecular Biology; James W. Valentine, University of California, Santa Barbara; Joseph Vanable, Purdue University; Theodore Van Bruggen, University of South Dakota; Kathryn VandenBosch, Texas A&M University; Gerald Van Dyke, North Carolina State University; Brandi Van Roo, Framingham State College; Moira Van Staaden, Bowling Green State University; Martin Vaughan, Indiana University-Purdue University Indianapolis; Sarah VanVickle-Chavez, Washington University, St. Louis; William Velhagen, New York University; Steven D. Verhey, Central Washington University; Kathleen Verville, Washington College; Sara Via, University of Maryland; Meena Vijayaraghavan, Tulane University; Frank Visco, Orange Coast College; Laurie Vitt, University of California, Los Angeles; Neal Voelz, St. Cloud State University; Thomas J. Volk, University of Wisconsin, La Crosse; Leif Asbjørn Vøllestad, University of Oslo; Amy Volmer, Swarthmore College; Janice Voltzow, University of Scranton; Margaret Voss, Penn State Erie; Susan D. Waaland, University of Washington; Charles Wade, C.S. Mott Community College; William Wade, Dartmouth Medical College; John Waggoner, Loyola Marymount University; Jyoti Wagle, Houston Community College; Edward Wagner, University of California, Irvine; D. Alexander Wait, Southwest Missouri State University; Claire Walczak, Indiana University; Jerry Waldvogel, Clemson University; Dan Walker, San Jose State University; Robert Lee Wallace, Ripon College; Jeffrey Walters, North Carolina State University; Linda Walters, University of Central Florida; James Wandersee, Louisiana State University; James T. Warren Jr., Pennsylvania State University; Nickolas M. Waser, University of California, Riverside; Fred Wasserman, Boston University; Margaret Waterman, University of Pittsburgh; Charles Webber, Loyola University of Chicago; Peter Webster, University of Massachusetts, Amherst; Terry Webster, University of Connecticut, Storrs; Beth Wee, Tulane University; James Wee, Loyola University, New Orleans; Andrea Weeks, George Mason University; John Weishampel, University of Central Florida; Peter Wejksnora, University of Wisconsin, Milwaukee; Charles Wellman, Sheffield University; Kentwood Wells, University of Connecticut; David J. Westenberg, University of Missouri, Rolla; Richard Wetts, University of California, Irvine; Christopher Whipples, State University of New York College of Environmental Science and Forestry; Jessica White-Phillip, Our Lady of the Lake University; Matt White, Ohio University; Philip White, James Hutton Institute; Susan Whittmore, Keene State College; Murray Wiegand, University of Winnipeg; Ernest H. Williams, Hamilton College; Kathy Williams, San Diego State University; Kimberly Williams, Kansas State University; Stephen Williams, Glendale Community College; Elizabeth Willott, University of Arizona; Christopher Wills, University of California, San Diego; Paul Wilson, California State University, Northridge; Fred Wilt, University of California, Berkeley; Peter Wimberger, University of Puget Sound; Robert Winning, Eastern Michigan University; E. William Wischusen, Louisiana State University; Clarence Wolfe, Northern Virginia Community College; Vickie L. Wolfe, Marshall University; Janet Wolkenstein, Hudson Valley Community College; Robert T. Woodland, University of Massachusetts Medical School; Joseph Woodring, Louisiana State University; Denise Woodward, Pennsylvania State University; Patrick Woolley, East Central College; Sarah E. Wyatt, Ohio University; Grace Wyngaard, James Madison University; Shuhai Xiao, Virginia Polytechnic Institute, Ramin Yadegari, University of Arizona; Paul Yancey, Whitman College; Philip Yant, University of Michigan; Linda Yasui, Northern Illinois University; Anne D. Yoder, Duke University; Hideo Yonenaka, San Francisco State University; Robert Yost, Indiana University-Purdue University Indianapolis; Tia Young, Pennsylvania State University; Gina M. Zainelli, Loyola University, Chicago; Edward Zalisko, Blackburn College; Nina Zanetti, Siena College; Sam Zeveloff, Weber State University; Zai Ming Zhao, University of Texas, Austin; John Zimmerman, Kansas State University; Miriam Zolan, Indiana University; Theresa Zuccherro, Methodist University; Uko Zylstra, Calvin College.

Detailed Contents

1 Evolution, the Themes of Biology, and Scientific Inquiry 2

CONCEPT 1.1 The study of life reveals unifying themes 3

- Theme: New Properties Emerge at Successive Levels of Biological Organization 4
- Theme: Life's Processes Involve the Expression and Transmission of Genetic Information 6
- Theme: Life Requires the Transfer and Transformation of Energy and Matter 9
- Theme: From Molecules to Ecosystems, Interactions Are Important in Biological Systems 9

CONCEPT 1.2 The Core Theme: Evolution accounts for the unity and diversity of life 11

- Classifying the Diversity of Life 12
- Charles Darwin and the Theory of Natural Selection 14
- The Tree of Life 15

CONCEPT 1.3 In studying nature, scientists form and test hypotheses 16

- Exploration and Observation 17
- Gathering and Analyzing Data 17
- Forming and Testing Hypotheses 17
- The Flexibility of the Scientific Process 18
- A Case Study in Scientific Inquiry: Investigating Coat Coloration in Mouse Populations* 20
- Variables and Controls in Experiments 20
- Theories in Science 21

CONCEPT 1.4 Science benefits from a cooperative approach and diverse viewpoints 22

- Building on the Work of Others 22
- Science, Technology, and Society 23
- The Value of Diverse Viewpoints in Science 24

Unit 1 The Chemistry of Life 27

Interview: Kenneth Olden 27

2 The Chemical Context of Life 28

CONCEPT 2.1 Matter consists of chemical elements in pure form and in combinations called compounds 29

- Elements and Compounds 29
- The Elements of Life 29
- Case Study: Evolution of Tolerance to Toxic Elements* 30

CONCEPT 2.2 An element's properties depend on the structure of its atoms 30

- Subatomic Particles 30
- Atomic Number and Atomic Mass 31
- Isotopes 31
- The Energy Levels of Electrons 32
- Electron Distribution and Chemical Properties 34
- Electron Orbitals 35

CONCEPT 2.3 The formation and function of molecules and ionic compounds depend on chemical bonding between atoms 36

- Covalent Bonds 36
- Ionic Bonds 37
- Weak Chemical Interactions 38
- Molecular Shape and Function 39

CONCEPT 2.4 Chemical reactions make and break chemical bonds 40

3 Water and Life 44

CONCEPT 3.1 Polar covalent bonds in water molecules result in hydrogen bonding 45

CONCEPT 3.2 Four emergent properties of water contribute to Earth's suitability for life 45

- Cohesion of Water Molecules 45
- Moderation of Temperature by Water 46
- Floating of Ice on Liquid Water 48
- Water: The Solvent of Life 49
- Possible Evolution of Life on Other Planets 50

CONCEPT 3.3 Acidic and basic conditions affect living organisms 51

- Acids and Bases 51
- The pH Scale 51
- Buffers 52
- Acidification: A Threat to Our Oceans 53



4 Carbon and the Molecular Diversity of Life 56

CONCEPT 4.1 Organic chemistry is key to the origin of life 57

CONCEPT 4.2 Carbon atoms can form diverse molecules by bonding to four other atoms 58

- The Formation of Bonds with Carbon 58
- Molecular Diversity Arising from Variation in Carbon Skeletons 60

CONCEPT 4.3 A few chemical groups are key to molecular function 62

- The Chemical Groups Most Important in the Processes of Life 62
- ATP: An Important Source of Energy for Cellular Processes 64
- The Chemical Elements of Life: *A Review* 64

5 The Structure and Function of Large Biological Molecules 66

CONCEPT 5.1 Macromolecules are polymers, built from monomers 67

- The Synthesis and Breakdown of Polymers 67
- The Diversity of Polymers 67

CONCEPT 5.2 Carbohydrates serve as fuel and building material 68

- Sugars 68
- Polysaccharides 70

CONCEPT 5.3 Lipids are a diverse group of hydrophobic molecules 72

- Fats 72
- Phospholipids 74
- Steroids 75

CONCEPT 5.4 Proteins include a diversity of structures, resulting in a wide range of functions 75

- Amino Acids (Monomers) 75
- Polypeptides (Amino Acid Polymers) 78
- Protein Structure and Function 78

CONCEPT 5.5 Nucleic acids store, transmit, and help express hereditary information 84

- The Roles of Nucleic Acids 84
- The Components of Nucleic Acids 84
- Nucleotide Polymers 85
- The Structures of DNA and RNA Molecules 86

CONCEPT 5.6 Genomics and proteomics have transformed biological inquiry and applications 86

- DNA and Proteins as Tape Measures of Evolution 87



Unit 2 The Cell

92

Interview: Diana Bautista 92

6 A Tour of the Cell 93

CONCEPT 6.1 Biologists use microscopes and biochemistry to study cells 94

- Microscopy 94
- Cell Fractionation 96

CONCEPT 6.2 Eukaryotic cells have internal membranes that compartmentalize their functions 97

- Comparing Prokaryotic and Eukaryotic Cells 97
- A Panoramic View of the Eukaryotic Cell 99

CONCEPT 6.3 The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes 102

- The Nucleus: Information Central 102
- Ribosomes: Protein Factories 102

CONCEPT 6.4 The endomembrane system regulates protein traffic and performs metabolic functions 104

- The Endoplasmic Reticulum: Biosynthetic Factory 104
- The Golgi Apparatus: Shipping and Receiving Center 105
- Lysosomes: Digestive Compartments 107
- Vacuoles: Diverse Maintenance Compartments 108
- The Endomembrane System: A Review 108

CONCEPT 6.5 Mitochondria and chloroplasts change energy from one form to another 109

- The Evolutionary Origins of Mitochondria and Chloroplasts 109
- Mitochondria: Chemical Energy Conversion 110
- Chloroplasts: Capture of Light Energy 110
- Peroxisomes: Oxidation 112

CONCEPT 6.6 The cytoskeleton is a network of fibers that organizes structures and activities in the cell 112

- Roles of the Cytoskeleton: Support and Motility 112
- Components of the Cytoskeleton 113

CONCEPT 6.7 Extracellular components and connections between cells help coordinate cellular activities 118

- Cell Walls of Plants 118
- The Extracellular Matrix (ECM) of Animal Cells 118
- Cell Junctions 119

CONCEPT 6.8 A cell is greater than the sum of its parts 121

7 Membrane Structure and Function 126

CONCEPT 7.1 Cellular membranes are fluid mosaics of lipids and proteins 127

- The Fluidity of Membranes 128
- Evolution of Differences in Membrane Lipid Composition 129
- Membrane Proteins and Their Functions 129
- The Role of Membrane Carbohydrates in Cell-Cell Recognition 130
- Synthesis and Sidedness of Membranes 131

CONCEPT 7.2 Membrane structure results in selective permeability 131

- The Permeability of the Lipid Bilayer 132
- Transport Proteins 132

CONCEPT 7.3 Passive transport is diffusion of a substance across a membrane with no energy investment 132

- Effects of Osmosis on Water Balance 133
- Facilitated Diffusion: Passive Transport Aided by Proteins 135

CONCEPT 7.4 Active transport uses energy to move solutes against their gradients 136

- The Need for Energy in Active Transport 136
- How Ion Pumps Maintain Membrane Potential 137
- Cotransport: Coupled Transport by a Membrane Protein 138

CONCEPT 7.5 Bulk transport across the plasma membrane occurs by exocytosis and endocytosis 139

- Exocytosis 139
- Endocytosis 139

8 An Introduction to Metabolism 143

CONCEPT 8.1 An organism's metabolism transforms matter and energy 144

- Metabolic Pathways 144
- Forms of Energy 144
- The Laws of Energy Transformation 145

CONCEPT 8.2 The free-energy change of a reaction tells us whether or not the reaction occurs spontaneously 147

- Free-Energy Change, ΔG 147
- Free Energy, Stability, and Equilibrium 147
- Free Energy and Metabolism 148

CONCEPT 8.3 ATP powers cellular work by coupling exergonic reactions to endergonic reactions 150

- The Structure and Hydrolysis of ATP 150
- How ATP Provides Energy That Performs Work 151
- The Regeneration of ATP 153

CONCEPT 8.4 Enzymes speed up metabolic reactions by lowering energy barriers 153

- The Activation Energy Barrier 153
- How Enzymes Speed Up Reactions 154
- Substrate Specificity of Enzymes 155
- Catalysis in the Enzyme's Active Site 156
- Effects of Local Conditions on Enzyme Activity 157
- The Evolution of Enzymes 159

CONCEPT 8.5 Regulation of enzyme activity helps control metabolism 159

- Allosteric Regulation of Enzymes 160
- Localization of Enzymes Within the Cell 161



9 Cellular Respiration and Fermentation 164

CONCEPT 9.1 Catabolic pathways yield energy by oxidizing organic fuels 165

- Catabolic Pathways and Production of ATP 165
- Redox Reactions: Oxidation and Reduction 165
- The Stages of Cellular Respiration: *A Preview* 168

CONCEPT 9.2 Glycolysis harvests chemical energy by oxidizing glucose to pyruvate 170

CONCEPT 9.3 After pyruvate is oxidized, the citric acid cycle completes the energy-yielding oxidation of organic molecules 171

- Oxidation of Pyruvate to Acetyl CoA 171
- The Citric Acid Cycle 172

CONCEPT 9.4 During oxidative phosphorylation, chemiosmosis couples electron transport to ATP synthesis 174

- The Pathway of Electron Transport 174
- Chemiosmosis: The Energy-Coupling Mechanism 175
- An Accounting of ATP Production by Cellular Respiration 177

CONCEPT 9.5 Fermentation and anaerobic respiration enable cells to produce ATP without the use of oxygen 179

- Types of Fermentation 180
- Comparing Fermentation with Anaerobic and Aerobic Respiration 181
- The Evolutionary Significance of Glycolysis 182

CONCEPT 9.6 Glycolysis and the citric acid cycle connect to many other metabolic pathways 182

- The Versatility of Catabolism 182
- Biosynthesis (Anabolic Pathways) 183
- Regulation of Cellular Respiration via Feedback Mechanisms 183



10 Photosynthesis 187

CONCEPT 10.1 Photosynthesis feeds the biosphere 188

CONCEPT 10.2 Photosynthesis converts light energy to the chemical energy of food 189

- Chloroplasts: The Sites of Photosynthesis in Plants 189
- Tracking Atoms Through Photosynthesis 189
- The Two Stages of Photosynthesis: *A Preview* 191

CONCEPT 10.3 The light reactions convert solar energy to the chemical energy of ATP and NADPH 192

- The Nature of Sunlight 192
- Photosynthetic Pigments: The Light Receptors 192
- Excitation of Chlorophyll by Light 195
- A Photosystem: A Reaction-Center Complex Associated with Light-Harvesting Complexes 195
- Linear Electron Flow 197
- Cyclic Electron Flow 198
- A Comparison of Chemiosmosis in Chloroplasts and Mitochondria 199

CONCEPT 10.4 The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO₂ to sugar 201

CONCEPT 10.5 Alternative mechanisms of carbon fixation have evolved in hot, arid climates 203

- Photorespiration: An Evolutionary Relic? 203
- C₄ Plants 203
- CAM Plants 205

CONCEPT 10.6 Photosynthesis is essential for life on Earth: a review 206



11 Cell Communication 212

CONCEPT 11.1 External signals are converted to responses within the cell 213

- Evolution of Cell Signaling 213
- Local and Long-Distance Signaling 215
- The Three Stages of Cell Signaling: A Preview 216

CONCEPT 11.2 Signal reception: A signaling molecule binds to a receptor, causing it to change shape 217

- Receptors in the Plasma Membrane 217
- Intracellular Receptors 220

CONCEPT 11.3 Signal transduction: Cascades of molecular interactions transmit signals from receptors to relay molecules in the cell 221

- Signal Transduction Pathways 221
- Protein Phosphorylation and Dephosphorylation 222
- Small Molecules and Ions as Second Messengers 223

CONCEPT 11.4 Cellular response: Cell signaling leads to regulation of transcription or cytoplasmic activities 226

- Nuclear and Cytoplasmic Responses 226
- Regulation of the Response 226

CONCEPT 11.5 Apoptosis requires integration of multiple cell-signaling pathways 229

- Apoptosis in the Soil Worm *Caenorhabditis elegans* 230
- Apoptotic Pathways and the Signals That Trigger Them 230

12 The Cell Cycle 234

CONCEPT 12.1 Most cell division results in genetically identical daughter cells 235

- Key Roles of Cell Division 235
- Cellular Organization of the Genetic Material 235
- Distribution of Chromosomes During Eukaryotic Cell Division 236

CONCEPT 12.2 The mitotic phase alternates with interphase in the cell cycle 237

- Phases of the Cell Cycle 237
- The Mitotic Spindle: A Closer Look 240
- Cytokinesis: A Closer Look 241
- Binary Fission in Bacteria 242
- The Evolution of Mitosis 243

CONCEPT 12.3 The eukaryotic cell cycle is regulated by a molecular control system 244

- The Cell Cycle Control System 244
- Loss of Cell Cycle Controls in Cancer Cells 248

Unit 3 Genetics

253

Interview: Francisco Mojica 253

13 Meiosis and Sexual Life Cycles 254

CONCEPT 13.1 Offspring acquire genes from parents by inheriting chromosomes 255

- Inheritance of Genes 255
- Comparison of Asexual and Sexual Reproduction 255

CONCEPT 13.2 Fertilization and meiosis alternate in sexual life cycles 256

- Sets of Chromosomes in Human Cells 256
- Behavior of Chromosome Sets in the Human Life Cycle 257
- The Variety of Sexual Life Cycles 258

CONCEPT 13.3 Meiosis reduces the number of chromosome sets from diploid to haploid 259

- The Stages of Meiosis 259
- Crossing Over and Synapsis During Prophase I 262
- A Comparison of Mitosis and Meiosis 262

CONCEPT 13.4 Genetic variation produced in sexual life cycles contributes to evolution 265

- Origins of Genetic Variation Among Offspring 265
- The Evolutionary Significance of Genetic Variation Within Populations 266

14 Mendel and the Gene Idea 269

CONCEPT 14.1 Mendel used the scientific approach to identify two laws of inheritance 270

- Mendel's Experimental, Quantitative Approach 270
- The Law of Segregation 271
- The Law of Independent Assortment 274

CONCEPT 14.2 Probability laws govern Mendelian inheritance 276

- The Multiplication and Addition Rules Applied to Monohybrid Crosses 277
- Solving Complex Genetics Problems with the Rules of Probability 277

CONCEPT 14.3 Inheritance patterns are often more complex than predicted by simple Mendelian genetics 278

- Extending Mendelian Genetics for a Single Gene 278
- Extending Mendelian Genetics for Two or More Genes 281
- Nature and Nurture: The Environmental Impact on Phenotype 282
- A Mendelian View of Heredity and Variation 282

CONCEPT 14.4 Many human traits follow Mendelian patterns of inheritance 284

- Pedigree Analysis 284
- Recessively Inherited Disorders 285
- Dominantly Inherited Disorders 287
- Multifactorial Disorders 287
- Genetic Testing and Counseling 287



15 The Chromosomal Basis of Inheritance 294

CONCEPT 15.1 Mendelian inheritance has its physical basis in the behavior of chromosomes 295

- Morgan's Choice of Experimental Organism 295
- Correlating Behavior of a Gene's Alleles with Behavior of a Chromosome Pair: *Scientific Inquiry* 295

CONCEPT 15.2 Sex-linked genes exhibit unique patterns of inheritance 298

- The Chromosomal Basis of Sex 298
- Inheritance of X-Linked Genes 299
- X Inactivation in Female Mammals 300

CONCEPT 15.3 Linked genes tend to be inherited together because they are located near each other on the same chromosome 301

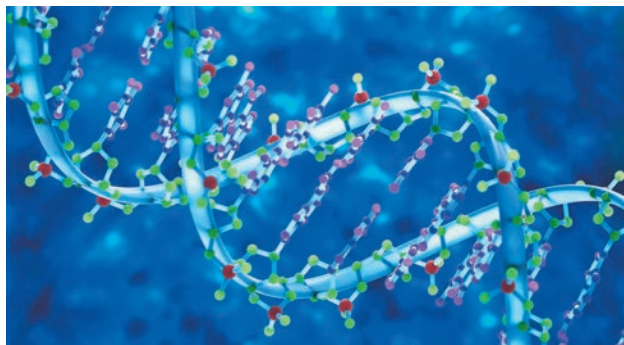
- How Linkage Affects Inheritance 301
- Genetic Recombination and Linkage 302
- Mapping the Distance Between Genes Using Recombination Data: *Scientific Inquiry* 305

CONCEPT 15.4 Alterations of chromosome number or structure cause some genetic disorders 306

- Abnormal Chromosome Number 307
- Alterations of Chromosome Structure 307
- Human Conditions Due to Chromosomal Alterations 308

CONCEPT 15.5 Some inheritance patterns are exceptions to standard Mendelian inheritance 310

- Genomic Imprinting 310
- Inheritance of Organelle Genes 311



16 The Molecular Basis of Inheritance 314

CONCEPT 16.1 DNA is the genetic material 315

- The Search for the Genetic Material: *Scientific Inquiry* 315
- Building a Structural Model of DNA 317

CONCEPT 16.2 Many proteins work together in DNA replication and repair 320

- The Basic Principle: Base Pairing to a Template Strand 321
- DNA Replication: *A Closer Look* 322
- Proofreading and Repairing DNA 327
- Evolutionary Significance of Altered DNA Nucleotides 328
- Replicating the Ends of DNA Molecules 328

CONCEPT 16.3 A chromosome consists of a DNA molecule packed together with proteins 330

17 Gene Expression: From Gene to Protein 335

CONCEPT 17.1 Genes specify proteins via transcription and translation 336

- Evidence from Studying Metabolic Defects 336
- Basic Principles of Transcription and Translation 337
- The Genetic Code 340

CONCEPT 17.2 Transcription is the DNA-directed synthesis of RNA: *A Closer Look* 342

- Molecular Components of Transcription 342
- Synthesis of an RNA Transcript 342

CONCEPT 17.3 Eukaryotic cells modify RNA after transcription 345

- Alteration of mRNA Ends 345
- Split Genes and RNA Splicing 345

CONCEPT 17.4 Translation is the RNA-directed synthesis of a polypeptide: *A Closer Look* 347

- Molecular Components of Translation 348
- Building a Polypeptide 350
- Completing and Targeting the Functional Protein 352
- Making Multiple Polypeptides in Bacteria and Eukaryotes 355

CONCEPT 17.5 Mutations of one or a few nucleotides can affect protein structure and function 357

- Types of Small-Scale Mutations 357
- New Mutations and Mutagens 360
- Using CRISPR to Edit Genes and Correct Disease-Causing Mutations 360
- What Is a Gene? *Revisiting the Question* 361

18 Regulation of Gene Expression 365

CONCEPT 18.1 Bacteria often respond to environmental change by regulating transcription 366

- Operons: The Basic Concept 366
- Repressible and Inducible Operons: Two Types of Negative Gene Regulation 368
- Positive Gene Regulation 369

CONCEPT 18.2 Eukaryotic gene expression is regulated at many stages 370

- Differential Gene Expression 370
- Regulation of Chromatin Structure 371
- Regulation of Transcription Initiation 373
- Mechanisms of Post-transcriptional Regulation 377

CONCEPT 18.3 Noncoding RNAs play multiple roles in controlling gene expression 379

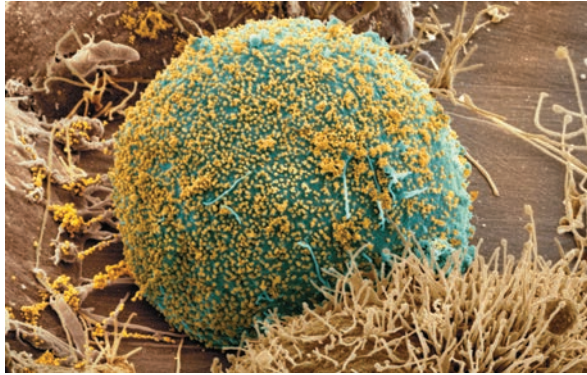
- Effects on mRNAs by MicroRNAs and Small Interfering RNAs 379
- Chromatin Remodeling and Effects on Transcription by ncRNAs 380

CONCEPT 18.4 A program of differential gene expression leads to the different cell types in a multicellular organism 381

- A Genetic Program for Embryonic Development 381
- Cytoplasmic Determinants and Inductive Signals 382
- Sequential Regulation of Gene Expression During Cellular Differentiation 383
- Pattern Formation: Setting Up the Body Plan 384

CONCEPT 18.5 Cancer results from genetic changes that affect cell cycle control 388

- Types of Genes Associated with Cancer 388
- Interference with Normal Cell-Signaling Pathways 389
- The Multistep Model of Cancer Development 391
- Inherited Predisposition and Environmental Factors Contributing to Cancer 394
- The Role of Viruses in Cancer 394



19 Viruses 398

CONCEPT 19.1 A virus consists of a nucleic acid surrounded by a protein coat 399

- The Discovery of Viruses: *Scientific Inquiry* 399
- Structure of Viruses 399

CONCEPT 19.2 Viruses replicate only in host cells 401

- General Features of Viral Replicative Cycles 401
- Replicative Cycles of Phages 402
- Replicative Cycles of Animal Viruses 404
- Evolution of Viruses 406

CONCEPT 19.3 Viruses and prions are formidable pathogens in animals and plants 408

- Viral Diseases in Animals 408
- Emerging Viral Diseases 409
- Viral Diseases in Plants 412
- Prions: Proteins as Infectious Agents 412

20 DNA Tools and Biotechnology 415

CONCEPT 20.1 DNA sequencing and DNA cloning are valuable tools for genetic engineering and biological inquiry 416

- DNA Sequencing 416
- Making Multiple Copies of a Gene or Other DNA Segment 418
- Using Restriction Enzymes to Make a Recombinant DNA Plasmid 419
- Amplifying DNA: The Polymerase Chain Reaction (PCR) and Its Use in DNA Cloning 420
- Expressing Cloned Eukaryotic Genes 422

CONCEPT 20.2 Biologists use DNA technology to study gene expression and function 423

- Analyzing Gene Expression 423
- Determining Gene Function 426

CONCEPT 20.3 Cloned organisms and stem cells are useful for basic research and other applications 428

- Cloning Plants: Single-Cell Cultures 428
- Cloning Animals: Nuclear Transplantation 428
- Stem Cells of Animals 430

CONCEPT 20.4 The practical applications of DNA-based biotechnology affect our lives in many ways 433

- Medical Applications 433
- Forensic Evidence and Genetic Profiles 436
- Environmental Cleanup 437
- Agricultural Applications 437
- Safety and Ethical Questions Raised by DNA Technology 438

21 Genomes and Their Evolution 442

CONCEPT 21.1 The Human Genome Project fostered development of faster, less expensive sequencing techniques 443

CONCEPT 21.2 Scientists use bioinformatics to analyze genomes and their functions 444

- Centralized Resources for Analyzing Genome Sequences 444
- Identifying Protein-Coding Genes and Understanding Their Functions 445
- Understanding Genes and Gene Expression at the Systems Level 446

CONCEPT 21.3 Genomes vary in size, number of genes, and gene density 448

- Genome Size 448
- Number of Genes 449
- Gene Density and Noncoding DNA 449

CONCEPT 21.4 Multicellular eukaryotes have a lot of noncoding DNA and many multigene families 450

- Transposable Elements and Related Sequences 451
- Other Repetitive DNA, Including Simple Sequence DNA 452
- Genes and Multigene Families 452

CONCEPT 21.5 Duplication, rearrangement, and mutation of DNA contribute to genome evolution 454

- Duplication of Entire Chromosome Sets 454
- Alterations of Chromosome Structure 454
- Duplication and Divergence of Gene-Sized Regions of DNA 455
- Rearrangements of Parts of Genes: Exon Duplication and Exon Shuffling 456
- How Transposable Elements Contribute to Genome Evolution 459

CONCEPT 21.6 Comparing genome sequences provides clues to evolution and development 459

- Comparing Genomes 459
- Widespread Conservation of Developmental Genes Among Animals 463



Interview: Cassandra Extavour 467

22 Descent with Modification: A Darwinian View of Life 468

CONCEPT 22.1 The Darwinian revolution challenged traditional views of a young Earth inhabited by unchanging species 469

- Endless Forms Most Beautiful 469
- Scala Naturae* and Classification of Species 470
- Ideas About Change over Time 470
- Lamarck's Hypothesis of Evolution 471

CONCEPT 22.2 Descent with modification by natural selection explains the adaptations of organisms and the unity and diversity of life 471

- Darwin's Research 471
- Ideas from *The Origin of Species* 473
- Key Features of Natural Selection 476

CONCEPT 22.3 Evolution is supported by an overwhelming amount of scientific evidence 476

- Direct Observations of Evolutionary Change 477
- Homology 479
- The Fossil Record 481
- Biogeography 482
- What Is Theoretical About Darwin's View of Life? 483



23 The Evolution of Populations 486

CONCEPT 23.1 Genetic variation makes evolution possible 487

- Genetic Variation 487
- Sources of Genetic Variation 488

CONCEPT 23.2 The Hardy-Weinberg equation can be used to test whether a population is evolving 489

- Gene Pools and Allele Frequencies 490
- The Hardy-Weinberg Equation 490

CONCEPT 23.3 Natural selection, genetic drift, and gene flow can alter allele frequencies in a population 493

- Natural Selection 494
- Genetic Drift 494
- Gene Flow 496

CONCEPT 23.4 Natural selection is the only mechanism that consistently causes adaptive evolution 497

- Natural Selection: *A Closer Look* 497
- The Key Role of Natural Selection in Adaptive Evolution 498

- Sexual Selection 499
- Balancing Selection 500
- Why Natural Selection Cannot Fashion Perfect Organisms 501

24 The Origin of Species 506

CONCEPT 24.1 The biological species concept emphasizes reproductive isolation 507

- The Biological Species Concept 507
- Other Definitions of Species 510

CONCEPT 24.2 Speciation can take place with or without geographic separation 511

- Allopatric ("Other Country") Speciation 511
- Sympatric ("Same Country") Speciation 513
- Allopatric and Sympatric Speciation: *A Review* 516

CONCEPT 24.3 Hybrid zones reveal factors that cause reproductive isolation 516

- Patterns Within Hybrid Zones 516
- Hybrid Zones and Environmental Change 517
- Hybrid Zones over Time 518

CONCEPT 24.4 Speciation can occur rapidly or slowly and can result from changes in few or many genes 520

- The Time Course of Speciation 520
- Studying the Genetics of Speciation 522
- From Speciation to Macroevolution 523

25 The History of Life on Earth 525

CONCEPT 25.1 Conditions on early Earth made the origin of life possible 526

- Synthesis of Organic Compounds on Early Earth 526
- Abiotic Synthesis of Macromolecules 527
- Protocells 527
- Self-Replicating RNA 528

CONCEPT 25.2 The fossil record documents the history of life 528

- The Fossil Record 529
- How Rocks and Fossils Are Dated 529
- The Origin of New Groups of Organisms 530



CONCEPT 25.3 Key events in life's history include the origins of unicellular and multicellular organisms and the colonization of land 532

- The First Single-Celled Organisms 533
- The Origin of Multicellularity 535
- The Colonization of Land 536

CONCEPT 25.4 The rise and fall of groups of organisms reflect differences in speciation and extinction rates 537

- Plate Tectonics 538
- Mass Extinctions 540
- Adaptive Radiations 542

CONCEPT 25.5 Major changes in body form can result from changes in the sequences and regulation of developmental genes 544

- Effects of Developmental Genes 544
- The Evolution of Development 545

CONCEPT 25.6 Evolution is not goal oriented 547

- Evolutionary Novelties 547
- Evolutionary Trends 548

Interview: Penny Chisholm 552

26 Phylogeny and the Tree of Life 553

CONCEPT 26.1 Phylogenies show evolutionary relationships 554

- Binomial Nomenclature 554
- Hierarchical Classification 554
- Linking Classification and Phylogeny 555
- What We Can and Cannot Learn from Phylogenetic Trees 555
- Applying Phylogenies 557

CONCEPT 26.2 Phylogenies are inferred from morphological and molecular data 558

- Morphological and Molecular Homologies 558
- Sorting Homology from Analogy 558
- Evaluating Molecular Homologies 559

CONCEPT 26.3 Shared characters are used to construct phylogenetic trees 559

- Cladistics 559
- Phylogenetic Trees with Proportional Branch Lengths 561
- Maximum Parsimony and Maximum Likelihood 562
- Phylogenetic Trees as Hypotheses 564

CONCEPT 26.4 An organism's evolutionary history is documented in its genome 565

- Gene Duplications and Gene Families 565
- Genome Evolution 566

CONCEPT 26.5 Molecular clocks help track evolutionary time 566

- Molecular Clocks 566
- Applying a Molecular Clock: Dating the Origin of HIV 567

CONCEPT 26.6 Our understanding of the tree of life continues to change based on new data 568

- From Two Kingdoms to Three Domains 568
- The Important Role of Horizontal Gene Transfer 568

27 Bacteria and Archaea 573

CONCEPT 27.1 Structural and functional adaptations contribute to prokaryotic success 574

- Cell-Surface Structures 574
- Motility 576
- Internal Organization and DNA 577
- Reproduction 577

CONCEPT 27.2 Rapid reproduction, mutation, and genetic recombination promote genetic diversity in prokaryotes 578

- Rapid Reproduction and Mutation 578
- Genetic Recombination 579

CONCEPT 27.3 Diverse nutritional and metabolic adaptations have evolved in prokaryotes 581

- The Role of Oxygen in Metabolism 582
- Nitrogen Metabolism 582
- Metabolic Cooperation 582

CONCEPT 27.4 Prokaryotes have radiated into a diverse set of lineages 583

- An Overview of Prokaryotic Diversity 583
- Bacteria 583
- Archaea 585

CONCEPT 27.5 Prokaryotes play crucial roles in the biosphere 586

- Chemical Recycling 586
- Ecological Interactions 587

CONCEPT 27.6 Prokaryotes have both beneficial and harmful impacts on humans 587

- Mutualistic Bacteria 587
- Pathogenic Bacteria 588
- Antibiotic Resistance 588
- Prokaryotes in Research and Technology 589

28 Protists 593

CONCEPT 28.1 Most eukaryotes are single-celled organisms 594

- Structural and Functional Diversity in Protists 594
- Endosymbiosis in Eukaryotic Evolution 594
- Four Supergroups of Eukaryotes 597

CONCEPT 28.2 Excavates include protists with modified mitochondria and protists with unique flagella 597

- Diplomonads and Parabasalids 600
- Euglenozoans 600

CONCEPT 28.3 SAR is a highly diverse group of protists defined by DNA similarities 601

- Stramenopiles 602
- Alveolates 604
- Rhizarians 606

CONCEPT 28.4 Red algae and green algae are the closest relatives of plants 609

- Red Algae 609
- Green Algae 610

CONCEPT 28.5 Unikonts include protists that are closely related to fungi and animals 611

- Amoebozoans 612
- Opisthokonts 613

CONCEPT 28.6 Protists play key roles in ecological communities 614

- Symbiotic Protists 614
- Photosynthetic Protists 614



29 Plant Diversity I: How Plants Colonized Land 618

CONCEPT 29.1 Plants evolved from green algae 619

- Evidence of Algal Ancestry 619
- Adaptations Enabling the Move to Land 619
- Derived Traits of Plants 621
- The Origin and Diversification of Plants 621

CONCEPT 29.2 Mosses and other nonvascular plants have life cycles dominated by gametophytes 623

- Bryophyte Gametophytes 624
- Bryophyte Sporophytes 625
- The Ecological and Economic Importance of Mosses 627

CONCEPT 29.3 Ferns and other seedless vascular plants were the first plants to grow tall 629

- Origins and Traits of Vascular Plants 629
- Classification of Seedless Vascular Plants 631
- The Significance of Seedless Vascular Plants 633

30 Plant Diversity II: The Evolution of Seed Plants 636

CONCEPT 30.1 Seeds and pollen grains are key adaptations for life on land 637

- Advantages of Reduced Gametophytes 637
- Heterospory: The Rule Among Seed Plants 638
- Ovules and Production of Eggs 638
- Pollen and Production of Sperm 638
- The Evolutionary Advantage of Seeds 639

CONCEPT 30.2 Gymnosperms bear “naked” seeds, typically on cones 640

- The Life Cycle of a Pine 640
- Early Seed Plants and the Rise of Gymnosperms 641
- Gymnosperm Diversity 641

CONCEPT 30.3 The reproductive adaptations of angiosperms include flowers and fruits 644

- Characteristics of Angiosperms 644
- Angiosperm Evolution 647
- Angiosperm Diversity 649

CONCEPT 30.4 Human welfare depends on seed plants 651

- Products from Seed Plants 651
- Threats to Plant Diversity 651



31 Fungi 654

CONCEPT 31.1 Fungi are heterotrophs that feed by absorption 655

- Nutrition and Ecology 655
- Body Structure 655
- Specialized Hyphae in Mycorrhizal Fungi 656

CONCEPT 31.2 Fungi produce spores through sexual or asexual life cycles 657

- Sexual Reproduction 658
- Asexual Reproduction 658



CONCEPT 31.3 The ancestor of fungi was an aquatic, single-celled, flagellated protist 659

- The Origin of Fungi 659
- The Move to Land 660

CONCEPT 31.4 Fungi have radiated into a diverse set of lineages 660

- Cryptomycetes and Microsporidians 661
- Zoopagomycetes 662
- Mucoromycetes 663
- Ascomycetes 663
- Basidiomycetes 665

CONCEPT 31.5 Fungi play key roles in nutrient cycling, ecological interactions, and human welfare 667

- Fungi as Decomposers 667
- Fungi as Mutualists 667
- Practical Uses of Fungi 670

32 An Overview of Animal Diversity 673

CONCEPT 32.1 Animals are multicellular, heterotrophic eukaryotes with tissues that develop from embryonic layers 674

- Nutritional Mode 674
- Cell Structure and Specialization 674
- Reproduction and Development 674

CONCEPT 32.2 The history of animals spans more than half a billion years 675

- Steps in the Origin of Multicellular Animals 675
- Neoproterozoic Era (1 Billion–541 Million Years Ago) 676
- Paleozoic Era (541–252 Million Years Ago) 677
- Mesozoic Era (252–66 Million Years Ago) 679
- Cenozoic Era (66 Million Years Ago to the Present) 679

CONCEPT 32.3 Animals can be characterized by body plans 679

- Symmetry 679
- Tissues 679
- Body Cavities 680
- Protostome and Deuterostome Development 681

CONCEPT 32.4 Views of animal phylogeny continue to be shaped by new molecular and morphological data 682

- The Diversification of Animals 682
- Future Directions in Animal Systematics 684

33 An Introduction to Invertebrates 686

CONCEPT 33.1 Sponges are basal animals that lack tissues 690

CONCEPT 33.2 Cnidarians are an ancient phylum of eumetazoans 691

Medusozoans 692

Anthozoans 693

CONCEPT 33.3 Lophotrochozoans, a clade identified by molecular data, have the widest range of animal body forms 694

Flatworms 694

Rotifers and

Acanthocephalans 697

Lophophorates: Ectoprocts and Brachiopods 698

Molluscs 699

Annelids 703

CONCEPT 33.4 Ecdysozoans are the most species-rich animal group 705

Nematodes 705

Arthropods 706

CONCEPT 33.5 Echinoderms and chordates are deuterostomes 713

Echinoderms 713

Chordates 715



34 The Origin and Evolution of Vertebrates 718

CONCEPT 34.1 Chordates have a notochord and a dorsal, hollow nerve cord 719

Derived Characters of Chordates 719

Lancelets 720

Tunicates 721

Early Chordate Evolution 722

CONCEPT 34.2 Vertebrates are chordates that have a backbone 722

Derived Characters of Vertebrates 722

Hagfishes and Lampreys 723

Early Vertebrate Evolution 724

CONCEPT 34.3 Gnathostomes are vertebrates that have jaws 725

Derived Characters of Gnathostomes 725

Fossil Gnathostomes 726

Chondrichthyans (Sharks, Rays, and Their Relatives) 726

Ray-Finned Fishes and Lobe-Fins 728



CONCEPT 34.4 Tetrapods are gnathostomes that have limbs 730

Derived Characters of Tetrapods 730

The Origin of Tetrapods 731

Amphibians 731

CONCEPT 34.5 Amniotes are tetrapods that have a terrestrially adapted egg 734

Derived Characters of Amniotes 734

Early Amniotes 735

Reptiles 735

CONCEPT 34.6 Mammals are amniotes that have hair and produce milk 741

Derived Characters of Mammals 741

Early Evolution of Mammals 741

Monotremes 742

Marsupials 743

Eutherians (Placental Mammals) 744

CONCEPT 34.7 Humans are mammals that have a large brain and bipedal locomotion 748

Derived Characters of Humans 748

The Earliest Hominins 748

Australopiths 749

Bipedalism 750

Tool Use 750

Early *Homo* 750

Neanderthals 752

Homo sapiens 753

Unit 6 Plant Form and Function 757

757

Interview: Dennis Gonsalves 757

35 Vascular Plant Structure, Growth, and Development 758

CONCEPT 35.1 Plants have a hierarchical organization consisting of organs, tissues, and cells 759

Vascular Plant Organs: Roots, Stems, and Leaves 759

Dermal, Vascular, and Ground

Tissues 762

Common Types of Plant Cells 763

CONCEPT 35.2 Different meristems generate new cells for primary and secondary growth 766

CONCEPT 35.3 Primary growth lengthens roots and shoots 768

Primary Growth of Roots 768

Primary Growth of Shoots 769

CONCEPT 35.4 Secondary growth increases the diameter of stems and roots in woody plants 772

The Vascular Cambium and Secondary Vascular Tissue 773

The Cork Cambium and the Production of Periderm 774

Evolution of Secondary Growth 774

CONCEPT 35.5 Growth, morphogenesis, and cell differentiation produce the plant body 775

Model Organisms: Revolutionizing the Study of Plants 776

Growth: Cell Division and Cell Expansion 776

Morphogenesis and Pattern Formation 777

Gene Expression and the Control of Cell Differentiation 778

Shifts in Development: Phase Changes 778

Genetic Control of Flowering 779



36 Resource Acquisition and Transport in Vascular Plants 784

CONCEPT 36.1 Adaptations for acquiring resources were key steps in the evolution of vascular plants 785

- Shoot Architecture and Light Capture 785
- Root Architecture and Acquisition of Water and Minerals 787

CONCEPT 36.2 Different mechanisms transport substances over short or long distances 787

- The Apoplast and Symplast: Transport Continuums 787
- Short-Distance Transport of Solutes Across Plasma Membranes 788
- Short-Distance Transport of Water Across Plasma Membranes 788
- Long-Distance Transport: The Role of Bulk Flow 791

CONCEPT 36.3 Transpiration drives the transport of water and minerals from roots to shoots via the xylem 792

- Absorption of Water and Minerals by Root Cells 792
- Transport of Water and Minerals into the Xylem 792
- Bulk Flow Transport via the Xylem 792
- Xylem Sap Ascent by Bulk Flow: A Review 796

CONCEPT 36.4 The rate of transpiration is regulated by stomata 796

- Stomata: Major Pathways for Water Loss 796
- Mechanisms of Stomatal Opening and Closing 797
- Stimuli for Stomatal Opening and Closing 798
- Effects of Transpiration on Wilting and Leaf Temperature 798
- Adaptations That Reduce Evaporative Water Loss 798

CONCEPT 36.5 Sugars are transported from sources to sinks via the phloem 799

- Movement from Sugar Sources to Sugar Sinks 799
- Bulk Flow by Positive Pressure: The Mechanism of Translocation in Angiosperms 800

CONCEPT 36.6 The symplast is highly dynamic 801

- Changes in Plasmodesmatal Number and Pore Size 802
- Phloem: An Information Superhighway 802
- Electrical Signaling in the Phloem 802



37 Soil and Plant Nutrition 805

CONCEPT 37.1 Soil contains a living, complex ecosystem 806

- Soil Texture 806
- Topsoil Composition 806
- Soil Conservation and Sustainable Agriculture 807

CONCEPT 37.2 Plant roots absorb many types of essential elements from the soil 809

- Essential Elements 810
- Symptoms of Mineral Deficiency 810
- Global Climate Change and Food Quality 812

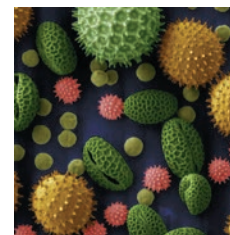
CONCEPT 37.3 Plant nutrition often involves relationships with other organisms 812

- Bacteria and Plant Nutrition 814
- Fungi and Plant Nutrition 817
- Epiphytes, Parasitic Plants, and Carnivorous Plants 818

38 Angiosperm Reproduction and Biotechnology 822

CONCEPT 38.1 Flowers, double fertilization, and fruits are key features of the angiosperm life cycle 823

- Flower Structure and Function 823
- Methods of Pollination 825
- The Angiosperm Life Cycle: An Overview 826
- Development of Female Gametophytes (Embryo Sacs) 826
- Development of Male Gametophytes in Pollen Grains 826
- Seed Development and Structure 828
- Sporophyte Development from Seed to Mature Plant 829
- Fruit Structure and Function 830



CONCEPT 38.2 Flowering plants reproduce sexually, asexually, or both 833

- Mechanisms of Asexual Reproduction 833
- Advantages and Disadvantages of Asexual and Sexual Reproduction 833
- Mechanisms That Prevent Self-Fertilization 834
- Totipotency, Vegetative Reproduction, and Tissue Culture 835

CONCEPT 38.3 People modify crops by breeding and genetic engineering 836

- Plant Breeding 837
- Plant Biotechnology and Genetic Engineering 837
- The Debate over Plant Biotechnology 839

39 Plant Responses to Internal and External Signals 842

CONCEPT 39.1 Signal transduction pathways link signal reception to response 843

- Reception 844
- Transduction 844
- Response 845

CONCEPT CHECK 39.2 Plants use chemicals to communicate 845

- General Characteristics of Plant Hormones 846
- A Survey of Plant Hormones 847

CONCEPT 39.3 Responses to light are critical for plant success 855

- Blue-Light Photoreceptors 855
- Phytochrome Photoreceptors 856
- Biological Clocks and Circadian Rhythms 857
- The Effect of Light on the Biological Clock 858
- Photoperiodism and Responses to Seasons 859

CONCEPT 39.4 Plants respond to a wide variety of stimuli other than light 861

- Gravity 861
- Mechanical Stimuli 861
- Environmental Stresses 862

CONCEPT 39.5 Plants respond to attacks by pathogens and herbivores 866

- Defenses Against Pathogens 866
- Defenses Against Herbivores 867



Unit 7 Animal Form and Function 872

Interview: Steffanie Strathdee 872

40 Basic Principles of Animal Form and Function 873

CONCEPT 40.1 Animal form and function are correlated at all levels of organization 874

- Evolution of Animal Size and Shape 874
- Exchange with the Environment 874
- Hierarchical Organization of Body Plans 876
- Coordination and Control 880

CONCEPT 40.2 Feedback control maintains the internal environment in many animals 881

- Regulating and Conforming 881
- Homeostasis 881

CONCEPT 40.3 Homeostatic processes for thermoregulation involve form, function, and behavior 884

- Endothermy and Ectothermy 884
- Variation in Body Temperature 884
- Balancing Heat Loss and Gain 885
- Acclimatization in Thermoregulation 888
- Physiological Thermostats and Fever 888

CONCEPT 40.4 Energy requirements are related to animal size, activity, and environment 889

- Energy Allocation and Use 889
- Quantifying Energy Use 890
- Minimum Metabolic Rate and Thermoregulation 890
- Influences on Metabolic Rate 891
- Torpor and Energy Conservation 892

41 Animal Nutrition 898

CONCEPT 41.1 An animal's diet must supply chemical energy, organic building blocks, and essential nutrients 899

- Essential Nutrients 899
- Variation in Diet 901
- Dietary Deficiencies 901
- Assessing Nutritional Needs 902

CONCEPT 41.2 Food processing involves ingestion, digestion, absorption, and elimination 902

- Digestive Compartments 904

CONCEPT 41.3 Organs specialized for sequential stages of food processing form the mammalian digestive system 905

- The Oral Cavity, Pharynx, and Esophagus 905
- Digestion in the Stomach 907
- Digestion in the Small Intestine 908
- Absorption in the Small Intestine 909
- Processing in the Large Intestine 910

CONCEPT 41.4 Evolutionary adaptations of vertebrate digestive systems correlate with diet 911

- Dental Adaptations 911
- Stomach and Intestinal Adaptations 912
- Mutualistic Adaptations 912

CONCEPT 41.5 Feedback circuits regulate digestion, energy storage, and appetite 915

- Regulation of Digestion 915
- Regulation of Energy Storage 915
- Regulation of Appetite and Consumption 917

42 Circulation and Gas Exchange 921

CONCEPT 42.1 Circulatory systems link exchange surfaces with cells throughout the body 922

- Gastrovascular Cavities 922
- Open and Closed Circulatory Systems 923
- Organization of Vertebrate Circulatory Systems 924

CONCEPT 42.2 Coordinated cycles of heart contraction drive double circulation in mammals 926

- Mammalian Circulation 926
- The Mammalian Heart: *A Closer Look* 926
- Maintaining the Heart's Rhythmic Beat 928

CONCEPT 42.3 Patterns of blood pressure and flow reflect the structure and arrangement of blood vessels 929

- Blood Vessel Structure and Function 929
- Blood Flow Velocity 930
- Blood Pressure 930
- Capillary Function 932
- Fluid Return by the Lymphatic System 933

CONCEPT 42.4 Blood components function in exchange, transport, and defense 934

- Blood Composition and Function 934
- Cardiovascular Disease 937

CONCEPT 42.5 Gas exchange occurs across specialized respiratory surfaces 939

- Partial Pressure Gradients in Gas Exchange 939
- Respiratory Media 939
- Respiratory Surfaces 940
- Gills in Aquatic Animals 940
- Tracheal Systems in Insects 941
- Lungs 942

CONCEPT 42.6 Breathing ventilates the lungs 944

- How an Amphibian Breathes 944
- How a Bird Breathes 944
- How a Mammal Breathes 945
- Control of Breathing in Humans 946

CONCEPT 42.7 Adaptations for gas exchange include pigments that bind and transport gases 947

- Coordination of Circulation and Gas Exchange 947
- Respiratory Pigments 947
- Respiratory Adaptations of Diving Mammals 949

43 The Immune System 952

CONCEPT 43.1 In innate immunity, recognition and response rely on traits common to groups of pathogens 953

Innate Immunity of Invertebrates 953

Innate Immunity of Vertebrates 954

Evasion of Innate Immunity by Pathogens 957

CONCEPT 43.2 In adaptive immunity, receptors provide pathogen-specific recognition 957

Antigens as the Trigger for Adaptive Immunity 958

Antigen Recognition by B Cells and Antibodies 958

Antigen Recognition by T Cells 959

B Cell and T Cell Development 960

CONCEPT 43.3 Adaptive immunity defends against infection of body fluids and body cells 963

Helper T Cells: Activating Adaptive Immunity 963

B Cells and Antibodies: A Response to Extracellular Pathogens 964

Cytotoxic T Cells: A Response to Infected Host Cells 966

Summary of the Humoral and Cell-Mediated Immune

Responses 967

Immunization 968

Active and Passive Immunity 968

Antibodies as Tools 969

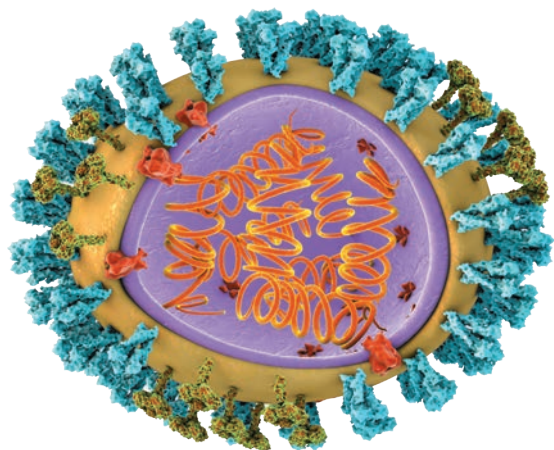
Immune Rejection 969

CONCEPT 43.4 Disruptions in immune system function can elicit or exacerbate disease 970

Exaggerated, Self-Directed, and Diminished Immune Responses 970

Evolutionary Adaptations of Pathogens That Underlie Immune System Avoidance 971

Cancer and Immunity 974



44 Osmoregulation and Excretion 977

CONCEPT 44.1 Osmoregulation balances the uptake and loss of water and solutes 978

Osmosis and Osmolarity 978

Osmoregulatory Challenges and Mechanisms 978

Energetics of Osmoregulation 980

Transport Epithelia in Osmoregulation 981

CONCEPT 44.2 An animal's nitrogenous wastes reflect its phylogeny and habitat 982

Forms of Nitrogenous Waste 982

The Influence of Evolution and Environment on Nitrogenous Wastes 983

CONCEPT 44.3 Diverse excretory systems are variations on a tubular theme 983

Survey of Excretory Systems 984

CONCEPT 44.4 The nephron is organized for stepwise processing of blood filtrate 987

From Blood Filtrate to Urine: A Closer Look 987

Solute Gradients and Water Conservation 989

Adaptations of the Vertebrate Kidney to Diverse Environments 991

CONCEPT 44.5 Hormonal circuits link kidney function, water balance, and blood pressure 994

Homeostatic Regulation of the Kidney 994

45 Hormones and the Endocrine System 999

CONCEPT 45.1 Hormones and other signaling molecules bind to target receptors, triggering specific response pathways 1000

Intercellular Information Flow 1000

Chemical Classes of Hormones 1001

Cellular Hormone Response Pathways 1002

Endocrine Tissues and Organs 1003

CONCEPT 45.2 Feedback regulation and coordination with the nervous system are common in hormone pathways 1004

Simple Endocrine Pathways 1004

Simple Neuroendocrine Pathways 1005

Feedback Regulation 1005

Coordination of the Endocrine and Nervous Systems 1006

Thyroid Regulation: A Hormone Cascade Pathway 1008

Hormonal Regulation of Growth 1009

CONCEPT 45.3 Endocrine glands respond to diverse stimuli in regulating homeostasis, development, and behavior 1011

Parathyroid Hormone and Vitamin D: Control of Blood Calcium 1011

Adrenal Hormones: Response to Stress 1012

Sex Hormones 1014

Hormones and Biological Rhythms 1015

Evolution of Hormone Function 1015

46 Animal Reproduction 1019

CONCEPT 46.1 Both asexual and sexual reproduction occur in the animal kingdom 1020

Mechanisms of Asexual Reproduction 1020

Variation in Patterns of Sexual Reproduction 1020

Reproductive Cycles 1021

Sexual Reproduction: An Evolutionary Enigma 1021

CONCEPT 46.2 Fertilization depends on mechanisms that bring together sperm and eggs of the same species 1022

Ensuring the Survival of Offspring 1023

Gamete Production and Delivery 1023



CONCEPT 46.3 Reproductive organs produce and transport gametes 1025

- Human Male Reproductive Anatomy 1025
- Human Female Reproductive Anatomy 1026
- Gametogenesis 1027

CONCEPT 46.4 The interplay of tropic and sex hormones regulates reproduction in mammals 1030

- Biological Sex, Gender Identity, and Sexual Orientation in Human Sexuality 1031
- Hormonal Control of the Male Reproductive System 1031
- Hormonal Control of Female Reproductive Cycles 1032
- Human Sexual Response 1034

CONCEPT 46.5 In placental mammals, an embryo develops fully within the mother's uterus 1034

- Conception, Embryonic Development, and Birth 1034
- Maternal Immune Tolerance of the Embryo and Fetus 1037
- Contraception and Abortion 1037
- Modern Reproductive Technologies 1039

47 Animal Development 1043

CONCEPT 47.1 Fertilization and cleavage initiate embryonic development 1044

- Fertilization 1044
- Cleavage 1046

CONCEPT 47.2 Morphogenesis in animals involves specific changes in cell shape, position, and survival 1049

- Gastrulation 1049
- Developmental Adaptations of Amniotes 1053
- Organogenesis 1054
- The Cytoskeleton in Morphogenesis 1056

CONCEPT 47.3 Cytoplasmic determinants and inductive signals regulate cell fate 1057

- Fate Mapping 1058
- Axis Formation 1059
- Restricting Developmental Potential 1060
- Cell Fate Determination and Pattern Formation by Inductive Signals 1061
- Cilia and Cell Fate 1064

48 Neurons, Synapses, and Signaling 1067

CONCEPT 48.1 Neuron structure and organization reflect function in information transfer 1068

- Neuron Structure and Function 1068
- Introduction to Information Processing 1068

CONCEPT 48.2 Ion pumps and ion channels establish the resting potential of a neuron 1069

- Formation of the Resting Potential 1070
- Modeling the Resting Potential 1071

CONCEPT 48.3 Action potentials are the signals conducted by axons 1072

- Hyperpolarization and Depolarization 1072
- Graded Potentials and Action Potentials 1073
- Generation of Action Potentials: A Closer Look 1073
- Conduction of Action Potentials 1075

CONCEPT 48.4 Neurons communicate with other cells at synapses 1077

- Generation of Postsynaptic Potentials 1078
- Summation of Postsynaptic Potentials 1079
- Termination of Neurotransmitter Signaling 1079
- Modulated Signaling at Synapses 1080
- Neurotransmitters 1080

49 Nervous Systems 1085

CONCEPT 49.1 Nervous systems consist of circuits of neurons and supporting cells 1086

- Organization of the Vertebrate Nervous System 1087
- The Peripheral Nervous System 1088
- Glia 1090

CONCEPT 49.2 The vertebrate brain is regionally specialized 1091

- Arousal and Sleep 1094
- Biological Clock Regulation 1094
- Emotions 1095
- Functional Imaging of the Brain 1096

CONCEPT 49.3 The cerebral cortex controls voluntary movement and cognitive functions 1096

- Information Processing 1097
- Language and Speech 1098
- Lateralization of Cortical Function 1098
- Frontal Lobe Function 1098
- Evolution of Cognition in Vertebrates 1098

CONCEPT 49.4 Changes in synaptic connections underlie memory and learning 1099

- Neuronal Plasticity 1100
- Memory and Learning 1100
- Long-Term Potentiation 1101

CONCEPT 49.5 Many nervous system disorders can now be explained in molecular terms 1102

- Schizophrenia 1102
- Depression 1102
- The Brain's Reward System and Drug Addiction 1103
- Alzheimer's Disease 1103
- Parkinson's Disease 1104
- Future Directions in Brain Research 1104

50 Sensory and Motor Mechanisms 1107

CONCEPT 50.1 Sensory receptors transduce stimulus energy and transmit signals to the central nervous system 1108

- Sensory Reception and Transduction 1108
- Transmission 1109
- Perception 1109
- Amplification and Adaptation 1109
- Types of Sensory Receptors 1110

CONCEPT 50.2 In hearing and equilibrium, mechanoreceptors detect moving fluid or settling particles 1112

- Sensing of Gravity and Sound in Invertebrates 1112
- Hearing and Equilibrium in Mammals 1112
- Hearing and Equilibrium in Other Vertebrates 1116

CONCEPT 50.3 The diverse visual receptors of animals depend on light-absorbing pigments 1117

- Evolution of Visual Perception 1117
- The Vertebrate Visual System 1119

CONCEPT 50.4 The senses of taste and smell rely on similar sets of sensory receptors 1123

- Taste in Mammals 1123
- Smell in Humans 1124

CONCEPT 50.5 The physical interaction of protein filaments is required for muscle function 1125

- Vertebrate Skeletal Muscle 1126
- Other Types of Muscle 1131

CONCEPT 50.6 Skeletal systems transform muscle contraction into locomotion 1132

- Types of Skeletal Systems 1132
- Types of Locomotion 1135

51 Animal Behavior 1139

CONCEPT 51.1 Discrete sensory inputs can stimulate both simple and complex behaviors 1140

- Fixed Action Patterns 1140
- Migration 1140
- Behavioral Rhythms 1141
- Animal Signals and Communication 1141

CONCEPT 51.2 Learning establishes specific links between experience and behavior 1143

- Experience and Behavior 1143
- Learning 1144

CONCEPT 51.3 Selection for individual survival and reproductive success can explain diverse behaviors 1148

- Evolution of Foraging Behavior 1148
- Mating Behavior and Mate Choice 1149

CONCEPT 51.4 Genetic analyses and the concept of inclusive fitness provide a basis for studying the evolution of behavior 1154

- Genetic Basis of Behavior 1155
- Genetic Variation and the Evolution of Behavior 1155
- Altruism 1156
- Inclusive Fitness 1157
- Evolution and Human Culture 1159

Unit 8 Ecology

1163

Interview: Chelsea Rochman 1163

52 An Introduction to Ecology and the Biosphere 1164

CONCEPT 52.1 Earth's climate varies by latitude and season and is changing rapidly 1167

- Global Climate Patterns 1167
- Regional and Local Effects on Climate 1167
- Effects of Vegetation on Climate 1169
- Microclimate 1169
- Global Climate Change 1170

CONCEPT 52.2 The distribution of terrestrial biomes is controlled by climate and disturbance 1171

- Climate and Terrestrial Biomes 1171
- General Features of Terrestrial Biomes 1172
- Disturbance and Terrestrial Biomes 1172

CONCEPT 52.3 Aquatic biomes are diverse and dynamic systems that cover most of Earth 1177

- Zonation in Aquatic Biomes 1177

CONCEPT 52.4 Interactions between organisms and the environment limit the distribution of species 1178

- Dispersal and Distribution 1183
- Biotic Factors 1184
- Abiotic Factors 1184

CONCEPT 52.5 Ecological change and evolution affect one another over long and short periods of time 1187

53 Population Ecology 1190

CONCEPT 53.1 Biotic and abiotic factors affect population density, dispersion, and demographics 1191

- Density and Dispersion 1191
- Demographics 1193

CONCEPT 53.2 The exponential model describes population growth in an idealized, unlimited environment 1196

- Changes in Population Size 1196
- Exponential Growth 1196

CONCEPT 53.3 The logistic model describes how a population grows more slowly as it nears its carrying capacity 1197

- The Logistic Growth Model 1198
- The Logistic Model and Real Populations 1199

CONCEPT 53.4 Life history traits are products of natural selection 1200

- Diversity of Life Histories 1200
- "Trade-offs" and Life Histories 1201

CONCEPT 53.5 Density-dependent factors regulate population growth 1202

- Population Change and Population Density 1202
- Mechanisms of Density-Dependent Population Regulation 1203
- Population Dynamics 1205



CONCEPT 53.6 The human population is no longer growing exponentially but is still increasing extremely rapidly 1207

The Global Human Population 1207

Global Carrying Capacity 1209

54 Community Ecology 1214

CONCEPT 54.1 Interactions between species can help, harm, or have no effect on the individuals involved 1215

Competition 1215

Exploitation 1217

Positive Interactions 1220

CONCEPT 54.2 Diversity and trophic structure characterize biological communities 1222

Species Diversity 1222

Diversity and Community Stability 1223

Trophic Structure 1223

Species with a Large Impact 1225

Bottom-Up and Top-Down Controls 1226

CONCEPT 54.3 Disturbance influences species diversity and composition 1228

Characterizing Disturbance 1228

Ecological Succession 1229

Human Disturbance 1231

CONCEPT 54.4 Biogeographic factors affect community diversity 1231

Latitudinal Gradients 1232

Area Effects 1232

Island Equilibrium Model 1232

CONCEPT 54.5 Pathogens alter community structure locally and globally 1234

Effects on Community Structure 1234

Community Ecology and Zoonotic Diseases 1234

55 Ecosystems and Restoration Ecology 1238

CONCEPT 55.1 Physical laws govern energy flow and chemical cycling in ecosystems 1239

Energy Flow and Chemical Cycling 1239

Conservation of Energy 1239

Conservation of Mass 1239

Energy, Mass, and Trophic Levels 1240

CONCEPT 55.2 Energy and other limiting factors control primary production in ecosystems 1241

Ecosystem Energy Budgets 1241

Primary Production in Aquatic Ecosystems 1242

Primary Production in Terrestrial Ecosystems 1243

CONCEPT 55.3 Energy transfer between trophic levels is typically only 10% efficient 1246

Production Efficiency 1246

Trophic Efficiency and Ecological Pyramids 1246

CONCEPT 55.4 Biological and geochemical processes cycle nutrients and water in ecosystems 1248

Decomposition and Nutrient Cycling Rates 1248

Biogeochemical Cycles 1249

Case Study: Nutrient Cycling in the Hubbard Brook Experimental Forest 1252

CONCEPT 55.5 Restoration ecologists return degraded ecosystems to a more natural state 1253

Bioremediation 1253

Biological Augmentation 1255

Ecosystems: A Review 1255



56 Conservation Biology and Global Change 1260

CONCEPT 56.1 Human activities threaten earth's biodiversity 1261

Three Levels of Biodiversity 1261

Biodiversity and Human Welfare 1262

Threats to Biodiversity 1263

Can Extinct Species Be Resurrected? 1266

CONCEPT 56.2 Population conservation focuses on population size, genetic diversity, and critical habitat 1266

Extinction Risks in Small Populations 1266

Critical Habitat 1269

Weighing Conflicting Demands 1270

CONCEPT 56.3 Landscape and regional conservation help sustain biodiversity 1270

Landscape Structure and Biodiversity 1270

Establishing Protected Areas 1272

Urban Ecology 1273

CONCEPT 56.4 Earth is changing rapidly as a result of human actions 1274

Nutrient Enrichment 1274

Toxins in the Environment 1275

Greenhouse Gases and Climate Change 1278

Depletion of Atmospheric Ozone 1283

CONCEPT 56.5 Sustainable development can improve human lives while conserving biodiversity 1284

Sustainable Development 1284

The Future of the Biosphere 1285

APPENDIX A Answers A-1

APPENDIX B Classification of Life B-1

APPENDIX C A Comparison of the Light Microscope and the Electron Microscope C-1

APPENDIX D Scientific Skills Review D-1

CREDITS CR-1

GLOSSARY G-1

INDEX I-1

