

CAMPBELL  
BIOLOGY

NINTH EDITION

REECE • URRY • CAIN  
WASSERMAN • MINORSKY • JACKSON



Editor-in-Chief: *Beth Wilbur*  
Executive Director of Development: *Deborah Gale*  
Acquisitions Editor: *Josh Frost*  
Senior Editorial Manager: *Ginnie Simone Jutson*  
Supervising Editors: *Beth N. Winickoff, Pat Burner*  
Developmental Editors: *Matt Lee, John Burner, Mary Catherine Hager*  
Developmental Artists: *Hilair Chism, Carla Simmons, Andrew Recher, Jay McElroy*  
Senior Supplements Project Editor: *Susan Berge*  
Associate Editor: *Brady Golden*  
Assistant Editor: *Logan Triglia*  
Executive Managing Editor: *Erin Gregg*  
Managing Editor: *Michael Early*  
Senior Production Project Manager: *Shannon Tozier*  
Production Management and Composition: *S4Carlisle Publishing Services*

Illustrations: *Precision Graphics*  
Senior Photo Editor: *Donna Kalal*  
Photo Researcher: *Maureen Spuhler*  
Design Director: *Mark Ong*  
Interior and Cover Design: *Hespenheide Design*  
Director of Editorial Content, MasteringBiology®: *Natania Mlawer*  
Developmental Editors for MasteringBiology®: *Sarah Jensen, Mary Catherine Hager, Alice Fugate*  
Senior Media Producer: *Jonathan Ballard*  
Web Developer: *Josh Gentry*  
Director of Marketing: *Christy Lawrence*  
Executive Marketing Manager: *Lauren Harp*  
Manufacturing Buyer: *Michael Penne*  
Cover Printer: *Moore Langen Printing*  
Printer and Binder: *Courier/Kendallville*

Cover Photo Credit: "Succulent I" ©2005 Amy Lamb, [www.amylamb.com](http://www.amylamb.com)

Credits and acknowledgments borrowed from other sources and reproduced, with permission, in this textbook appear starting on page CR-1.

Copyright © 2011, 2008, 2005 Pearson Education, Inc., publishing as Pearson Benjamin Cummings, 1301 Sansome St., San Francisco, CA 94111. All rights reserved. Manufactured in the United States of America. This publication is protected by Copyright and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. To obtain permission(s) to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, 1900 E. Lake Ave., Glenview, IL 60025. For information regarding permissions, call (847) 486-2635.

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

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

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

Campbell biology. -- 9th ed.

p. cm.

Rev. ed. of: *Biology* / Neil A. Campbell, Jane B. Reece. 8th ed. c2009.

ISBN-13: 978-0-321-55823-7

ISBN-10: 0-321-55823-5

I. Reece, Jane B. II. Campbell, Neil A., 1946–2004. *Biology*. III.

Title: *Biology* / Jane B. Reece . . . [et al.].

QH308.2.C34 2011

570--dc22

2010020623

ISBN 10: 0321558235; ISBN 13: 9780321558237 (Student edition)

ISBN 10: 0321697308; ISBN 13: 9780321697301 (Professional copy)

**Benjamin Cummings**  
is an imprint of



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

3 4 5 6 7 8 9 10—CRK—14 13 12 11

Manufactured in the United States of America.

# CAMPBELL BIOLOGY

NINTH EDITION



**Jane B. Reece**

Berkeley, California

**Lisa A. Urry**

Mills College, Oakland, California

**Michael L. Cain**

Bowdoin College, Brunswick, Maine

**Steven A. Wasserman**

University of California, San Diego

**Peter V. Minorsky**

Mercy College, Dobbs Ferry, New York

**Robert B. Jackson**

Duke University, Durham, North Carolina

**Benjamin Cummings**

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

*This page intentionally left blank*

# Brief Contents

## 1 Introduction: Themes in the Study of Life 1

### UNIT

## 1

## The Chemistry of Life 28

- 2 The Chemical Context of Life 30
- 3 Water and Life 46
- 4 Carbon and the Molecular Diversity of Life 58
- 5 The Structure and Function of Large Biological Molecules 68

### UNIT

## 2

## The Cell 92

- 6 A Tour of the Cell 94
- 7 Membrane Structure and Function 125
- 8 An Introduction to Metabolism 142
- 9 Cellular Respiration and Fermentation 163
- 10 Photosynthesis 184
- 11 Cell Communication 206
- 12 The Cell Cycle 228

### UNIT

## 3

## Genetics 246

- 13 Meiosis and Sexual Life Cycles 248
- 14 Mendel and the Gene Idea 262
- 15 The Chromosomal Basis of Inheritance 286
- 16 The Molecular Basis of Inheritance 305
- 17 From Gene to Protein 325
- 18 Regulation of Gene Expression 351
- 19 Viruses 381
- 20 Biotechnology 396
- 21 Genomes and Their Evolution 426

### UNIT

## 4

## Mechanisms of Evolution 450

- 22 Descent with Modification: A Darwinian View of Life 452
- 23 The Evolution of Populations 469
- 24 The Origin of Species 488
- 25 The History of Life on Earth 507

### UNIT

## 5

## The Evolutionary History of Biological Diversity 534

- 26 Phylogeny and the Tree of Life 536
- 27 Bacteria and Archaea 556
- 28 Protists 575

## 29 Plant Diversity I: How Plants Colonized Land 600

## 30 Plant Diversity II: The Evolution of Seed Plants 618

## 31 Fungi 636

## 32 An Overview of Animal Diversity 654

## 33 An Introduction to Invertebrates 666

## 34 The Origin and Evolution of Vertebrates 697

### UNIT

## 6

## Plant Form and Function 736

## 35 Plant Structure, Growth, and Development 738

## 36 Resource Acquisition and Transport in Vascular Plants 764

## 37 Soil and Plant Nutrition 785

## 38 Angiosperm Reproduction and Biotechnology 801

## 39 Plant Responses to Internal and External Signals 821

### UNIT

## 7

## Animal Form and Function 850

## 40 Basic Principles of Animal Form and Function 852

## 41 Animal Nutrition 875

## 42 Circulation and Gas Exchange 897

## 43 The Immune System 929

## 44 Osmoregulation and Excretion 953

## 45 Hormones and the Endocrine System 974

## 46 Animal Reproduction 996

## 47 Animal Development 1021

## 48 Neurons, Synapses, and Signaling 1045

## 49 Nervous Systems 1062

## 50 Sensory and Motor Mechanisms 1085

## 51 Animal Behavior 1118

### UNIT

## 8

## Ecology 1142

## 52 An Introduction to Ecology and the Biosphere 1144

## 53 Population Ecology 1170

## 54 Community Ecology 1194

## 55 Ecosystems and Restoration Ecology 1218

## 56 Conservation Biology and Global Change 1238

# About the Authors



The Ninth Edition author team's contributions reflect their biological expertise as researchers and teaching sensibilities gained from years of experience as instructors at diverse institutions. The team's highly collaborative style continues to be evident in the cohesiveness and consistency of the Ninth Edition.

## Jane B. Reece



The head of the Ninth Edition author team, Jane Reece was Neil Campbell's longtime collaborator. She has participated in every edition of *BIOLOGY*. Earlier, Jane taught biology at Middlesex County College and Queensborough Community College. She holds an A.B. in Biology from Harvard University, an M.S. in Micro-

biology from Rutgers University, and a Ph.D. in Bacteriology from the University of California, Berkeley. Jane's research as a doctoral student and postdoctoral fellow focused on genetic recombination in bacteria. Besides her work on *CAMPBELL BIOLOGY*, she has been a coauthor of *Biology: Concepts & Connections*, *Essential Biology*, and *The World of the Cell*.

## Lisa A. Urry



Lisa Urry (Chapter 1 and Units 1–3) is a professor and developmental biologist and recent Chair of the Biology Department at Mills College. After graduating from Tufts University with a double major in Biology and French, Lisa completed her Ph.D. in molecular and developmental biology at Massachusetts Institute of Technology (MIT). She has published a number of research papers, most of them focused on gene expression during embryonic and larval development in sea urchins. Lisa is also deeply committed to promoting opportunities for women in science education and research.

## Michael L. Cain



Michael Cain (Units 4 and 5) is an ecologist and evolutionary biologist who is now writing full-time. Michael earned a joint degree in Biology and Math at Bowdoin College, an M.Sc. from Brown University, and a Ph.D. in Ecology and Evolutionary Biology from Cornell University. As a faculty member at New Mexico State University and Rose-Hulman Institute of Technology, he taught a wide range of courses, including 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. In addition to his work on *CAMPBELL BIOLOGY*, Michael is also the lead author of an ecology textbook.



## Steven A. Wasserman



Steve Wasserman (Unit 7) is a professor at the University of California, San Diego (UCSD). He earned his A.B. in Biology from Harvard University and his Ph.D. in Biological Sciences from MIT. Through his research on regulatory pathway mechanisms in the fruit fly *Drosophila*, Steve has contributed to the fields of developmen-

tal biology, reproduction, and immunity. As a faculty member at the University of Texas Southwestern Medical Center and UCSD, he has taught genetics, development, and physiology to undergraduate, graduate, and medical students. He has also served as the research mentor for more than a dozen doctoral students and more than 50 aspiring scientists at the undergraduate and high school levels. Steve has been the recipient of distinguished scholar awards from both the Markey Charitable Trust and the David and Lucille Packard Foundation. In 2007, he received UCSD's Distinguished Teaching Award for undergraduate teaching.

## Peter V. Minorsky



Peter Minorsky (Unit 6) is a professor at Mercy College in New York, where he teaches evolution, ecology, botany, and introductory biology. He received his B.A. in Biology from Vassar College and his Ph.D. in Plant Physiology from Cornell University. He is also the science writer for the journal *Plant Physiology*. After a post-

doctoral fellowship at the University of Wisconsin at Madison, Peter taught at Kenyon College, Union College, Western Connecticut State University, and Vassar College. He is an electrophysiologist who studies responses of plants to stress. Peter received the 2008 Award for Teaching Excellence at Mercy College.

## Robert B. Jackson



Rob Jackson (Unit 8) is a professor of biology and Nicholas Chair of Environmental Sciences at Duke University. Rob holds a B.S. in Chemical Engineering from Rice University, as well as M.S. degrees in Ecology and Statistics and a Ph.D. in Ecology from Utah State University. Rob directed Duke's Program in Ecology for many

years and just finished a term as the Vice President of Science for the Ecological Society of America. Rob has received numerous awards, including a Presidential Early Career Award in Science and Engineering from the National Science Foundation. He also enjoys popular writing, having published a trade book about the environment, *The Earth Remains Forever*, and two books of poetry for children, *Animal Mischief* and *Weekend Mischief*.

## Neil A. Campbell



Neil Campbell combined the investigative nature of a research scientist with the soul of an experienced and caring teacher. He earned his M.A. in Zoology from UCLA and his Ph.D. in Plant Biology from the University of California, Riverside, where he received the Distinguished Alumnus Award in 2001. Neil published numer-

ous research articles on desert and coastal plants and how the sensitive plant (*Mimosa*) and other legumes move their leaves. His 30 years of teaching in diverse environments included general biology courses at Cornell University, Pomona College, and San Bernardino Valley College, where he received the college's first Outstanding Professor Award in 1986. Neil was a visiting scholar in the Department of Botany and Plant Sciences at the University of California, Riverside. In addition to his authorship of this book, he coauthored *Biology: Concepts & Connections* and *Essential Biology* with Jane Reece. For the Ninth Edition of this book, we honor Neil's contributions to biology education by adopting the title *CAMPBELL BIOLOGY*.

# Preface

Biology is an enormous subject, one that can seem overwhelming to students and scientists alike. Moreover, discoveries are being made at an unprecedented pace—from new kinds of small RNA molecules to the Neanderthal genome, from new biofuels to communities of organisms thriving beneath vast glaciers, from emerging infectious diseases to cancer vaccines. As a result, a general biology course faces a daunting challenge: to keep students from suffocating under an avalanche of information. *CAMPBELL BIOLOGY* addresses this challenge by providing a strong foundation for understanding both current knowledge and new developments in the context of underlying biological concepts.

## Key Concepts and Unifying Themes

In each chapter of this textbook, a framework of three to six carefully chosen **Key Concepts** provide context for supporting details, helping students distinguish the “forest” from the “trees.” The numbered Key Concepts are presented at the beginning of the chapter and then serve as headings for each chapter section. *Concept Check Questions* at the end of each section provide a hierarchical framework for self-assessment that builds students’ confidence and then challenges them to push the limits of their understanding with several types of critical thinking questions. The *Summary of Key Concepts* at the end of the chapter refocuses students on the main points. *CAMPBELL BIOLOGY* also helps students organize and make sense of what they learn on a grander scale by emphasizing **evolution and other unifying themes** that pervade biology. These themes are introduced in Chapter 1 and integrated throughout the book.

## New to This Edition: An Emphasis on Making Connections

In addition to Key Concepts and themes, we’ve created new features for the Ninth Edition that help students see the big picture by *making connections*. These include the following:

### New Make Connections Questions: Making connections across chapters

New **Make Connections Questions** help students see how different areas of biology tie together, helping them overcome the tendency to compartmentalize information. Each question challenges students to move beyond memorization and gain a deeper understanding of biological principles by asking them to relate chapter content to material

they learned earlier in the course. For example, we ask students to connect

- DNA replication (Chapter 16, see p. 319) to the cell cycle (Chapter 12);
- Soil formation (Chapter 37, see p. 789) to the properties of water (Chapter 3); and
- Aquatic biomes (Chapter 52, see p. 1163) to osmoregulation (Chapter 44).

At least three Make Connections Questions appear in each chapter. In addition, online *Make Connections Tutorials* in MasteringBiology® (see p. xi) connect content from two different chapters using figures from the book.

## Expanded Evolution Coverage: Making connections to evolution in every chapter

Evolution is the core theme of biology, and in this edition it is more evident than ever. At least one **Evolution section in every chapter** focuses on evolutionary aspects of the chapter material, highlighted by a new Evolution banner. See, for example, the new discussions of enzyme evolution (p. 157), coevolution of flowers and pollinators (p. 806), and evolution of hormone function in animals (pp. 988–989).

## New Impact Figures: Making connections between scientific advances and the real world

Our new **Impact Figures** motivate students by highlighting the dramatic impact of recent discoveries in biology. These figures feature high-interest topics such as induced pluripotent stem cells and regenerative medicine (Chapter 20, p. 417), the discovery of *Tiktaalik* (Chapter 34, p. 710), and the use of forensic ecology to track elephant poaching (Chapter 56, p. 1243). The *Why It Matters* section of each figure explains the relevance of the research to students’ lives, global problems, or the field of biology itself. Each Impact Figure ends with a suggestion for *Further Reading* and a *What If?* or *Make Connections Question* to develop critical thinking skills.

## New Visual Organizers and 3-D Art: Making connections visually

The new **Visual Organizer** format highlights the main parts of a figure, helping students see the key categories at a glance. See, for instance, Figure 17.24 on types of small-scale mutations (p. 345) or Figure 27.3, Gram staining (p. 557). Throughout the book, selected figures have been rendered in a more **3-D art style** while keeping an appropriate balance between realism and teaching effectiveness. Figure 52.3, Exploring Global Climate Patterns (p. 1146), is one example.



## Restructured Chapter Reviews: Making connections at a higher level

In the chapter summaries, each concept section now concludes with a new **Summary of Key Concepts Question** that is tied to a major learning goal. Also, this edition increases student awareness of different levels of thinking by organizing the end-of-chapter questions into three levels based on **Bloom's taxonomy**, which classifies types of thinking that are important in learning. Our levels are (1) Knowledge/Comprehension, (2) Application/Analysis, and (3) Synthesis/Evaluation. (These same levels are used in the Campbell Test Bank.) The range of question types helps students develop critical thinking skills and prepare for the kinds of questions they'll encounter on exams. New **Write About a Theme Questions** give students practice writing short, coherent essays that connect the chapter's content to one of the book's themes. (A suggested grading rubric can be found on p. xv, and sample answers are provided for instructors in the MasteringBiology Instructor Resources area.) A new **MasteringBiology preview section** at the end of each chapter lists *Assignments*—tutorials, activities, and questions that instructors can assign. This section also directs students to the *eText* and *Study Area* for online self study.

## New Content: Making connections to advances in science

As in each new edition, the Ninth Edition incorporates **new scientific content** and **organizational improvements**. These are summarized on pp. viii–ix, following this Preface.

## MasteringBiology®: Making connections outside of class

MasteringBiology, the most widely used online assessment and tutorial program for biology, provides an extensive library of homework assignments that are graded automatically. In addition to BioFlix® Tutorials, other Tutorials, Activities, Reading Quiz Questions in every chapter, and 4,500 Test Bank Questions, MasteringBiology for the Ninth Edition features an **improved user interface** and the following **new Tutorials and Questions**: *Make Connections Tutorials*, *Student Misconceptions Questions* for every chapter, *Data Analysis Tutorials*, *Experimental Inquiry Tutorials*, *Video Tutor Sessions*, and *MasteringBiology: Virtual Biology Labs*. For more information, see pp. xvi–xix and [www.masteringbiology.com](http://www.masteringbiology.com).

## Our Hallmark Features

Besides our Key Concepts and unifying themes, several other features have contributed to the success of *CAMPBELL BIOLOGY*. Because text and illustrations are equally important for learning biology, **integration of figures and text** has been a hallmark of this book since its inception. Our popular *Exploring Figures* on selected topics epitomize this approach:

Each is a learning unit of core content that brings together related illustrations and text. Another example is our *Guided Tour Figures*, which use descriptions in blue type to walk students through complex figures like an instructor would, pointing out key structures, functions, and steps of processes.

To encourage **active learning**, recent editions have incorporated new types of questions: *What If? Questions*, *Figure Legend Questions*, and *Draw It Questions* that ask students to sketch a structure, annotate a figure, or graph data. In the Ninth Edition, these questions are augmented by the new *Make Connections Questions*. Online, the highly interactive *MasteringBiology tutorials* are sophisticated active-learning tools.

Finally, *CAMPBELL BIOLOGY* features **scientific inquiry**, an essential component of any biology course. Complementing stories of scientific discovery in the text narrative and the unit-opening interviews, *Inquiry Figures* help students understand “how we know what we know” and provide a model of how to think like a scientist. Each one begins with a research question and then describes how researchers designed an experiment, interpreted their results, and drew conclusions. The source article is referenced, and a What If? Question asks students to consider an alternative scenario. Selected Inquiry Figures invite students to read and analyze the original research article in the supplement *Inquiry in Action: Interpreting Scientific Papers* (see p. xxi). At the end of each chapter, *Scientific Inquiry Questions* give students additional opportunities to practice critical thinking by developing hypotheses, designing experiments, and analyzing real research data. Beyond the book, activities involving scientific inquiry are featured in MasteringBiology and other supplements, both print and electronic (see pp. xviii–xxi).

## Our Partnership with Instructors

A core value underlying all our work as authors is our belief in the importance of our partnership with instructors. Our primary way of serving instructors, of course, is providing a textbook, supplements, and media resources that serve their students well. In addition, Benjamin Cummings makes available a rich variety of instructor resources, in both print and electronic form (see p. xx). In our continuing efforts to improve the book and its supplements, we benefit tremendously from instructor feedback, not only in formal reviews from hundreds of scientists, but also via informal communication, often by e-mail.

The real test of any textbook is how well it helps instructors teach and students learn. We welcome comments from the students and instructors who use *CAMPBELL BIOLOGY*. Please address your suggestions to any of us:

Jane Reece at [janereece@cal.berkeley.edu](mailto:janereece@cal.berkeley.edu)  
Lisa Urry (Chapter 1 and Units 1–3) at [lurry@mills.edu](mailto:lurry@mills.edu)  
Michael Cain (Units 4 and 5) at [mcain@bowdoin.edu](mailto:mcain@bowdoin.edu)  
Peter Minorsky (Unit 6) at [pminorsky@mercy.edu](mailto:pminorsky@mercy.edu)  
Steve Wasserman (Unit 7) at [stevenw@ucsd.edu](mailto:stevenw@ucsd.edu)  
Rob Jackson (Unit 8) at [jackson@duke.edu](mailto:jackson@duke.edu)

# New Content

This section provides just a few highlights of new content and organizational improvements in *CAMPBELL BIOLOGY*, Ninth Edition.

## CHAPTER 1 Introduction: Themes in the Study of Life

We have added a separate new theme on energy flow while retaining a theme on environmental interactions. Concept 1.3, on the scientific method, has been reframed to more accurately reflect the scientific process, with a focus on observations and hypotheses. A new Concept 1.4 discusses the value of technology to society while emphasizing the cooperative nature of science and the value of diversity among scientists.

## UNIT ONE The Chemistry of Life

For this edition, the basic chemistry is enlivened by new content connecting it to evolution, ecology, and other areas of biology. Examples of new material include omega-3 fatty acids, the isomeric forms of methamphetamine, arsenic contamination of groundwater, and the basis of mad cow disease. The burgeoning importance of nucleic acids throughout biology has prompted us to expand our coverage of DNA and RNA structures in this first unit. In fact, a general aim for the first two units is to infuse the chapters with more detail about nucleic acids, genes, and related topics. Another enhancement, in this and the next two units, is the inclusion of more computer models of important proteins in contexts where they support students' understanding of molecular function.

## UNIT TWO The Cell

For Chapter 6, we developed an Exploring Figure on microscopy, which includes new types of microscopy, and we added micrographs of various cell types to the Exploring Figure on eukaryotic cells. We also expanded our description of chromosome composition, with the goal of preempting some common student misconceptions about chromosomes and DNA. New connections to evolution include an introduction to the endosymbiont theory in Chapter 6 and some interesting evolutionary adaptations of cell membranes in Chapter 7. We've added a new section to Chapter 8 on the evolution of enzymes with new functions, which not only strengthens enzyme coverage but also provides an early introduction to the concept that mutations contribute to molecular evolution. In Chapter 9, we simplified the glycolysis figure and emphasized pyruvate oxidation as a separate step to help students focus on the main ideas. In keeping with our increased focus on global

issues in the Ninth Edition, Chapter 10 has an Impact Figure on biofuels and a discussion of the possible effect of climate change on the distribution of  $C_3$  and  $C_4$  plants. In Chapter 11, we have added an Impact Figure to highlight the importance and medical relevance of G protein-coupled receptors.

## UNIT THREE Genetics

In Chapters 13–17, we have added material to stimulate student interest—for example, a new Impact Figure on genetic testing for disease-associated mutations. As done throughout the Ninth Edition, we ask students to make connections between chapters so that they avoid the trap of compartmentalizing the information in each chapter. For instance, Chapter 15 discusses the Philadelphia chromosome associated with chronic myelogenous leukemia and asks students to connect this information to what they learned about signaling in the cell cycle in Chapter 12. Also, we encourage students to connect what they learn about DNA replication and chromosome structure in Chapter 16 to the material on chromosome behavior during the cell cycle in Chapter 12. Chapter 16 has a new figure showing a current 3-D model of the DNA replication complex, with the lagging strand looping back through it.

Chapters 18–21 are extensively updated, with the changes dominated by new genomic sequence data and discoveries about the regulation of gene expression. (The introduction to genes, genomes, and gene expression in Units One and Two should help prepare students for these revisions.) Chapter 18 includes a new section on nuclear architecture, which describes the organization of chromatin in the nucleus in relation to gene expression. The roles of various types of RNA molecules in regulation also receive special attention. In the section on cancer, we describe how technical advances can contribute to personalized cancer treatments based on the molecular characteristics of an individual's tumor. Chapter 19 discusses the 2009 H1N1 flu pandemic. Chapter 20 includes advances in techniques for DNA sequencing and for obtaining induced pluripotent stem (iPS) cells. Finally, the heavily revised Chapter 21 describes what has been learned from the sequencing of many genomes, including those of a number of human individuals.

## UNIT FOUR Mechanisms of Evolution

For this edition, we have continued to bolster our presentation of the vast evidence for evolution by adding new examples and figures that illustrate key conceptual points throughout the unit. For example, Chapter 22 now presents research data on

adaptive evolution in soapberry bugs, fossil findings that shed light on the origins of cetaceans, and an Impact Figure on the rise of methicillin-resistant *Staphylococcus aureus*. Chapter 23 examines gene flow and adaptation in songbird populations. Chapter 24 incorporates several new examples of speciation research, including reproductive isolation in mosquitofish, speciation in shrimp, and hybridization of bear species. Other changes strengthen the storyline of the unit, ensuring that the chapters flow smoothly and build to a clear overall picture of what evolution is and how it works. For instance, new connections between Chapters 24 and 25 illustrate how differences in speciation and extinction rates shape the broad patterns in the history of life. We've also added earlier and more discussion of "tree thinking," the interpretation and application of phylogenetic trees, beginning in Chapter 22.

---

## UNIT FIVE The Evolutionary History of Biological Diversity

One of our goals for the diversity unit was to expand the coverage of the scientific evidence underlying the evolutionary story told in the chapters. So, for example, Chapter 27 now presents new findings on the evolutionary origin of bacterial flagella. In keeping with our increased emphasis on big-picture "tree thinking," we've added an "evogram" on tetrapod evolution in Chapter 34. (An evogram is a diagram illustrating the multiple lines of evidence that support the hypothesis shown in an evolutionary tree.) In addition, to help engage students, we've included new applications and woven more ecological information into our discussions of groups of organisms. Examples include new material on global growth of photosynthetic protists (Chapter 28), endangered molluscs (Chapter 33), and the impact of a pathogenic chytrid fungus on amphibian population declines (Chapters 31 and 34).

---

## UNIT SIX Plant Form and Function

Plant biology is in a transitional phase; some professors prefer strong coverage of classical botany while others seek more in-depth coverage of the molecular biology of plants. In developing the Ninth Edition, we have continued to balance the old and the new to provide students with a basic understanding of plant anatomy and function while highlighting dynamic areas of plant research and the many important connections between plants and other organisms. One major revision goal was to provide more explicit discussion of the evolutionary aspects of plant biology, such as the coevolution of flowering plants and pollinators (Chapter 38). Updates include new findings in plant development in Concept 35.5 and new material on the dynamism of plant architecture as it relates to resource acquisition in Chapter 36.

---

## UNIT SEVEN Animal Form and Function

In revising this unit, we strove to introduce physiological systems through a comparative approach that underscores how adaptations are linked to shared physiological challenges. In particular, we have highlighted the interrelationship of the endocrine and nervous systems at multiple points in the unit, helping students appreciate how these two forms of communication link tissues, organs, and individuals. Other revisions aim to keep students focused on fundamental concepts amid the details of complex systems. For example, many figures have been reconceived to emphasize key information, including new figures comparing single and double circulation (Chapter 42) and examining the function of antigen receptors (Chapter 43), as well as new Exploring Figures on the vertebrate kidney (Chapter 44) and the structure and function of the human eye (Chapter 50). Chapter 43 has been significantly revised to support students' conceptual understanding of basic immunological responses and the key cellular players. Throughout the unit, new state-of-the-art images and material on current and compelling topics—such as circadian rhythms (Chapter 40), novel strains of influenza (Chapter 43), the effects of climate change on animal reproductive cycles (Chapter 46), and advances in understanding brain plasticity and function (Chapter 49)—will help engage students and encourage them to make connections beyond the text.

---

## UNIT EIGHT Ecology

Our revision was informed by the fact that biologists are increasingly asked to apply their knowledge to help solve global problems, such as climate change, that already are profoundly affecting life on Earth. As part of our increased emphasis on global ecology in this edition, we have made significant changes to Unit Eight's organization and content. The organizational changes begin with the introductory chapter of the unit (Chapter 52), which includes a new Key Concept 52.1: "Earth's climate varies by latitude and season and is changing rapidly." Introducing the global nature of climate and its effects on life at the beginning of the chapter provides a logical foundation for the rest of the material. New content in Chapters 53 and 54 highlights factors that limit population growth, the ecological importance of disease, positive interactions among organisms, and biodiversity. Chapter 55 now explores restoration ecology together with ecosystem ecology because successful restoration efforts depend on understanding ecosystem structure and function. Finally, the new title of the unit's capstone, Chapter 56, reflects its emphasis on the combined importance of conservation and our changing Earth: "Conservation Biology and Global Change." Several new Impact Figures in the unit show students how ecologists apply biological knowledge and ecological theory at all scales to understand and solve problems in the world around them.



# To the Student: How to Use This Book

## Focus on the Key Concepts.

Each chapter is organized around a framework of 3 to 6 **Key Concepts** that will help you stay focused on the big picture and give you a context for the supporting details.

Before you begin reading the chapter, get oriented by reading the **list of Key Concepts**, which introduces the big ideas covered in the chapter.

Each **Key Concept** serves as the heading for a major section of the chapter.

After reading a concept section, check your understanding using the **Concept Check Questions** at the end of the section. Work through these questions on your own or in a study group—they're good practice for the kinds of questions you might be asked on an exam.

**What If? Questions** ask you to apply what you've learned. New **Make Connections Questions** ask you to relate content in the chapter to a concept you learned earlier in the course.

If you can answer these questions (see Appendix A to check your work), you're ready to move on.

## 52

### An Introduction to Ecology and the Biosphere



▲ Figure 52.1 What threatens this amphibian's survival?

#### KEY CONCEPTS

- 52.1 Earth's climate varies by latitude and season and is changing rapidly
- 52.2 The structure and distribution of terrestrial biomes are controlled by climate and disturbance
- 52.3 Aquatic biomes are diverse and dynamic systems that cover most of Earth
- 52.4 Interactions between organisms and the environment limit the distribution of species

#### OVERVIEW

##### Discovering Ecology

When University of Delaware undergraduate Justin Yeager spent his summer abroad in Costa Rica, all he wanted was to see the tropical rain forest and to practice his Spanish. Instead, he rediscovered the variable harlequin toad (*Atelopus varius*), a species thought to be extinct in the mountain slopes of Costa

Rica and Panama where it once lived (Figure 52.1). During the 1980s and 1990s, roughly two-thirds of the 82 known species of harlequin toads vanished. Scientists think that a disease-causing chytrid fungus, *Batrachochytrium dendrobatidis* (see Figure 31.26), contributed to many of these extinctions. Why was the fungus suddenly thriving in the rain forest? Cloudier days and warmer nights associated with global warming appear to have created an environment ideal for its success. As of 2009, the species that Yeager found was surviving as a single known population of fewer than 100 individuals.

What environmental factors limit the geographic distribution of harlequin toads? How do variations in their food supply or interactions with other species, such as pathogens, affect the size of their population? Questions like these are the subject of **ecology** (from the Greek *oikos*, home, and *logos*, study), the scientific study of the interactions between organisms and the environment. Ecological interactions occur at a hierarchy of scales that ecologists study, from single organisms to the globe (Figure 52.2).

Ecology's roots are in our basic human interest in observing other organisms. Naturalists, including Aristotle and Darwin, have long studied the living world and systematically recorded their observations. However, modern ecology involves more than observation. It is a rigorous experimental science that requires a breadth of biological knowledge. Ecologists generate hypotheses, manipulate environmental variables, and observe the outcome. In this unit, you will encounter many examples of ecological experiments, whose complex challenges have made ecologists innovators in experimental design and statistical inference.

In addition to providing a conceptual framework for understanding the field of ecology, Figure 52.2 provides the organizational framework for our final unit. In this chapter, we first describe Earth's climate and the importance of climate and other physical factors in determining the location of major life zones on land and in the oceans. We then examine how ecologists determine what controls the distribution and abundance of individual species. The next three chapters investigate population, community, and ecosystem ecology in detail, including approaches for restoring degraded ecosystems. The final chapter explores conservation biology and global ecology as we consider how ecologists apply biological knowledge to predict the global consequences of human activities and to conserve Earth's biodiversity.

#### CONCEPT 52.1

##### Earth's climate varies by latitude and season and is changing rapidly

The most significant influence on the distribution of organisms on land and in the oceans is **climate**, the long-term, prevailing weather conditions in a given area. Four physical

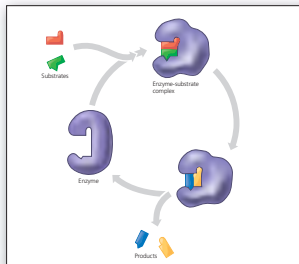
#### CONCEPT CHECK 52.1

1. Explain how the sun's unequal heating of Earth's surface leads to the development of deserts around 30° north and south of the equator.
2. What are some of the differences in microclimate between an unplanted agricultural field and a nearby stream corridor with trees?
3. **WHAT IF?** Changes in Earth's climate at the end of the last ice age happened gradually, taking centuries to thousands of years. If the current global warming happens very quickly, as predicted, how may this rapid climate change affect the ability of long-lived trees to evolve, compared with annual plants, which have much shorter generation times?
4. **MAKE CONNECTIONS** In Concept 10.4 (pp. 199–201), you learned about the important differences between C<sub>3</sub> and C<sub>4</sub> plants. Focusing just on the effects of temperature, would you expect the global distribution of C<sub>4</sub> plants to expand or contract as Earth becomes warmer? Why?

For suggested answers, see Appendix A.

## Make connections across biology.

By relating the content of a chapter to material you learned earlier in the course, new **Make Connections Questions** help you develop a deeper understanding of biological principles.

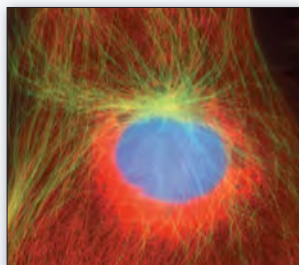


### CONCEPT CHECK 41.1

2. **MAKE CONNECTIONS** Review the discussion of enzymes in metabolic reactions in Concept 8.4 (pp. 152–156). Then explain why vitamins are required in very small amounts in the diet.

**Enzymes**  
(Chapter 8)

**Animal nutrition**  
(Chapter 41)

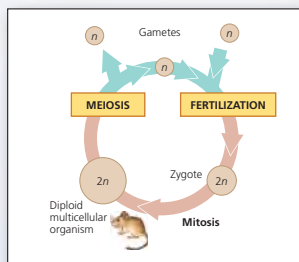
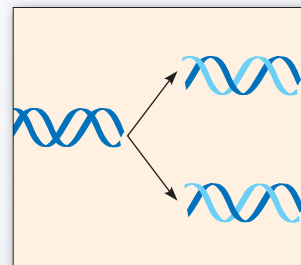


### CONCEPT CHECK 16.2

3. **MAKE CONNECTIONS** What is the relationship between DNA replication and the S phase of the cell cycle? See Figure 12.6, page 231.

**Cell cycle**  
(Chapter 12)

**DNA replication**  
(Chapter 16)



### CONCEPT CHECK 31.2

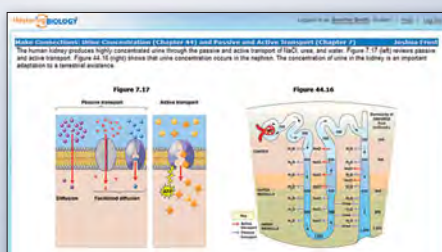
1. **MAKE CONNECTIONS** Compare Figure 31.5 with Figure 13.6 (p. 252). In terms of haploidy versus diploidy, how do the life cycles of fungi and animals differ?

**Meiosis**  
(Chapter 13)

**Fungi**  
(Chapter 31)



MasteringBIOLOGY<sup>®</sup>  
www.masteringbiology.com



New **Make Connections Tutorials** help you connect biological concepts across chapters in an interactive way.

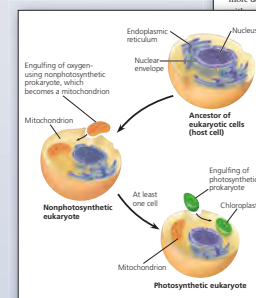
Make connections to **evolution**, the fundamental theme of biology.

Look for new **Evolution banners** highlighting sections in each chapter that focus on evolutionary aspects of the topic.

#### The Evolutionary Origins of Mitochondria and Chloroplasts

**KEY CONCEPT** Mitochondria and chloroplasts display similarities with bacteria that led to the **endosymbiont theory**, illustrated in Figure 6.16. This theory states that an early ancestor of eukaryotic cells engulfed an oxygen-using nonphotosynthetic prokaryotic cell. Eventually, the engulfed cell formed a relationship with the host cell in which it was enclosed, becoming an **endosymbiont** (a cell living within another cell). Indeed, over the course of evolution, the host cell and its endosymbiont merged into a single organism, a eukaryotic cell with a mitochondrion. At least one of these cells may have then taken up a photosynthetic prokaryote, becoming the ancestor of eukaryotic cells that contain chloroplasts. This is a widely accepted theory, which we will discuss in more detail in Chapter 25. The model it proposes is consistent with many structural features of mitochondria and chloroplasts.

Many structural features of mitochondria and chloroplasts also have an internal system of membranes, rather than being bounded by a single membrane. There is evidence that the ancestral engulfed cell had two outer membranes, which became the membranes of mitochondria and chloroplasts. Second, ribosomes, mitochondria and chloroplasts contain ribosomes, as well as circular DNA molecules attached to their ribosomes. The DNA in these organelles programs the synthesis of some of their own proteins, which are made on ribosomes inside the organelles. Third, also consistent with the endosymbiont theory, mitochondria and chloroplasts are autonomous (somewhat independent) and can grow and reproduce within the cell.

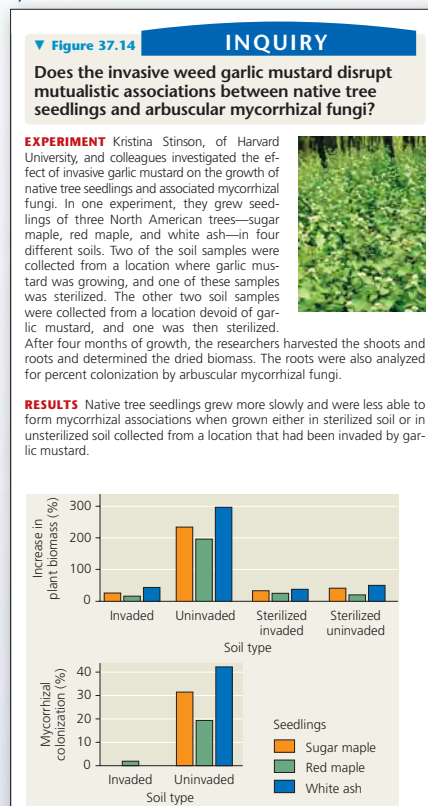




# Practice thinking like a scientist.

New **Impact Figures** demonstrate the dramatic impact of recent discoveries in biology and show that biology is constantly changing as new discoveries add to our understanding.

**Inquiry Figures** reveal “how we know what we know” by highlighting how researchers designed an experiment, interpreted their results, and drew conclusions.



**CONCLUSION** The data support the hypothesis that garlic mustard suppresses growth of native trees by affecting the soil in a way that disrupts mutualistic associations between the trees and arbuscular mycorrhizal fungi.

**SOURCE** K. A. Stinson et al., Invasive plant suppresses the growth of native tree seedlings by disrupting belowground mutualisms, *PLoS Biol* (Public Library of Science: Biology) 4(5): e140 (2006).

**INQUIRY IN ACTION** Read and analyze the original paper in *Inquiry in Action: Interpreting Scientific Papers*.

**WHAT IF?** What effect would applying inorganic phosphate to soil invaded by garlic mustard have on the plant's ability to outcompete native species?

After exploring the featured experiment, test your analytical skills by answering the **What If? Question**. Suggested answers are provided in Appendix A to help you gauge your understanding.

## Figure 56.9 IMPACT

### Forensic Ecology and Elephant Poaching



This array of severed tusks is part of an illegal shipment of 6,000 kg of ivory intercepted on its way from Africa to Singapore in 2002. Investigators wondered whether the elephants slaughtered for the ivory—perhaps as many as 6,500—were killed in the area where the shipment originated, primarily Zambia, or instead were killed across Africa, indicating a broader smuggling ring. Samuel Wasser, of the University of Washington, and colleagues amplified specific segments of DNA from the tusks using the polymerase chain reaction (PCR). These segments included stretches of DNA containing short tandem repeats (STRs; see Concept 20.4, pp. 420–421), the number of which varies among different elephant populations. The researchers then compared alleles at seven or more loci with a reference DNA database they had generated for elephants of known geographic origin. Their results showed conclusively that the elephants came from a narrow east-west band centered on Zambia rather than from across Africa.

**WHY IT MATTERS** The DNA analyses suggested that poaching rates were 30 times higher in Zambia than previously estimated. This news led to improved antipoaching efforts by the Zambian government. Techniques like those used in this study are being employed by conservation biologists to track the harvesting of many endangered species, including whales, sharks, and orchids.

**FURTHER READING** S. K. Wasser et al., Forensic tools battle ivory poachers, *Scientific American* 399:68–76 (2009); S. K. Wasser et al., Using DNA to track the origin of the largest ivory seizure since the 1989 trade ban, *Proceedings of the National Academy of Sciences USA* 104:4228–4233 (2007).

**MAKE CONNECTIONS** Figure 26.6 (p. 539) describes another example in which conservation biologists used DNA analyses to compare harvested samples with a reference DNA database. How are these examples similar, and how are they different? What limitations might there be to using such forensic methods in other suspected cases of poaching?

**Why It Matters** explains the relevance of the research.

**Further Reading** directs you to articles to explore.

A **Make Connections** or **What If? Question** encourages critical thinking.

Some **Inquiry Figures** invite you to read and analyze the original research paper in its complete form. You can find the journal article, along with a worksheet guiding you through it, in the separate book ***Inquiry in Action: Interpreting Scientific Papers***.

MasteringBIOLOGY  
www.masteringbiology.com



New **Experimental Inquiry Tutorials** give you practice analyzing experimental design and data and drawing conclusions.

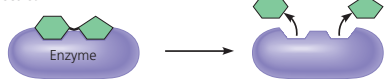
# Study the figures as you read the text.

▼ **Figure 5.15** An overview of protein functions.

## Enzymatic proteins

**Function:** Selective acceleration of chemical reactions

**Example:** Digestive enzymes catalyze the hydrolysis of bonds in food molecules.



## Storage proteins

**Function:** Storage of amino acids

**Examples:** Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.



Ovalbumin

Amino acids for embryo

## Hormonal proteins

**Function:** Coordination of an organism's activities

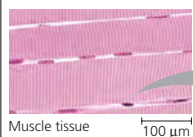
**Example:** Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.



## Contractile and motor proteins

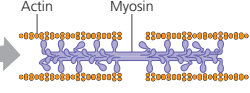
**Function:** Movement

**Examples:** Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Actin

Myosin

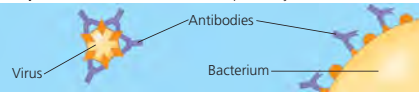


Muscle tissue 100  $\mu\text{m}$

## Defensive proteins

**Function:** Protection against disease

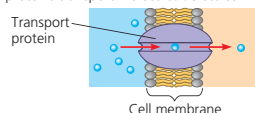
**Example:** Antibodies inactivate and help destroy viruses and bacteria.



## Transport proteins

**Function:** Transport of substances

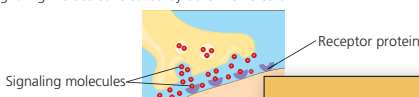
**Examples:** Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.



## Receptor proteins

**Function:** Response of cell to chemical stimuli

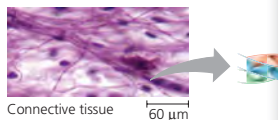
**Example:** Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



## Structural proteins

**Function:** Support

**Examples:** Keratin is the protein of hair, horn, and appendages. Insects and spiders use silk fiber and webs, respectively. Collagen and elastin form the framework in animal connective tissues.



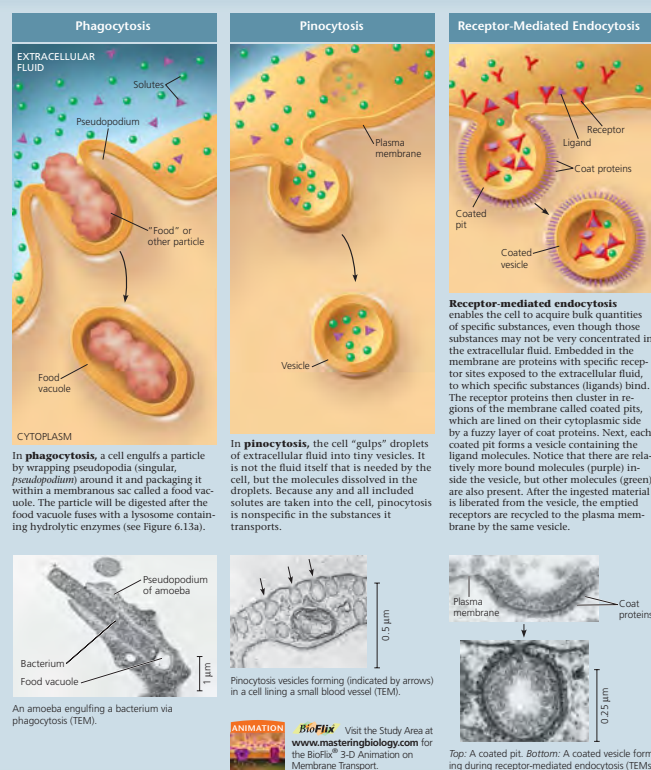
Connective tissue 60  $\mu\text{m}$

► New **Visual Organizers** help you to see important categories at a glance.

By integrating text and visuals, **Exploring Figures** help you learn more efficiently.

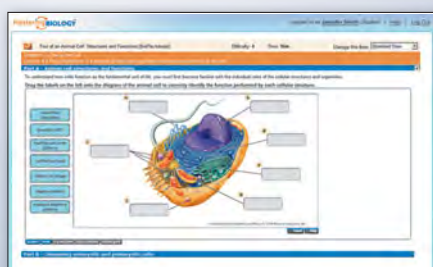
▼ **Figure 7.22**

## Exploring Endocytosis in Animal Cells



In selected illustrations, a **three-dimensional art style** helps you visualize biological structures.

**MasteringBIOLOGY**  
www.masteringbiology.com



Many **Tutorials** and **Activities** integrate art from the textbook, providing a unified learning experience.

► **BioFlix**® icons direct you to high-impact 3-D animations in the Study Area at [www.masteringbiology.com](http://www.masteringbiology.com).


# Review what you've learned.

**Chapter Reviews** help you efficiently master the chapter content by focusing on the main points of the chapter and offering opportunities to practice for exams.

**Summary Figures** present key information in a visual way.

## 23

### The Evolution of Populations



▲ Figure 23.1 Is this finch evolving?

**EVOLUTION**

**KEY CONCEPTS**

**23.1** Genetic variation makes evolution possible

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

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

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

**OVERVIEW**

**The Smallest Unit of Evolution**

One common misconception about evolution is that individual organisms evolve. It is true that natural selection acts on individuals: Each organism's traits affect its survival and reproductive success compared with other individuals. But the evolutionary impact of natural selection is only apparent in the changes in a *population* of organisms over time.

**Key Concepts**, which were introduced in the beginning of the chapter and developed in the text, are summarized in the Chapter Review.

New **Summary of Key Concepts Questions** appear at the end of each concept summary. Check your answers using Appendix A.

## 23

### CHAPTER REVIEW

**SUMMARY OF KEY CONCEPTS**

**CONCEPT 23.1**

**Genetic variation makes evolution possible (pp. 469–473)**

- **Genetic variation** refers to genetic differences among individuals within a population.
- The nucleotide differences that provide the basis of genetic variation arise by mutation and other processes that produce new alleles and new genes.
- New genetic variants are produced rapidly in organisms with short generation times. In sexually reproducing organisms, most of the genetic differences among individuals result from crossing over, the independent assortment of chromosomes, and fertilization.

**?** Why do biologists estimate gene variability and nucleotide variability, and what do these estimates represent?

**CONCEPT 23.2**

**The Hardy-Weinberg equation can be used to test whether a population is evolving (pp. 473–476)**

- A **population**, a localized group of organisms belonging to one species, is united by its **gene pool**, the aggregate of all the alleles in the population.
- The **Hardy-Weinberg principle** states that the allele and genotype frequencies of a population will remain constant if the population is large, mating is random, mutation is negligible, there is no gene flow, and there is no natural selection. For such a population, if  $p$  and  $q$  represent the frequencies of the only two possible alleles at a particular locus, then  $p^2$  is the frequency of one kind of homozygote,  $q^2$  is the frequency of the other kind of homozygote, and  $2pq$  is the frequency of the heterozygous genotype.

**?** Is it circular reasoning to calculate  $p$  and  $q$  from observed genotype frequencies and then use those values of  $p$  and  $q$  to test if the population is in Hardy-Weinberg equilibrium? Explain your answer. (Hint: Consider a specific case, such as a population with 195 individuals of genotype AA, 10 of genotype Aa, and 195 of genotype aa.)

**CONCEPT 23.3**

**Natural selection, genetic drift, and gene flow can alter allele frequencies in a population (pp. 476–480)**

- In natural selection, individuals that have certain inherited traits tend to survive and reproduce at higher rates than other individuals *because* of those traits.
- In **genetic drift**, chance fluctuations in allele frequencies over generations tend to reduce genetic variation.
- **Gene flow**, the transfer of alleles between populations, tends to reduce genetic differences between populations over time.

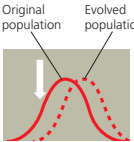
**?** Would two small, geographically isolated populations in very different environments be likely to evolve in similar ways? Explain.

**CONCEPT 23.4**

**Natural selection is the only mechanism that consistently causes adaptive evolution (pp. 480–485)**

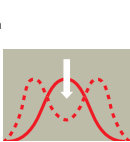
- One organism has greater **relative fitness** than a second organism if it leaves more fertile descendants than the second

organism. The modes of natural selection differ in how selection acts on phenotype (the white arrows in the summary diagram below represent selective pressure on a population).

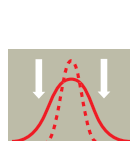


Original population  
Evolved population

Directional selection



Disruptive selection



Stabilizing selection

- Unlike genetic drift and gene flow, natural selection consistently increases the frequencies of alleles that enhance survival and reproduction, thus improving the match between organisms and their environment.
- **Sexual selection** influences evolutionary change in secondary sex characteristics that can give individuals advantages in mating.
- Despite the winnowing effects of selection, populations have considerable genetic variation. Some of this variation represents **neutral variation**; additional variation can be maintained by diploidy and balancing selection.
- There are constraints to evolution: Natural selection can act only on available variation; structures result from modified ancestral anatomy; adaptations are often compromises; and chance, natural selection, and the environment interact.

**?** How might secondary sex characteristics differ between males and females in a species in which females compete for mates?

**TEST YOUR UNDERSTANDING**

**LEVEL 1: KNOWLEDGE/COMPREHENSION**

1. Natural selection changes allele frequencies because some \_\_\_\_\_ survive and reproduce more successfully than others.
 

a. alleles
c. gene pools
e. individuals

b. loci
d. species
2. No two people are genetically identical, except for identical twins. The main source of genetic variation among human individuals is
 

a. new mutations that occurred in the preceding generation.
b. genetic drift due to the small size of the population.

c. the reshuffling of alleles in sexual reproduction.
d. geographic variation within the population.

e. environmental effects.
3. Sparrows with average-sized wings survive severe storms better than those with longer or shorter wings, illustrating
 

a. the bottleneck effect.
b. disruptive selection.

c. frequency-dependent selection.
d. neutral variation.

e. stabilizing selection.

To help you prepare for the various kinds of questions that may appear on a test, the end-of-chapter questions are now organized into three levels based on Bloom's Taxonomy:

- Level 1: Knowledge/Comprehension**
- Level 2: Application/Analysis**
- Level 3: Synthesis/Evaluation**



## Evolution Connection Questions

in the Chapter Review ask you to think critically about how an aspect of the chapter relates to evolution.

## Scientific Inquiry Questions

at the end of each chapter give you opportunities to practice scientific thinking by developing hypotheses, designing experiments, and analyzing real research data.

**Draw It Exercises** in each chapter ask you to put pencil to paper and draw a structure, annotate a figure, or graph experimental data.

### LEVEL 2: APPLICATION/ANALYSIS

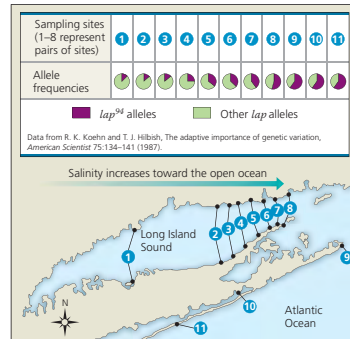
4. If the nucleotide variability of a locus equals 0%, what is the gene variability and number of alleles at that locus?
  - a. gene variability = 0%; number of alleles = 0
  - b. gene variability = 0%; number of alleles = 1
  - c. gene variability = 0%; number of alleles = 2
  - d. gene variability > 0%; number of alleles = 2
  - e. Without more information, gene variability and number of alleles cannot be determined.
5. There are 40 individuals in population 1, all with genotype  $A_1A_1$ , and there are 25 individuals in population 2, all with genotype  $A_2A_2$ . Assume that these populations are located far from each other and that their environmental conditions are very similar. Based on the information given here, the observed genetic variation is most likely an example of
  - a. genetic drift.
  - b. gene flow.
  - c. disruptive selection.
  - d. discrete variation.
  - e. directional selection.
6. A fruit fly population has a gene with two alleles,  $A_1$  and  $A_2$ . Tests show that 70% of the gametes produced in the population contain the  $A_1$  allele. If the population is in Hardy-Weinberg equilibrium, what proportion of the flies carry both  $A_1$  and  $A_2$ ?
  - a. 0.7
  - b. 0.49
  - c. 0.21
  - d. 0.42
  - e. 0.09

### LEVEL 3: SYNTHESIS/EVALUATION

7. **EVOLUTION CONNECTION**  
How is the process of evolution revealed by the imperfections of living organisms?

#### 8. SCIENTIFIC INQUIRY

**DRAW IT** Richard Koehn, of the State University of New York, Stony Brook, and Thomas Hilbish, of the University of South Carolina, studied genetic variation in the marine mussel *Mytilus edulis* around Long Island, New York. They measured the frequency of a particular allele ( $lap^{24}$ ) for an enzyme involved in regulating the mussel's internal saltwater balance. The researchers presented their data as a series of pie charts linked to sampling sites within Long Island Sound, where the salinity is highly variable, and along the coast of the open ocean, where salinity is constant:



(Question 8, continued)

Create a data table for the 11 sampling sites by estimating the frequency of  $lap^{24}$  from the pie charts. (Hint: Think of each pie chart as a clock face to help you estimate the proportion of the shaded area.) Then graph the frequencies for sites 1-8 to show how the frequency of this allele changes with increasing salinity in Long Island Sound (from southwest to northeast). How do the data from sites 9-11 compare with the data from the sites within the Sound?

Construct a hypothesis that explains the patterns you observe in the data and that accounts for the following observations: (1) the  $lap^{24}$  allele helps mussels maintain osmotic balance in water with a high salt concentration but is costly to use in less salty water; and (2) mussels produce larvae that can disperse long distances before they settle on rocks and grow into adults.

#### 9. WRITE ABOUT A THEME

**Emergent Properties** Heterozygotes at the sickle-cell locus produce both normal and abnormal (sickle-cell) hemoglobin (see Concept 14.4). When hemoglobin molecules are packed into a heterozygote's red blood cells, some cells receive relatively large quantities of abnormal hemoglobin, making these cells prone to sickling. In a short essay (approximately 100-150 words), explain how these molecular and cellular events lead to emergent properties at the individual and population levels of biological organization.

For selected answers, see Appendix A.

MasteringBIOLOGY® www.masteringbiology.com

#### 1. MasteringBiology® Assignments

**Make Connections Tutorial** Hardy-Weinberg Principle (Chapter 23) and Inheritance of Alleles (Chapter 14)

**Experimental Inquiry Tutorial** Did Natural Selection of Ground Finches Occur When the Environment Changed?

**BioFlix® Tutorial** Mechanisms of Evolution

**Tutorial** Hardy-Weinberg Principle

**Activities** Genetic Variation from Sexual Recombination • The Hardy-Weinberg Principle • Causes of Evolutionary Change • Three Modes of Natural Selection

**Questions** Student Misconceptions • Reading Quiz • Multiple Choice • End-of-Chapter

#### 2. eText

Read your book online, search, take notes, highlight text, and more.

#### 3. The Study Area

Practice Tests • Cumulative Test • **BioFlix®** 3-D Animations • MP3 Tutor Sessions • Videos • Activities • Investigations • Lab Media • Audio Glossary • Word Study Tools • Art

## New Write About a Theme Questions

give you practice writing a short essay that connects the chapter's content to one of the bookwide themes introduced in Chapter 1.

Each chapter now ends with a preview of the **MasteringBiology®** resources that can help you succeed in the course.

### Suggested Grading Rubric for "Write About a Theme" Short-Answer Essays

	Understanding of Theme and Relationship to Topic	Use of Supporting Examples or Details	Appropriate Use of Terminology	Quality of Writing
4	Evidence of full and complete understanding	Examples well chosen, details accurate and applied to theme	Accurate scientific terminology enhances the essay	Excellent organization, sentence structure, and grammar
3	Evidence of good understanding	Examples or details are generally well applied to theme	Terminology is correctly used	Good sentence flow, sentence structure, and grammar
2	Evidence of a basic understanding	Supporting examples and details are adequate	Terminology used is not totally accurate or appropriate	Some organizational and grammatical problems
1	Evidence of limited understanding	Examples and details are minimal	Appropriate terminology is not present	Poorly organized. Grammatical and spelling errors detract from essay
0	Essay shows no understanding of theme	Examples lacking or incorrect	Terminology lacking or incorrect	Essay is very poorly written

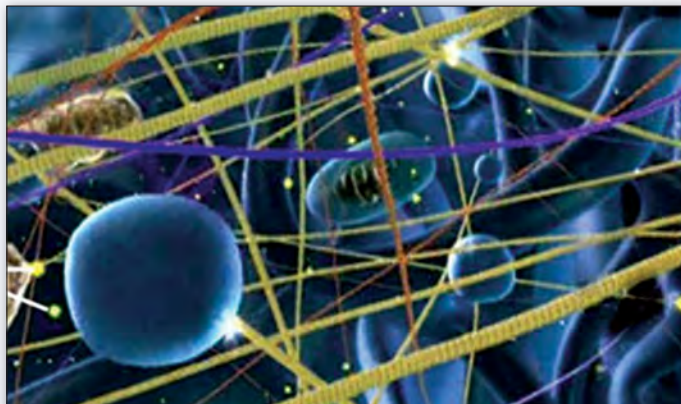
This **Writing Rubric** explains criteria on which your writing may be graded. The rubric and tips for writing good short-answer essays can be found in the Study Area at [www.masteringbiology.com](http://www.masteringbiology.com).

# To the Student: How to Effectively



The Mastering system empowers you to take charge of your learning—at your convenience, 24/7.

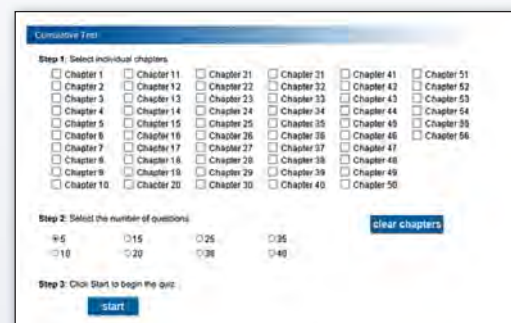
Use the Study Area on your own or in a study group.



**BioFlix® 3-D animations** explore the most difficult biology topics, reinforced with tutorials, quizzes, and more.

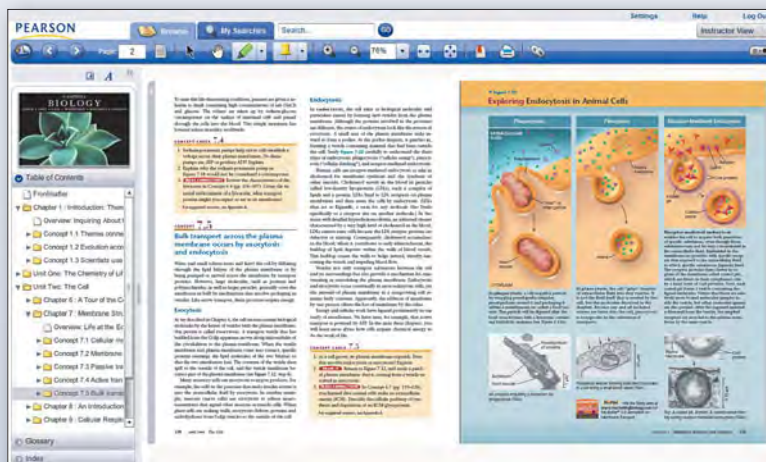


**Practice Tests** help you assess your understanding of each chapter, providing feedback for right and wrong answers.



The **Cumulative Test** allows you to build a practice test with questions from multiple chapters.

Access your book online.



The **Pearson eText** gives you access to the text whenever and wherever you can access the Internet. The eText includes powerful interactive and customization functions:

- write notes
- highlight text
- bookmark pages
- zoom
- click hyperlinked words to view definitions
- search
- link to media activities and quizzes

Your professor can also write notes for the class and highlight important material using a new tool that works like an electronic pen on a whiteboard.



# Use MasteringBiology®

## Get personalized coaching & feedback.

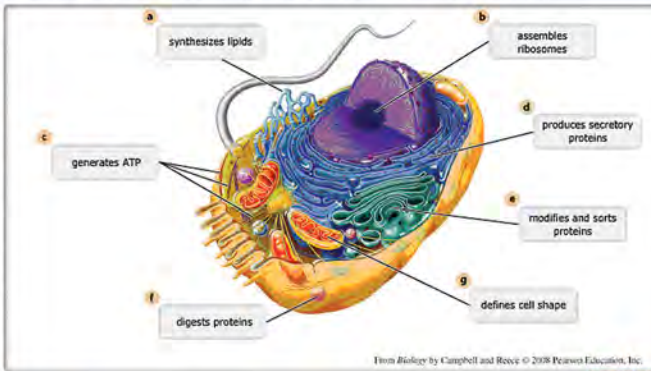
Your instructor may assign self-paced **MasteringBiology®** tutorials that provide individualized coaching with specific hints and feedback on the toughest topics in the course.

MasteringBIOLOGY®

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

**Part A - Animal cell structures and functions**

To understand how cells function as the fundamental unit of life, you must first become familiar with the individual roles of the cellular structures and organelles. Drag the labels on the left onto the diagram of the animal cell to correctly identify the function performed by each cellular structure.



Labels on the left (from top to bottom):

- 
- 
- 
- 
- 
- 

Labels on the right (from top to bottom):

- a synthesizes lipids
- b assembles ribosomes
- c generates ATP
- d produces secretory proteins
- e modifies and sorts proteins
- f digests proteins
- g defines cell shape

From Biology by Campbell and Reece © 2008 Pearson Education, Inc.

Try Again: 4 attempts remaining

submit hints my answers show answer review part

**Feedback**

You labeled 2 of 7 targets incorrectly. You have labeled target (c) incorrectly. These cellular components give the cell its structure, similar to the way your skeleton gives your body its basic structure.

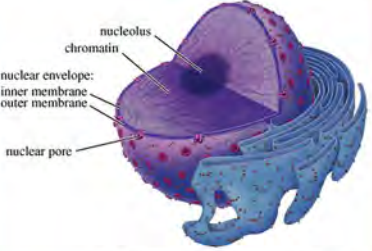
1 If you get stuck...

**Feedback**

You labeled 2 of 7 targets incorrectly. You have labeled target (c) incorrectly. These cellular components give the cell its structure, similar to the way your skeleton gives your body its basic structure.

Tour of an Animal Cell: Structures and Functions (BioRx tutorial) - Windows Internet Explorer

The nucleus is the defining characteristic of eukaryotic cells. This structure is best known for its role in housing the cell's genetic information, but there is more to this organelle than simply storing DNA.



From Biology by Campbell and Reece © 2008 Pearson Education, Inc.

Drag the terms from the left to the appropriate blanks on the right to complete the sentences. Terms can be used once or not at all.

Terms on the left:

- chromatin
- nucleoid
- nuclear lamina
- nuclear pore
- nuclear envelope
- nucleolus

Sentences on the right:

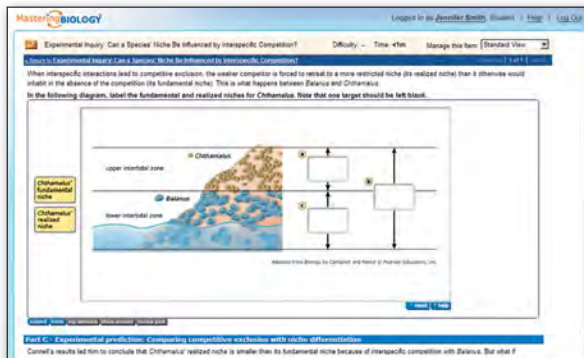
1. The genetic information housed within the nucleus is associated with protein and is called \_\_\_\_\_.
2. The \_\_\_\_\_ is a double membrane that separates the nucleus from the cytoplasm.
3. The synthesis and assembly of ribosomal components occurs in the \_\_\_\_\_.
4. The shape of the nucleus is maintained by a network of protein filaments called the \_\_\_\_\_.
5. Before RNA can be translated into protein, it first must be exported from the nucleus through a \_\_\_\_\_.

2 Specific wrong-answer **feedback** appears in the purple feedback box.

3 You are offered **hints** to coach you to the correct response.

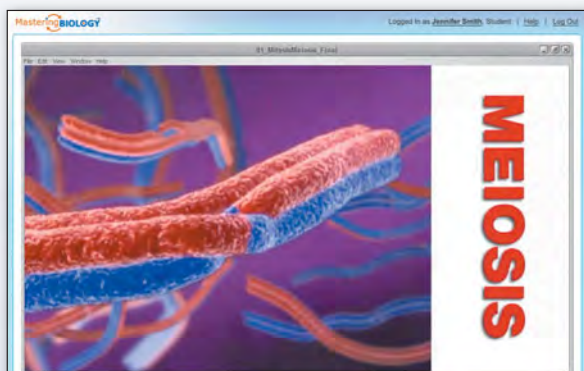






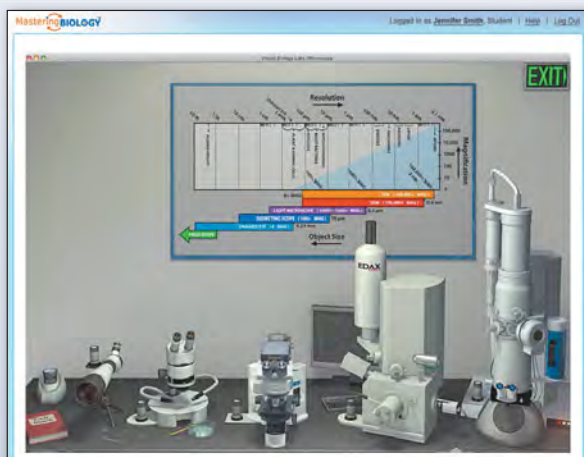
◀ New **Experimental Inquiry Tutorials**, based on some of biology's most influential experiments, give students practice analyzing experimental design and data, and help students understand how to reach conclusions based on collected data. Topics include:

- What Can You Learn About the Process of Science from Investigating a Cricket's Chirp?
- Which Wavelengths of Light Drive Photosynthesis?
- What Is the Inheritance Pattern of Sex-Linked Traits?
- Does DNA Replication Follow the Conservative, Semiconservative, or Dispersive Model?
- Did Natural Selection of Ground Finches Occur When the Environment Changed?
- What Effect Does Auxin Have on Coleoptile Growth?
- What Role Do Genes Play in Appetite Regulation?
- How Do Calcium Ions Help to Prevent Polyspermy During Egg Fertilization?
- Can a Species' Niche Be Influenced by Interspecific Competition?
- What Factors Influence the Loss of Nutrients from a Forest Ecosystem?



◀ The New **Video Tutor Sessions** walk students through tough topics with clearly explained visuals and demonstrations. Topics include:

- Mitosis and Meiosis
- Sex-Linked Pedigrees
- DNA Structure
- DNA Profiling Techniques
- Biodiversity
- Phylogenetic Trees



◀ The new **MasteringBiology: Virtual Biology Labs** online environment promotes critical thinking skills using virtual experiments and explorations that may be difficult to perform in a wet lab environment due to time, cost, or safety concerns.

- MasteringBiology: Virtual Biology Labs offer unique learning experiences in microscopy, molecular biology, genetics, ecology, and systematics.
- Choose from 20–30 automatically graded, “pre-set” lab activities that are ready to assign to students, or create your own from scratch.
- Each “pre-set” lab provides an assignable lab report with questions that are automatically graded and recorded in the MasteringBiology gradebook.
- Student subscriptions are available standalone or packaged with the *CAMPBELL BIOLOGY* textbook.

# Supplements

## For Instructors

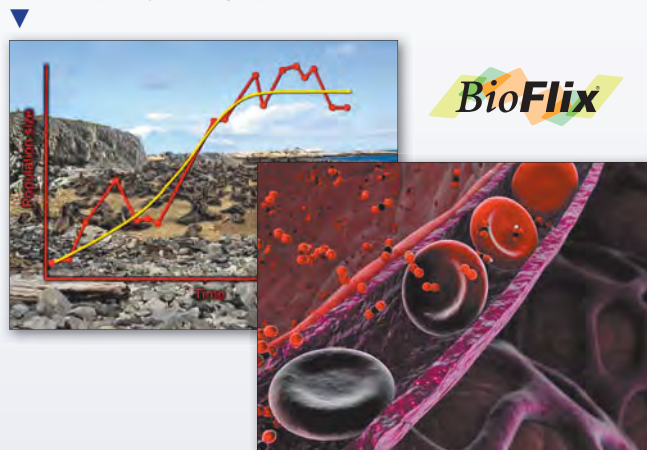
### Instructor Resource DVD

978-0-321-67786-0 • 0-321-67786-2

Assets for each chapter include:

- All figures, photos, and tables in JPEG and PowerPoint®
- Prepared PowerPoint Presentations for each chapter, with lecture notes, editable figures from the text, and links to animations and videos
- Clicker Questions in PowerPoint
- 250+ Instructor Animations, including 3-D BioFlix®
- Discovery Channel™ Videos
- Test Bank questions in TestGen® software and Microsoft® Word

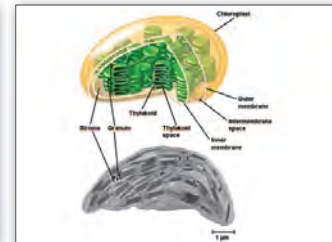
**BioFlix® animations** invigorate classroom lectures with 3-minute “movie quality” 3-D graphics (see list on p. xviii).



**Customizable PowerPoints** provide a jumpstart for each lecture.

### Chloroplasts: The Sites of Photosynthesis in Plants

- Leaves are the major locations of photosynthesis
- Their green color is from **chlorophyll**, the green pigment within chloroplasts
- Light energy absorbed by chlorophyll drives the synthesis of organic molecules in the chloroplast
- CO<sub>2</sub> enters and O<sub>2</sub> exits the leaf through microscopic pores called **stomata**



**Clicker Questions** can be used to stimulate effective classroom discussions (for use with or without clickers).

### Energy Transfer

Like jackrabbits, elephants have many blood vessels in their ears that help them cool their bodies by radiating heat. Which of the following statements about this radiated energy would be accurate?

- The original source of the energy was the sun.
- The energy will be recycled through the ecosystem.
- The radiated energy will be trapped by predators of the elephants.
- More energy is radiated in cold conditions than in hot conditions.
- More energy is radiated at night than during the day.

### Experiments: Data Interpretation

Vegetarian snakes on islands eat only vegetation from banded to unbanded. Researchers hypothesized that unbanded snakes escape predation from hawks at higher rates than do banded snakes. Imagine that you tested survival rates on four different islands by measuring capture rates of banded and unbanded snakes and collected the data shown below. Which of the following conclusions best derive from the data shown?

- Lack of bands helps snakes escape predation by hawks.
- Lack of bands improves snake survival but the mechanism is unknown.
- Lack of bands decreases snake survival rates.
- The two groups do not differ in survival rates.
- Survival rates of banded snakes differ among islands.

**All of the art and photos** from the book are provided with customizable labels. More than 1,600 photos from the text and other sources are included.



### Printed Test Bank

by Louise Paquin, *McDaniel College*, Michael Dini, *Texas Tech University*, John Lepri, *University of North Carolina, Greensboro*, Jung Choi, *Georgia Institute of Technology*, John Zarnetske, *Hoosick Falls Central School*, and Ronald Balsamo, *Villanova University*  
978-0-321-69729-5 • 0-321-69729-4

For the Ninth Edition, the Test Bank authors have increased the number of high-level application and synthesis questions.

### Transparency Acetates

978-0-321-69708-0 • 0-321-69708-1

### Course Management Systems

Test Bank questions, quizzes, and selected content from the Study Area of MasteringBiology are available in these popular course management systems:

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

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

### Instructor Resources Area in MasteringBiology

This area includes:

- PowerPoint® Lectures
- Clicker Questions
- JPEG Images
- Animations
- Videos
- Lecture Outlines
- Learning Objectives
- Strategies for Overcoming Common Student Misconceptions
- Instructor Guides for Supplements
- Write About a Theme: Tips for Grading Short-Answer Essays
- Suggested Answers for Essay Questions
- Test Bank Files
- Lab Media

## For Students

### **Study Guide, Ninth Edition**

by Martha R. Taylor, *Cornell University*  
978-0-321-62992-0 • 0-321-62992-2

This popular study guide helps students extract key ideas from the textbook and organize their knowledge of biology. Exercises include concept maps, chapter summaries, word roots, chapter tests, and a variety of interactive questions in various formats.

### **Inquiry in Action: Interpreting Scientific Papers, Second Edition\***

by Ruth Buskirk, *University of Texas at Austin*,  
and Christopher M. Gillen, *Kenyon College*  
978-0-321-68336-6 • 0-321-68336-6

Selected Inquiry Figures in the Ninth Edition direct students to read and analyze the complete original research paper. In this supplement, those articles are reprinted and accompanied by questions that help students analyze the article. The Inquiry Figures from the book are reprinted in the supplement.

### **Practicing Biology: A Student Workbook, Fourth Edition\***

by Jean Heitz and Cynthia Giffen, *University of Wisconsin, Madison*  
978-0-321-68328-1 • 0-321-68328-5

This workbook offers a variety of activities to suit different learning styles. Activities such as modeling and 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, Third Edition\***

by Margaret Waterman, *Southeast Missouri State University*, and  
Ethel Stanley, *BioQUEST Curriculum Consortium and Beloit College*  
978-0-321-68320-5 • 0-321-68320-X

This workbook offers ten investigative cases. A student website is in the Study Area at [www.masteringbiology.com](http://www.masteringbiology.com).

### **Study Card, Ninth Edition**

978-0-321-68322-9 • 0-321-68322-6

This quick-reference card provides an overview of the entire field of biology and helps students see the connections between topics.

### **Spanish Glossary, Ninth Edition**

by Laura P. Zanello, *University of California, Riverside*  
978-0-321-68321-2 • 0-321-68321-8

This resource provides definitions in Spanish for all the glossary terms.

### **Into the Jungle: Great Adventures in the Search for Evolution**

by Sean B. Carroll, *University of Wisconsin, Madison*  
978-0-321-55671-4 • 0-321-55671-2

These nine short tales vividly depict key discoveries in evolutionary biology and the excitement of the scientific process. Online resources available at [www.aw-bc.com/carroll](http://www.aw-bc.com/carroll).

### **Get Ready for Biology**

978-0-321-50057-1 • 0-321-50057-1

This engaging workbook helps students brush up on important math and study skills and get up to speed on biological terminology and the basics of chemistry and cell biology.

### **A Short Guide to Writing About Biology, Seventh Edition**

by Jan A. Pechenik, *Tufts University*  
978-0-321-66838-7 • 0-321-66838-3

This best-selling writing guide teaches students to think as biologists and to express ideas clearly and concisely through their writing.

### **An Introduction to Chemistry for Biology Students, Ninth Edition**

by George I. Sackheim, *University of Illinois, Chicago*  
978-0-8053-9571-6 • 0-8053-9571-7

This text/workbook helps students review and master all the basic facts, concepts, and terminology of chemistry that they need for their life science course.

### **The Chemistry of Life CD-ROM, Biology Version, Second Edition**

by Robert M. Thornton, *University of California, Davis*  
978-0-8053-3063-2 • 0-8053-3063-1

This CD-ROM uses animations, interactive simulations, and quizzes with feedback to help students learn or review the chemistry needed to succeed in introductory biology.

## For Lab

### **Investigating Biology Laboratory Manual, Seventh Edition**

by Judith G. Morgan, *Emory University*, and M. Eloise Brown  
Carter, *Oxford College of Emory University*  
978-0-321-66821-9 • 0-321-66821-9

The Seventh Edition emphasizes connections to recurring themes in biology, including structure and function, unity and diversity, and the overarching theme of evolution.

### **Annotated Instructor Edition for Investigating Biology Laboratory Manual, Seventh Edition**

by Judith G. Morgan, *Emory University*, and M. Eloise Brown  
Carter, *Oxford College of Emory University*  
978-0-321-67668-9 • 0-321-67668-8

### **Preparation Guide for Investigating Biology Laboratory Manual, Seventh Edition**

by Judith G. Morgan, *Emory University*, and M. Eloise  
Brown Carter, *Oxford College of Emory University*  
978-0-321-67669-6 • 0-321-67669-6

### **Symbiosis: The Benjamin Cummings Custom Laboratory Program for the Biological Sciences**

[www.pearsoncustom.com/database/symbiosis/bc.html](http://www.pearsoncustom.com/database/symbiosis/bc.html)

### **MasteringBiology®: Virtual Biology Labs**

#### **www.masteringbiology.com**

This online environment promotes critical thinking skills using virtual experiments and explorations that may be difficult to perform in a wet lab environment due to time, cost, or safety concerns. Designed to supplement or substitute for existing wet labs, this product offers students unique learning experiences and critical thinking exercises in the areas of microscopy, molecular biology, genetics, ecology, and systematics.

\* An Instructor Guide is available for download in the Instructor Resources Area at [www.masteringbiology.com](http://www.masteringbiology.com).



# Featured Figures

## Impact Figures

- 3.12** The Threat of Ocean Acidification to Coral Reef Ecosystems 55
- 7.11** Blocking HIV Entry into Cells as a Treatment for HIV Infections 130
- 10.3** Alternative Fuels from Plants and Algae 185
- 11.8** Determining the Structure of a G Protein-Coupled Receptor (GPCR) 213
- 12.21** Advances in Treatment of Breast Cancer 243
- 14.18** Genetic Testing 280
- 16.23** Painting Chromosomes 322
- 20.22** The Impact of Induced Pluripotent Stem (iPS) Cells on Regenerative Medicine 417
- 22.14** The Rise of MRSA 462
- 28.28** Marine Protists in a Warmer World 597
- 30.16** Clear-Cutting of Tropical Forests 633
- 31.26** Amphibians Under Attack 651
- 33.22** Molluscs: The Silent Extinction 681
- 34.20** Discovery of a “Fishapod”: *Tiktaalik* 710
- 38.17** Fighting World Hunger with Transgenic Cassava 817
- 43.26** Vaccinating Against Cervical Cancer 950
- 49.14** Using Functional Brain Imaging to Map Activity in the Working Brain 1072
- 50.21** Gene Therapy for Vision 1100
- 54.29** Identifying Lyme Disease Host Species 1214
- 55.7** Ocean Production Revealed 1222
- 56.9** Forensic Ecology and Elephant Poaching 1243

## Exploring Figures

- 1.4** Levels of Biological Organization 4
- 4.9** Some Biologically Important Chemical Groups 64
- 5.20** Levels of Protein Structure 82
- 6.3** Microscopy 96
- 6.8** Eukaryotic Cells 100
- 6.32** Cell Junctions in Animal Tissues 121
- 7.22** Endocytosis in Animal Cells 139
- 11.7** Cell-Surface Transmembrane Receptors 211
- 12.7** Mitosis in an Animal Cell 232
- 13.8** Meiosis in an Animal Cell 254
- 16.22** Chromatin Packing in a Eukaryotic Chromosome 320
- 24.3** Reproductive Barriers 490
- 25.6** The Origin of Mammals 513
- 27.17** Major Groups of Bacteria 568
- 28.3** Protistan Diversity 578
- 29.5** Derived Traits of Land Plants 602
- 29.9** Bryophyte Diversity 608
- 29.15** Seedless Vascular Plant Diversity 614
- 30.5** Gymnosperm Diversity 622
- 30.13** Angiosperm Diversity 630
- 31.11** Fungal Diversity 642
- 33.3** Invertebrate Diversity 667
- 33.38** Insect Diversity 690
- 34.41** Mammalian Diversity 724
- 35.10** Examples of Differentiated Plant Cells 744
- 37.15** Unusual Nutritional Adaptations in Plants 798
- 38.4** Flower Pollination 804

- 38.11** Fruit and Seed Dispersal 811
- 40.5** Structure and Function in Animal Tissues 856
- 41.6** Four Main Feeding Mechanisms of Animals 881
- 42.5** Double Circulation in Vertebrates 901
- 44.14** The Mammalian Excretory System 962
- 46.12** Human Gametogenesis 1006
- 49.9** The Organization of the Human Brain 1068
- 50.10** The Structure of the Human Ear 1091
- 50.17** The Structure of the Human Eye 1096
- 50.30** The Regulation of Skeletal Muscle Contraction 1107
- 52.2** The Scope of Ecological Research 1145
- 52.3** Global Climate Patterns 1146
- 52.12** Terrestrial Biomes 1153
- 52.16** Aquatic Biomes 1159
- 53.17** Mechanisms of Density-Dependent Regulation 1183
- 55.14** Water and Nutrient Cycling 1228
- 55.19** Restoration Ecology Worldwide 1234

## Inquiry Figures

- \*†1.27** Does the presence of venomous coral snakes affect predation rates on their mimics, kingsnakes? 22
- \*2.2** What creates “devil’s gardens” in the rain forest? 31
- 4.2** Can organic molecules form under conditions estimated to simulate those on the early Earth? 59
- 5.24** What can the 3-D shape of the enzyme RNA polymerase II tell us about its function? 86
- 6.29** What role do microtubules play in orienting deposition of cellulose in cell walls? 119
- 7.7** Do membrane proteins move? 128
- 8.20** Are there allosteric inhibitors of caspase enzymes? 159
- †10.10** Which wavelengths of light are most effective in driving photosynthesis? 191
- 11.17** How do signals induce directional cell growth during mating in yeast? 221
- 12.9** At which end do kinetochore microtubules shorten during anaphase? 235
- 12.14** Do molecular signals in the cytoplasm regulate the cell cycle? 238
- 14.3** When F<sub>1</sub> hybrid pea plants self- or cross-pollinate, which traits appear in the F<sub>2</sub> generation? 264
- 14.8** Do the alleles for one character assort into gametes dependently or independently of the alleles for a different character? 268
- †15.4** In a cross between a wild-type female fruit fly and a mutant white-eyed male, what color eyes will the F<sub>1</sub> and F<sub>2</sub> offspring have? 289
- 15.9** How does linkage between two genes affect inheritance of characters? 293
- 16.2** Can a genetic trait be transferred between different bacterial strains? 306
- 16.4** Is protein or DNA the genetic material of phage T2? 307
- \*†16.11** Does DNA replication follow the conservative, semi-conservative, or dispersive model? 312
- 17.2** Do individual genes specify the enzymes that function in a biochemical pathway? 327
- 18.22** Is Bicoid a morphogen that determines the anterior end of a fruit fly? 372

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

† See the related Experimental Inquiry Tutorial in MasteringBiology® ([www.masteringbiology.com](http://www.masteringbiology.com)).

- 19.2** What causes tobacco mosaic disease? 382
- 20.18** Can the nucleus from a differentiated animal cell direct development of an organism? 413
- 21.17** What is the function of a gene (*FOXP2*) that is rapidly evolving in the human lineage? 444
- 22.13** Can a change in a population's food source result in evolution by natural selection? 461
- \*23.16** Do females select mates based on traits indicative of "good genes"? 483
- 24.10** Can divergence of allopatric populations lead to reproductive isolation? 495
- 24.12** Does sexual selection in cichlids result in reproductive isolation? 497
- 24.19** How does hybridization lead to speciation in sunflowers? 503
- 25.25** What causes the loss of spines in lake stickleback fish? 528
- 26.6** What is the species identity of food being sold as whale meat? 539
- 27.10** Can prokaryotes evolve rapidly in response to environmental change? 561
- 28.23** What is the root of the eukaryotic tree? 593
- 29.10** Can bryophytes reduce the rate at which key nutrients are lost from soils? 609
- 31.21** Do endophytes benefit a woody plant? 648
- 32.6** Did  $\beta$ -catenin play an ancient role in the molecular control of gastrulation? 659
- 33.29** Did the arthropod body plan result from new *Hox* genes? 685
- 34.50** Did Neanderthals give rise to European humans? 732
- 35.9** Do soybean pod trichomes deter herbivores? 743
- 36.19** Does phloem sap contain more sugar near sources than sinks? 781
- \*37.14** Does the invasive weed garlic mustard disrupt mutualistic associations between native tree seedlings and arbuscular mycorrhizal fungi? 797
- 39.5** What part of a grass coleoptile senses light, and how is the signal transmitted? 825
- †39.6** Does asymmetrical distribution of a growth-promoting chemical cause a coleoptile to grow toward the light? 826
- 39.7** What causes polar movement of auxin from shoot tip to base? 828
- 39.17** How does the order of red and far-red illumination affect seed germination? 836
- 40.14** How does a Burmese python generate heat while incubating eggs? 867
- 40.21** What happens to the circadian clock during hibernation? 872
- \*41.4** Can diet influence the frequency of birth defects? 879
- †41.22** What are the roles of the *ob* and *db* genes in appetite regulation? 894
- 42.21** Can inactivating a liver enzyme lower plasma LDL levels? 914
- 42.26** What causes respiratory distress syndrome? 920
- 43.5** Can a single antimicrobial peptide protect fruit flies against infection? 931
- 44.21** Can aquaporin mutations cause diabetes insipidus? 970
- 45.22** What role do hormones play in making a mammal male or female? 992
- 46.9** Why is sperm usage biased when female fruit flies mate twice? 1002
- †47.4** Does the distribution of  $\text{Ca}^{2+}$  in an egg correlate with formation of the fertilization envelope? 1024
- 47.22** How does distribution of the gray crescent affect the developmental potential of the first two daughter cells? 1038
- 47.23** Can the dorsal lip of the blastopore induce cells in another part of the amphibian embryo to change their developmental fate? 1039
- 47.25** What role does the zone of polarizing activity (ZPA) play in limb pattern formation in vertebrates? 1041
- 48.18** Does the brain have a specific protein receptor for opiates? 1059
- 49.12** Which cells control the circadian rhythm in mammals? 1071
- 50.23** How do mammals detect different tastes? 1102
- 50.40** What are the energy costs of locomotion? 1114
- 51.8** Does a digger wasp use landmarks to find her nest? 1125
- 51.23** Are the songs of green lacewing species under the control of multiple genes? 1134
- 51.26** Are differences in migratory orientation within a species genetically determined? 1136
- 52.20** Does feeding by sea urchins limit seaweed distribution? 1165
- 53.13** How does caring for offspring affect parental survival in kestrels? 1180
- 53.20** How does food availability affect emigration and foraging in a cellular slime mold? 1186
- †54.3** Can a species' niche be influenced by interspecific competition? 1196
- 54.17** Is *Pisaster ochraceus* a keystone predator? 1205
- 54.28** How does species richness relate to area? 1213
- 55.8** Which nutrient limits phytoplankton production along the coast of Long Island? 1223
- 55.15** How does temperature affect litter decomposition in an ecosystem? 123
- \*56.13** What caused the drastic decline of the Illinois greater prairie chicken population? 1246

## Research Method Figures

- 2.6** Radioactive Tracers 34
- 6.4** Cell Fractionation 97
- 7.4** Freeze-fracture 126
- 10.9** Determining an Absorption Spectrum 190
- 13.3** Preparing a Karyotype 250
- 14.2** Crossing Pea Plants 263
- 14.7** The Testcross 267
- 15.11** Constructing a Linkage Map 296
- 20.4** Cloning Genes in Bacterial Plasmids 399
- 20.7** Detecting a Specific DNA Sequence by Hybridization with a Nucleic Acid Probe 402
- 20.8** The Polymerase Chain Reaction (PCR) 404
- 20.9** Gel Electrophoresis 405
- 20.11** Southern Blotting of DNA Fragments 407
- 20.12** Dideoxy Chain Termination Method for Sequencing DNA 408
- 20.13** RT-PCR Analysis of the Expression of Single Genes 409
- 20.15** DNA Microarray Assay of Gene Expression Levels 411
- 20.19** Reproductive Cloning of a Mammal by Nuclear Transplantation 414
- 20.26** Using the Ti Plasmid to Produce Transgenic Plants 422
- 26.15** Applying Parsimony to a Problem in Molecular Systematics 546
- 35.21** Using Dendrochronology to Study Climate 753
- 37.7** Hydroponic Culture 790
- 48.9** Intracellular Recording 1050
- 53.2** Determining Population Size Using the Mark-Recapture Method 1171
- 54.11** Determining Microbial Diversity Using Molecular Tools 1201
- 55.5** Determining Primary Production with Satellites 1221

# Interviews

UNIT

1



**The Chemistry of Life** 28

**Susan Solomon**

National Oceanic and  
Atmospheric Administration,  
Boulder, Colorado

UNIT

5



**The Evolutionary History  
of Biological Diversity** 534

**W. Ford  
Doolittle**

Dalhousie University, Canada

UNIT

2



**The Cell** 92

**Bonnie L.  
Bassler**

Princeton University

UNIT

6



**Plant Form  
and Function** 736

**Luis Herrera-  
Estrella**

National Polytechnic  
Institute, Mexico

UNIT

3



**Genetics** 246

**Joan A. Steitz**

Yale University

UNIT

7



**Animal Form  
and Function** 850

**Baldomero M.  
Olivera**

University of Utah

UNIT

4



**Mechanisms  
of Evolution** 450

**Geerat J.  
Vermeij**

University of California, Davis

UNIT

8



**Ecology** 1142

**Camille  
Parmesan**

University of Texas, Austin

# Acknowledgments

The authors wish to express their gratitude to the global community of instructors, researchers, students, and publishing professionals who have contributed to this edition.

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 edition 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: John Archibald, John Armour, Kristian Axelsen, Scott Bowling, Barbara Bowman, Andy Cameron, Scott Carroll, Amy Cheng-Vollmer, Michele Clamp, David DeRosier, Doug DeSimone, Binh An Diep, David Ehrhardt, Robert Fowler, Peter Fraser, Matt Friedman, Tom Gingeras, Anita Gondor, Ken Halanych, Jeff Hardin, Catherine Hurlbut, Adam Johnson, Dale Kaiser, Patrick Keeling, Emir Khatipov, Chris Killian, Andrew Knoll, Nikos Kyrpides, Teri Liegler, Zhe-Xi Luo, Kent MacDonald, Nick Matzke, Melissa Michael, Nadia Naffakh, Rolf Ohlsson, Aharon Oren, Tom Owens, Kevin Padian, Nathalie Pardigon, Bruce Pavlik, Kevin J. Peterson, Michael Pollock, Rebekah Rasooly, Andrew Roger, Ole Seehausen, Alastair Simpson, Betty Smocovitis, Frank Solomon, Pam Soltis, Hans Thewissen, Mark Uhen, Vance Vredenburg, Elisabeth Wade, Phil Zamore, and Christine Zardecki. In addition, a total of 168 biologists, listed on pages xxvi–xxvii, provided detailed reviews of chapters for this edition, helping us ensure the book's scientific accuracy and improve its pedagogical effectiveness. And finally, we thank Marty Taylor, author of all nine editions of the *Student Study Guide*, for her many contributions to the accuracy, clarity, and consistency of the book.

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

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 Susan Solomon, Bonnie Bassler, Joan Steitz, Geerat Vermeij, Ford Doolittle, Luis Herrera-Estrella, Toto Olivera, and Camille Parmesan.

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 much appreciate the hard work and creativity of all the authors listed, with their creations, on pages xx–xxi. In addition, we are grateful to Joan Sharp (*Lecture Outlines*, *Learning Objectives*, and *Student Misconceptions*) and Erin Barley and Kathleen Fitzpatrick (*PowerPoint® Lectures*).

The electronic media for this text are invaluable teaching and learning aids. We thank the hardworking and creative authors of the new material for this edition: Tom Owens, Joan Sharp, and Jennifer Yeh (*MasteringBiology®*); Richard Cowlshaw, Tod Duncan, and Stephanie Pandolfi (*Study Area Practice Tests*); and Eric Simon (*VideoTutors*). And we thank Brian White for his work. Also, we are grateful to the many other people—biology instructors, editors, artists, production experts, and narrators—who are listed in the credits for these and other elements of the electronic media that accompany the book. And we thank the reviewers and class testers of BioFlix® and MasteringBiology.

*CAMPBELL BIOLOGY*, Ninth Edition, results from an unusually strong synergy between a team of scientists and a team of publishing

professionals. Our editorial team at Benjamin Cummings again demonstrated unmatched talents, commitment, and pedagogical insights. Our new Acquisitions Editor, Josh Frost, 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 Pat Burner and Beth Winickoff, who headed the top-notch development team: Developmental Editors John Burner, Matt Lee, and Mary Catherine Hager; and Developmental Artists Hilair Chism, Carla Simmons, Andrew Recher, and Jay McElroy. Our unsurpassed Senior Editorial Manager Ginnie Simone Jutson, Executive Director of Development Deborah Gale, Assistant Editor Logan Triglia, and Editor-in-Chief 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.

You would not have this beautiful book in your hands today if not for the work of the book production team: Executive Managing Editor Erin Gregg; Managing Editor Michael Early; Senior Production Project Manager Shannon Tozier; Senior Photo Editor Donna Kalal; Photo Researcher Maureen Spuhler; Copy Editor Janet Greenblatt; Art Editor Laura Murray; Proofreaders Joanna Dinsmore and Pete Shanks; Permissions Editors Sue Ewing and Beth Keister; Senior Project Editor Emily Bush, S4Carlisle; Composition Manager Holly Paige, S4Carlisle; Art Production Manager Kristina Seymour, Precision Graphics; Design Director Mark Ong; Designer Gary Hespeneide; and Manufacturing Buyer Michael Penne. We also thank those who worked on the book's supplements: Susan Berge, Nina Lewallen Hufford, Brady Golden, Jane Brundage, James Bruce, and John Hammett. And for creating the wonderful package of electronic media that accompanies the book, we are grateful to Tania Mlawer, Director of Editorial Content for MasteringBiology, and Jonathan Ballard, Deb Greco, Sarah Jensen, Mary Catherine Hager, Alice Fugate, Juliana Tringali, Josh Gentry, Steve Wright, Kristen Sutton, Katie Foley, Karen Sheh, and David Kokorowski, as well as Director of Media Development Lauren Fogel and Director of Media Strategy Stacy Treco.

For their important roles in marketing the book, we thank Christy Lawrence, Lauren Harp, Scott Dustan, Lillian Carr, Jane Campbell, Jessica Perry, Nora Massuda, and Jessica Tree.

We are grateful to Linda Davis, President of Pearson Math and Science, who has shared our commitment to excellence and provided strong support for five editions now. Moreover, we thank Paul Corey, President of Pearson Benjamin Cummings, and Editorial Director Frank Ruggirello for their enthusiasm, encouragement, and support.

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 book, communicate the features of the book, and provide prompt service. We thank them for their hard work and professionalism. For representing our book 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 Paul, Dan, Maria, Armelle, and Sean (J.B.R.); Lily, Ross, Lily-too, and Alex (L.A.U.); Debra and Hannah (M.L.C.); Harry, Elga, Aaron, Sophie, Noah, and Gabriele (S.A.W.); Natalie (P.V.M.); and Sally, Robert, David, and Will (R.B.J.). And, as always, thanks to Rochelle, Allison, Jason, and McKay.

Jane Reece, Lisa Urry, Michael Cain,  
Steve Wasserman, Peter Minorsky, and Rob Jackson



# Reviewers

## Ninth Edition Reviewers

Ann Aguanno, *Marymount Manhattan College*  
Marc Albrecht, *University of Nebraska*  
John Alcock, *Arizona State University*  
Eric Alcorn, *Acadia University*  
Terry Austin, *Temple College*  
Brian Bagatto, *University of Akron*  
Virginia Baker, *Chipola College*  
Bonnie Baxter, *Westminster College*  
Marilee Benore, *University of Michigan, Dearborn*  
Catherine Black, *Idaho State University*  
William Blaker, *Furman University*  
Edward Blumenthal, *Marquette University*  
David Bos, *Purdue University*  
Scott Bowling, *Auburn University*  
Beth Burch, *Huntington University*  
Ragan Callaway, *The University of Montana*  
Kenneth M. Cameron, *University of Wisconsin, Madison*  
Patrick Canary, *Northland Pioneer College*  
Cheryl Keller Capone, *Pennsylvania State University*  
Karen I. Champ, *Central Florida Community College*  
David Champlin, *University of Southern Maine*  
Brad Chandler, *Palo Alto College*  
Wei-Jen Chang, *Hamilton College*  
Jung Choi, *Georgia Institute of Technology*  
Steve Christensen, *Brigham Young University, Idaho*  
James T. Colbert, *Iowa State University*  
William Cushwa, *Clark College*  
Shannon Datwyler, *California State University, Sacramento*  
Eugene Delay, *University of Vermont*  
Daniel DerVartanian, *University of Georgia*  
Janet De Souza-Hart, *Massachusetts College of Pharmacy & Health Sciences*  
Kathryn A. Durham, *Lorain Community College*  
Curt Elderkin, *College of New Jersey*  
Mary Ellard-Ivey, *Pacific Lutheran University*  
George Ellmore, *Tufts University*  
Robert C. Evans, *Rutgers University, Camden*  
Sam Fan, *Bradley University*  
Paul Farnsworth, *University of New Mexico*  
Myriam Alhadeff Feldman, *Cascadia Community College*  
Teresa Fischer, *Indian River Community College*  
David Fitch, *New York University*  
T. Fleming, *Bradley University*  
Robert Fowler, *San Jose State University*  
Robert Franklin, *College of Charleston*  
Art Fredeen, *University of Northern British Columbia*  
Matt Friedman, *University of Chicago*  
Cynthia M. Galloway, *Texas A&M University, Kingsville*  
Simon Gilroy, *University of Wisconsin, Madison*  
Jim Goetze, *Laredo Community College*  
Lynda Goff, *University of California, Santa Cruz*  
Roy Golsteyn, *University of Lethbridge*  
Barbara E. Goodman, *University of South Dakota*  
David Grise, *Texas A&M University, Corpus Christi*  
Devney Hamilton, *Stanford University (student)*  
Matthew B. Hamilton, *Georgetown University*  
Jeanne M. Harris, *University of Vermont*  
Stephanie Harvey, *Georgia Southwestern State University*  
Bernard Hauser, *University of Florida*  
Andreas Hejnol, *Sars International Centre for Marine Molecular Biology*  
Jason Hodin, *Stanford University*  
Sara Huang, *Los Angeles Valley College*  
Catherine Hurlbut, *Florida State College, Jacksonville*  
Diane Husic, *Moravian College*  
Thomas Jacobs, *University of Illinois*  
Mark Jaffe, *Nova Southeastern University*  
Douglas Jensen, *Converse College*  
Lance Johnson, *Midland Lutheran College*  
Cheryl Jorcyk, *Boise State University*  
Caroline Kane, *University of California, Berkeley*  
Jennifer Katcher, *Pima Community College*  
Eric G. Keeling, *Cary Institute of Ecosystem Studies*  
Chris Kennedy, *Simon Fraser University*  
Hillar Klandorf, *West Virginia University*  
Mark Knauss, *Georgia Highlands College*

Roger Koepp, *University of Arkansas*  
Peter Kourtev, *Central Michigan University*  
Eliot Krause, *Seton Hall University*  
Steven Kristoff, *Ivy Tech Community College*  
William Kroll, *Loyola University*  
Rukmani Kuppaswami, *Laredo Community College*  
Lee Kurtz, *Georgia Gwinnett College*  
Michael P. Labare, *United States Military Academy, West Point*  
Ellen Lamb, *University of North Carolina, Greensboro*  
William Lamberts, *College of St Benedict and St John's University*  
Tali D. Lee, *University of Wisconsin, Eau Claire*  
Hugh Lefcort, *Gonzaga University*  
Alcinda Lewis, *University of Colorado, Boulder*  
Graeme Lindbeck, *Valencia Community College*  
Hannah Lui, *University of California, Irvine*  
Cindy Malone, *California State University, Northridge*  
Julia Marrs, *Barnard College (student)*  
Kathleen Marrs, *Indiana University-Purdue University, Indianapolis*  
Mike Mayfield, *Ball State University*  
Kamau Mbutia, *Bowling Green State University*  
Tanya McGhee, *Craven Community College*  
Darcy Medica, *Pennsylvania State University*  
Susan Meiers, *Western Illinois University*  
Alex Mills, *University of Windsor*  
Eli Minkoff, *Bates College*  
Subhash Minocha, *University of New Hampshire*  
Ivona Mladenovic, *Simon Fraser University*  
Courtney Murren, *College of Charleston*  
Kimberlyn Nelson, *Pennsylvania State University*  
Jacalyn Newman, *University of Pittsburgh*  
Kathleen Nolte, *University of Michigan*  
Aharon Oren, *The Hebrew University*  
Henry R. Owen, *Eastern Illinois University*  
Stephanie Pandolfi, *Michigan State University*  
Nathalie Pardigon, *Institut Pasteur*  
Cindy Paszkowski, *University of Alberta*  
Andrew Pease, *Stevenson University*  
Nancy Pelaez, *Purdue University*  
Irene Perry, *University of Texas of the Permian Basin*  
Roger Persell, *Hunter College*  
Mark Pilgrim, *College of Coastal Georgia*  
Vera M. Piper, *Shenandoah University*  
Crima Pogge, *City College of San Francisco*  
Michael Pollock, *Mount Royal University*  
Roberta Pollock, *Occidental College*  
Therese M. Poole, *Georgia State University*  
Angela R. Porta, *Kean University*  
Robert Powell, *Avila University*  
Elena Pravosudova, *University of Nevada, Reno*  
Terrell Pritts, *University of Arkansas, Little Rock*  
Monica Ranes-Goldberg, *University of California, Berkeley*  
Robert S. Rawding, *Gannon University*  
Sarah Richart, *Azusa Pacific University*  
Kenneth Robinson, *Purdue University*  
Heather Roffey, *Marianopolis College*  
Patricia Rugaber, *College of Coastal Georgia*  
Scott Russell, *University of Oklahoma*  
Louis Santiago, *University of California, Riverside*  
Tom Sawicki, *Spartanburg Community College*  
Thomas W. Schoener, *University of California, Davis*  
Patricia Schulte, *University of British Columbia*  
Brenda Schumpert, *Valencia Community College*  
David Schwartz, *Houston Community College*  
Brent Selinger, *University of Lethbridge*  
Alison M. Shakarian, *Salve Regina University*  
Robin L. Sherman, *Nova Southeastern University*  
Sedonia Sipes, *Southern Illinois University, Carbondale*  
Joel Stafstrom, *Northern Illinois University*  
Alam Stam, *Capital University*  
Judy Stone, *Colby College*  
Cynthia Surmacz, *Bloomsburg University*  
David Tam, *University of North Texas*  
Yves Tan, *Cabrillo College*  
Emily Taylor, *California Polytechnic State University*  
Franklyn Tan Te, *Miami Dade College*  
Kent Thomas, *Wichita State University*



Saba Valadkhan, *Center for RNA Molecular Biology*  
 Sarah VanVickle-Chavez, *Washington University, St. Louis*  
 William Velhagen, *New York University*  
 Janice Voltzow, *University of Scranton*  
 Margaret Voss, *Penn State Erie*  
 Charles Wade, *C.S. Mott Community College*  
 Claire Walczak, *Indiana University*  
 Jerry Waldvogel, *Clemson University*  
 Robert Lee Wallace, *Ripon College*  
 Fred Wasserman, *Boston University*  
 John Weishampel, *University of Central Florida*  
 Susan Whittemore, *Keene State College*  
 Janet Wolkenstein, *Hudson Valley Community College*  
 Grace Wyngaard, *James Madison University*  
 Paul Yancey, *Whitman College*  
 Anne D. Yoder, *Duke University*  
 Nina Zanetti, *Siena College*  
 Sam Zeveloff, *Weber State University*  
 Theresa Zuccherro, *Methodist University*

## Reviewers of Previous Editions

Kenneth Able (*State University of New York, Albany*)  
 Thomas Adams (*Michigan State University*)  
 Martin Adamson (*University of British Columbia*)  
 Dominique Adriaens (*Ghent University*)  
 Shylaja Akkaraju (*Bronx Community College of CUNY*)  
 John Alcock (*Arizona State University*)  
 George R. Aliaga (*Tarrant County College*)  
 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*)  
 P. Stephen Baenziger (*University of Nebraska*)  
 Ellen Baker (*Santa Monica College*)  
 Katherine Baker (*Millersville University*)  
 William Barklow (*Framingham State College*)  
 Susan Barman (*Michigan State University*)  
 Steven Barnhart (*Santa Rosa Junior College*)  
 Andrew Barton (*University of Maine Farmington*)  
 Rebecca A. Bartow (*Western Kentucky University*)  
 Ron Basmajian (*Merced College*)  
 David Bass (*University of Central Oklahoma*)  
 Bonnie Baxter (*Hobart & William Smith Colleges*)  
 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.*)  
 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*)  
 Dorothy Berner (*Temple University*)  
 Annalisa Berta (*San Diego State University*)  
 Paulette Bierzychudek (*Pomona College*)  
 Charles Biggers (*Memphis State University*)  
 Kenneth Birnbaum (*New York University*)  
 Michael W. Black (*California Polytechnic State University, San Luis Obispo*)  
 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*)  
 Oliver Bossdorf (*State University of New York, Stony Brook*)  
 James L. Botsford (*New Mexico State University*)  
 Lisa Boucher (*University of Nebraska, Omaha*)  
 J. Michael Bowes (*Humboldt State University*)  
 Richard Bowker (*Alma College*)  
 Robert Bowker (*Glendale Community College, Arizona*)  
 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*)  
 Danny Brower (*University of Arizona*)  
 Carole Browne (*Wake Forest University*)  
 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*)  
 Al Burchsted (*College of Staten Island*)  
 Meg Burke (*University of North Dakota*)  
 Edwin Burling (*De Anza College*)  
 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*)  
 Guy A. Caldwell (*University of Alabama*)  
 Jane Caldwell (*West Virginia University*)  
 Kim A. Caldwell (*University of Alabama*)  
 R. Andrew Cameron (*California Institute of Technology*)  
 Alison Campbell (*University of Waikato*)  
 Iain Campbell (*University of Pittsburgh*)  
 W. Zacheus Cande (*University of California, Berkeley*)  
 Robert E. Cannon (*University of North Carolina, Greensboro*)  
 Deborah Canington (*University of California, Davis*)  
 Frank Cantelmo (*St. John's University*)  
 John Capeheart (*University of Houston, Downtown*)  
 Gregory Capelli (*College of William and Mary*)  
 Richard Cardullo (*University of California, Riverside*)  
 Nina Caris (*Texas A&M University*)  
 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*)  
 David Champlin (*University of Southern Maine*)  
 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*)  
 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*)  
 William P. Coffman (*University of Pittsburgh*)  
 Austin Randy Cohen (*California State University, Northridge*)  
 J. John Cohen (*University of Colorado Health Science Center*)  
 Jim Colbert (*Iowa State University*)  
 Jan Colpaert (*Hasselt University*)

Robert Colvin (*Ohio University*)  
 Jay Comeaux (*McNeese State University*)  
 David Cone (*Saint Mary's University*)  
 Elizabeth Connor (*University of Massachusetts*)  
 Joanne Conover (*University of Connecticut*)  
 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*)  
 Anne Cusic (*University of Alabama, Birmingham*)  
 Richard Cyr (*Pennsylvania State University*)  
 Marymegan Daly (*The Ohio State University*)  
 W. Marshall Darley (*University of Georgia*)  
 Cynthia Dassler (*The Ohio State University*)  
 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*)  
 John Dearn (*University of Canberra*)  
 Maria E. de Bellard (*California State University, Northridge*)  
 Teresa DeGolier (*Bethel College*)  
 James Dekloe (*University of California, Santa Cruz*)  
 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*)  
 Daniel Dervartanian (*University of Georgia*)  
 Jean DeSaix (*University of North Carolina, Chapel Hill*)  
 Biao Ding (*Ohio State University*)  
 Michael Dini (*Texas Tech University*)  
 Andrew Dobson (*Princeton University*)  
 Stanley Dodson (*University of Wisconsin, Madison*)  
 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*)  
 Susan Dunford (*University of Cincinnati*)  
 Betsey Dyer (*Wheaton College*)  
 Robert Eaton (*University of Colorado*)  
 Robert S. Edgar (*University of California, Santa Cruz*)  
 Douglas J. Eernisse (*California State University, Fullerton*)  
 Betty J. Eidemiller (*Lamar University*)  
 Brad Elder (*Doane College*)  
 William D. Eldred (*Boston University*)  
 Michelle Elekonich (*University of Nevada, Las Vegas*)  
 Mary Ellard-Ivey (*Pacific Lutheran University*)  
 Norman Ellstrand (*University of California, Riverside*)  
 Johnny El-Rady (*University of South Florida*)  
 Dennis Emery (*Iowa State University*)  
 John Endler (*University of California, Santa Barbara*)  
 Margaret T. Erskine (*Lansing Community College*)  
 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*)  
 Lynn Fancher (*College of DuPage*)  
 Ellen H. Fanning (*Vanderbilt University*)  
 Paul Farnsworth (*University of Texas, San Antonio*)  
 Larry Farrell (*Idaho State University*)  
 Jerry F. Feldman (*University of California, Santa Cruz*)  
 Lewis Feldman (*University of California, Berkeley*)  
 Eugene Fenster (*Longview Community College*)  
 Russell Fernald (*University of Oregon*)  
 Rebecca Ferrell (*Metropolitan State College of Denver*)  
 Kim Finer (*Kent State University*)  
 Milton Fingerma (*Tulane University*)  
 Barbara Finney (*Regis 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*)  
 Kirk Fitzhugh (*Natural History Museum of Los Angeles County*)  
 Lloyd Fitzpatrick (*University of North Texas*)  
 William Fixsen (*Harvard University*)  
 Abraham Flexer (*Manuscript Consultant, Boulder, Colorado*)  
 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*)  
 James Franzen (*University of Pittsburgh*)  
 Bill Freedman (*Dalhousie University*)  
 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*)  
 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*)  
 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 (*Agnes Scott College*)  
 Frank Gilliam (*Marshall University*)  
 Simon Gilroy (*Pennsylvania State University*)  
 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*)  
 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*)  
 Anne Good (*University of California, Berkeley*)  
 Judith Goodenough (*University of Massachusetts, Amherst*)  
 Wayne Goodey (*University of British Columbia*)  
 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*)  
 Phyllis Griffard (*University of Houston, Downtown*)  
 A. J. F. Griffiths (*University of British Columbia*)  
 William Grimes (*University of Arizona*)  
 Mark Gromko (*Bowling Green State University*)  
 Serine Gropper (*Auburn University*)  
 Katherine L. Gross (*Ohio State University*)  
 Gary Gussin (*University of Iowa*)  
 Mark Guyer (*National Human Genome Research Institute*)  
 Ruth Levy Guyer (*Bethesda, Maryland*)  
 R. Wayne Habermehl (*Montgomery County Community College*)  
 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*)  
 Douglas Hallett (*Northern Arizona University*)  
 Rebecca Halyard (*Clayton State College*)  
 E. William Hamilton (*Washington and Lee University*)  
 Sam Hammer (*Boston University*)  
 Penny Hanchey-Bauer (*Colorado State University*)  
 William F. Hanna (*Massasoit Community College*)

Laszlo Hanzely (*Northern Illinois University*)  
 Jeff Hardin (*University of Wisconsin, Madison*)  
 Lisa Harper (*University of California, Berkeley*)  
 Richard Harrison (*Cornell 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*)  
 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*)  
 David Hibbett (*Clark University*)  
 R. James Hickey (*Miami 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*)  
 James Hoffman (*University of Vermont*)  
 A. Scott Holaday (*Texas Tech University*)  
 N. Michele Holbrook (*Harvard University*)  
 James Holland (*Indiana State University, Bloomington*)  
 Charles Holliday (*Lafayette College*)  
 Lubbock Karl Holte (*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*)  
 Daniel J. Howard (*New Mexico State University*)  
 Ronald R. Hoy (*Cornell University*)  
 Cristin Hulslander (*University of Oregon*)  
 Donald Humphrey (*Emory University School of Medicine*)  
 Robert J. Huskey (*University of Virginia*)  
 Steven Hutcheson (*University of Maryland, College Park*)  
 Sandra Hsu (*Skyline College*)  
 Linda L. Hyde (*Gordon College*)  
 Bradley Hyman (*University of California, Riverside*)  
 Mark Iked (*San Bernardino Valley College*)  
 Jeffrey Ihara (*Mira Costa College*)  
 Cheryl Ingram-Smith (*Clemson University*)  
 Alice Jacklet (*State University of New York, Albany*)  
 John Jackson (*North Hennepin Community College*)  
 John C. Jahoda (*Bridgewater State College*)  
 Dan Johnson (*East Tennessee State University*)  
 Lee Johnson (*The Ohio State University*)  
 Randall Johnson (*University of California, San Diego*)  
 Stephen Johnson (*William Penn University*)  
 Wayne Johnson (*Ohio State University*)  
 Kenneth C. Jones (*California State University, Northridge*)  
 Russell Jones (*University of California, Berkeley*)  
 Chad Jordan (*North Carolina State University*)  
 Alan Journet (*Southeast Missouri State University*)  
 Walter Judd (*University of Florida*)  
 Thomas W. Jurik (*Iowa State University*)  
 Caroline M. Kane (*University of California, Berkeley*)  
 Thomas C. Kane (*University of Cincinnati*)  
 Tamos Kapros (*University of Missouri*)  
 E. L. Karlstrom (*University of Puget Sound*)  
 Jennifer Katcher (*Pima Community College*)  
 Laura A. Katz (*Smith College*)  
 Maureen Kearney (*Field Museum of Natural History*)  
 Patrick Keeling (*University of British Columbia*)  
 Elizabeth A. Kellogg (*University of Missouri, St. Louis*)  
 Norm Kenkel (*University of Manitoba*)  
 Chris Kennedy (*Simon Fraser University*)  
 George Khoury (*National Cancer Institute*)  
 Rebecca T. Kimball (*University of Florida*)  
 Mark Kirk (*University of Missouri, Columbia*)  
 Robert Kitchin (*University of Wyoming*)  
 Attila O. Klein (*Brandeis University*)  
 Daniel Klionsky (*University of Michigan*)  
 Jennifer Knight (*University of Colorado*)  
 Ned Knight (*Linfield College*)  
 David Kohl (*University of California, Santa Barbara*)  
 Greg Kopf (*University of Pennsylvania School of Medicine*)  
 Thomas Koppenheffer (*Trinity University*)  
 Margareta Krabbe (*Uppsala University*)  
 Anselm Kratochwil (*Universität Osnabrück*)  
 Deborah M. Kristan (*California State University, San Marcos*)  
 William Kroll (*Loyola University, Chicago*)  
 Janis Kuby (*San Francisco State University*)  
 Justin P. Kumar (*Indiana University*)  
 David Kurijaka (*Ohio University*)  
 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*)  
 Lynn Lamoreux (*Texas A&M University*)  
 William L'Amoreaux (*College of Staten Island*)  
 Carmine A. Lanciani (*University of Florida*)  
 Kenneth Lang (*Humboldt State University*)  
 Dominic Lannutti (*El Paso Community College*)  
 Allan Larson (*Washington University*)  
 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*)  
 Robert Leonard (*University of California, Riverside*)  
 Michael R. Leonardo (*Coe College*)  
 John Lepri (*University of North Carolina, Greensboro*)  
 Donald Levin (*University of Texas, Austin*)  
 Mike Levine (*University of California, Berkeley*)  
 Joseph Levine (*Boston College*)  
 Bill Lewis (*Shoreline Community College*)  
 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*)  
 Diana Lipscomb (*George Washington University*)  
 Christopher Little (*The University of Texas, Pan American*)  
 Kevin D. Livingstone (*Trinity University*)  
 Andrea Lloyd (*Middlebury College*)  
 Sam Loker (*University of New Mexico*)  
 Christopher A. Loretz (*State University of New York, Buffalo*)  
 Jane Lubchenco (*Oregon State University*)  
 Douglas B. Luckie (*Michigan State University*)  
 Margaret A. Lynch (*Tufts University*)  
 Steven Lynch (*Louisiana State University, Shreveport*)  
 Richard Machemer Jr. (*St. John Fisher College*)  
 Elizabeth Machunis-Masuoka (*University of Virginia*)  
 James MacMahon (*Utah State 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*)  
 Carol Mapes (*Kutztown University of Pennsylvania*)  
 William Margolin (*University of Texas Medical School*)  
 Lynn Margulis (*Boston University*)  
 Kathleen A. Marrs (*Indiana University-Purdue University, Indianapolis*)  
 Edith Marsh (*Angelo State University*)  
 Diane L. Marshall (*University of New Mexico*)  
 Linda Martin Morris (*University of Washington*)  
 Karl Mattox (*Miami University of Ohio*)  
 Joyce Maxwell (*California State University, Northridge*)  
 Jeffrey D. May (*Marshall University*)  
 Lee McClenaghan (*San Diego State University*)  
 Richard McCracken (*Purdue University*)  
 Andrew McCubbin (*Washington State University*)  
 Kerry McDonald (*University of Missouri, Columbia*)  
 Jacqueline McLaughlin (*Pennsylvania State University, Lehigh Valley*)  
 Neal McReynolds (*Texas A&M International*)



Lisa Marie Meffert (*Rice 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*)  
 Ralph Meyer (*University of Cincinnati*)  
 James Mickle (*North Carolina State University*)  
 Roger Milkman (*University of Iowa*)  
 Helen Miller (*Oklahoma State University*)  
 John Miller (*University of California, Berkeley*)  
 Kenneth R. Miller (*Brown University*)  
 John E. Minnich (*University of Wisconsin, Milwaukee*)  
 Michael J. Misamore (*Texas Christian University*)  
 Kenneth Mitchell (*Tulane University School of Medicine*)  
 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*)  
 Randy Moore (*Wright State University*)  
 William Moore (*Wayne State University*)  
 Carl Moos (*Veterans Administration Hospital, Albany, New York*)  
 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*)  
 John Mutchmor (*Iowa State University*)  
 Elliot Myerowitz (*California Institute of Technology*)  
 Gavin Naylor (*Iowa State University*)  
 John Neess (*University of Wisconsin, Madison*)  
 Tom Neils (*Grand Rapids Community College*)  
 Raymond Neubauer (*University of Texas, Austin*)  
 Todd Newbury (*University of California, Santa Cruz*)  
 James Newcomb (*New England College*)  
 Harvey Nichols (*University of Colorado, Boulder*)  
 Deborah Nickerson (*University of South Florida*)  
 Bette Nicotri (*University of Washington*)  
 Caroline Niederman (*Tomball College*)  
 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*)  
 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*)  
 Nathan O. Okia (*Auburn University, Montgomery*)  
 Jeanette Oliver (*St. Louis Community College, Florissant Valley*)  
 Gary P. Olivetti (*University of Vermont*)  
 John Olsen (*Rhodes College*)  
 Laura J. Olsen (*University of Michigan*)  
 Sharman O'Neill (*University of California, Davis*)  
 Wan Ooi (*Houston Community College*)  
 John Oross (*University of California, Riverside*)  
 Gay Ostarello (*Diablo Valley College*)  
 Catherine Ortega (*Fort Lewis College*)  
 Charissa Osborne (*Butler 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*)  
 Barry Palevitz (*University of Georgia*)  
 Michael A. Palladino (*Monmouth University*)  
 Daniel Papaj (*University of Arizona*)  
 Peter Pappas (*County College of Morris*)  
 Bulah Parker (*North Carolina State University*)  
 Stanton Parmeter (*Chemeketa Community College*)  
 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*)  
 Shelley Penrod (*North Harris College*)  
 Imara Y. Perera (*North Carolina State University*)  
 Beverly Perry (*Houston Community College*)  
 David Pfennig (*University of North Carolina, Chapel Hill*)  
 David S. Pilliod (*California Polytechnic State University, San Luis Obispo*)  
 J. Chris Pires (*University of Missouri, Columbia*)  
 Bob Pittman (*Michigan State University*)  
 James Platt (*University of Denver*)  
 Martin Poenie (*University of Texas, Austin*)  
 Scott Poethig (*University of Pennsylvania*)  
 Jeffrey Pommerville (*Texas A&M University*)  
 Angela R. Porta (*Kean University*)  
 Warren Porter (*University of Wisconsin*)  
 Daniel Potter (*University of California, Davis*)  
 Donald Potts (*University of California, Santa Cruz*)  
 Andy Pratt (*University of Canterbury*)  
 David Pratt (*University of California, Davis*)  
 Halina Presley (*University of Illinois, Chicago*)  
 Mary V. Price (*University of California, Riverside*)  
 Mitch Price (*Pennsylvania State University*)  
 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*)  
 Talitha Rajah (*Indiana University Southeast*)  
 Charles Ralph (*Colorado State University*)  
 Thomas Rand (*Saint Mary's 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*)  
 Douglas Rhoads (*University of Arkansas*)  
 Fred Rhoades (*Western Washington State University*)  
 Eric Ribbens (*Western Illinois University*)  
 Christina Richards (*New York University*)  
 Christopher Riegler (*Irvine Valley College*)  
 Loren Rieseberg (*University of British Columbia*)  
 Bruce B. Riley (*Texas A&M University*)  
 Donna Ritch (*Pennsylvania State University*)  
 Carol Rivin (*Oregon State University East*)  
 Laurel Roberts (*University of Pittsburgh*)  
 Thomas Rodella (*Merced College*)  
 Rodney Rogers (*Drake University*)  
 William Roosenburg (*Ohio University*)  
 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*)  
 Neil Sabine (*Indiana University*)  
 Tyson Sacco (*Cornell University*)  
 Rowan F. Sage (*University of Toronto*)  
 Tammy Lynn Sage (*University of Toronto*)  
 Don Sakaguchi (*Iowa State University*)  
 Walter Sakai (*Santa Monica College*)  
 Mark F. Sanders (*University of California, Davis*)  
 Ted Sargent (*University of Massachusetts, Amherst*)  
 K. Sathasivan (*University of Texas, Austin*)  
 Gary Saunders (*University of New Brunswick*)  
 Thomas R. Sawicki (*Spartanburg Community College*)  
 Inder Saxena (*University of Texas, Austin*)  
 Carl Schaefer (*University of Connecticut*)  
 Maynard H. Schaus (*Virginia Wesleyan College*)



Renate Scheibe (*University of Osnabrück*)  
 David Schimpf (*University of Minnesota, Duluth*)  
 William H. Schlesinger (*Duke University*)  
 Mark Schlissel (*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*)  
 David J. Schwartz (*Houston Community College*)  
 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*)  
 Orono Shukdeb Sen (*Bethune-Cookman College*)  
 Wendy Sera (*Seton Hill University*)  
 Timothy E. Shannon (*Francis Marion University*)  
 Joan Sharp (*Simon Fraser University*)  
 Victoria C. Sharpe (*Blinn College*)  
 Elaine Shea (*Loyola College, Maryland*)  
 Stephen Sheckler (*Virginia Polytechnic Institute and State University*)  
 Richard Sherwin (*University of Pittsburgh*)  
 Lisa Shimeld (*Crafton Hills College*)  
 James Shinkle (*Trinity University*)  
 Barbara Shipes (*Hampton University*)  
 Richard M. Showman (*University of South Carolina*)  
 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*)  
 Roger Sloboda (*Dartmouth University*)  
 John Smarrelli (*Le Moyne 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. Snopce (*Essex Community College*)  
 Julio G. Soto (*San Jose State University*)  
 Mitchell Sogin (*Woods Hole Marine Biological Laboratory*)  
 Susan Sovonick-Dunford (*University of Cincinnati*)  
 Frederick W. Spiegel (*University of Arkansas*)  
 John Stachowicz (*University of California, Davis*)  
 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*)  
 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 (*University of Michigan, Flint*)  
 John Sullivan (*Southern Oregon State University*)  
 Gerald Summers (*University of Missouri*)  
 Judith Sumner (*Assumption College*)  
 Marshall D. Sundberg (*Emporia State University*)  
 Lucinda Swatzell (*Southeast Missouri State University*)  
 Daryl Sweeney (*University of Illinois, Champaign-Urbana*)  
 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*)  
 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*)  
 Martha R. Taylor (*Cornell University*)  
 Thomas Terry (*University of Connecticut*)  
 Roger Thibault (*Bowling Green State University*)  
 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*)  
 Eric Toolson (*University of New Mexico*)  
 Leslie Towill (*Arizona State University*)  
 James Traniello (*Boston University*)  
 Paul Q. Trombley (*Florida State University*)  
 Nancy J. Trun (*Duquesne University*)  
 Constantine Tsoukas (*San Diego State University*)  
 Marsha Turell (*Houston Community College*)  
 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 (*Case Western Reserve University School of Medicine*)  
 James W. Valentine (*University of California, Santa Barbara*)  
 Joseph Venable (*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*)  
 Steven D. Verhey (*Central Washington University*)  
 Kathleen Verville (*Washington College*)  
 Sara Via (*University of Maryland*)  
 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*)  
 Susan D. Waaland (*University of Washington*)  
 William Wade (*Dartmouth Medical College*)  
 D. Alexander Wait (*Southwest Missouri State University*)  
 John Waggoner (*Loyola Marymount University*)  
 Jyoti Wagle (*Houston Community College*)  
 Edward Wagner (*University of California, Irvine*)  
 Dan Walker (*San Jose State University*)  
 Robert L. Wallace (*Ripon College*)  
 Jeffrey Walters (*North Carolina State University*)  
 Linda Walters (*University of Central Florida*)  
 Nickolas M. Waser (*University of California, Riverside*)  
 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*)  
 Andrea Weeks (*George Mason University*)  
 Peter Wejksnora (*University of Wisconsin, Milwaukee*)  
 Kentwood Wells (*University of Connecticut*)  
 David J. Westenberg (*University of Missouri, Rolla*)  
 Richard Wetts (*University of California, Irvine*)  
 Matt White (*Ohio University*)  
 Ernest H. Williams (*Hamilton College*)  
 Kathy Williams (*San Diego 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*)  
 Susan Whittemore (*Keene State College*)  
 Clarence Wolfe (*Northern Virginia Community College*)  
 Vickie L. Wolfe (*Marshall University*)  
 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*)  
 Ramin Yadegari (*University of Arizona*)  
 Paul Yancey (*Whitman College*)  
 Philip Yant (*University of Michigan*)  
 Linda Yasui (*Northern Illinois University*)  
 Hideo Yonenaka (*San Francisco State University*)  
 Gina M. Zainelli (*Loyola University, Chicago*)  
 Edward Zalisko (*Blackburn College*)  
 Zai Ming Zhao (*University of Texas, Austin*)  
 John Zimmerman (*Kansas State University*)  
 Miriam Zolan (*Indiana University*)  
 Uko Zylstra (*Calvin College*)

# Detailed Contents

## 1

### Introduction: Themes in the Study of Life 1

#### OVERVIEW Inquiring About Life 1

#### CONCEPT 1.1 The themes of this book make connections across different areas of biology 2

- Theme: New Properties Emerge at Each Level in the Biological Hierarchy 3
- Theme: Organisms Interact with Other Organisms and the Physical Environment 6
- Theme: Life Requires Energy Transfer and Transformation 6
- Theme: Structure and Function Are Correlated at All Levels of Biological Organization 7
- Theme: The Cell Is an Organism's Basic Unit of Structure and Function 8
- Theme: The Continuity of Life Is Based on Heritable Information in the Form of DNA 8
- Theme: Feedback Mechanisms Regulate Biological Systems 10
- Evolution, the Overarching Theme of Biology 11

#### 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 16

#### CONCEPT 1.3 In studying nature, scientists make observations and then form and test hypotheses 18

- Making Observations 18
- Forming and Testing Hypotheses 19
- The Flexibility of the Scientific Method 20
- A Case Study in Scientific Inquiry: Investigating Mimicry in Snake Populations 20
- Theories in Science 23

#### CONCEPT 1.4 Science benefits from a cooperative approach and diverse viewpoints 23

- Building on the Work of Others 23
- Science, Technology, and Society 24
- The Value of Diverse Viewpoints in Science 25

#### UNIT

## 1

### The Chemistry of Life 28

Interview: Susan Solomon

## 2

### The Chemical Context of Life 30

#### OVERVIEW A Chemical Connection to Biology 30

#### CONCEPT 2.1 Matter consists of chemical elements in pure form and in combinations called compounds 31

- Elements and Compounds 31
- The Elements of Life 32
- Case Study: Evolution of Tolerance to Toxic Elements 32

#### CONCEPT 2.2 An element's properties depend on the structure of its atoms 33

- Subatomic Particles 33
- Atomic Number and Atomic Mass 33
- Isotopes 34
- The Energy Levels of Electrons 35
- Electron Distribution and Chemical Properties 36
- Electron Orbitals 37

#### CONCEPT 2.3 The formation and function of molecules depend on chemical bonding between atoms 38

- Covalent Bonds 38
- Ionic Bonds 39
- Weak Chemical Bonds 40
- Molecular Shape and Function 41

#### CONCEPT 2.4 Chemical reactions make and break chemical bonds 42

## 3

### Water and Life 46

#### OVERVIEW The Molecule That Supports All of Life 46

#### CONCEPT 3.1 Polar covalent bonds in water molecules result in hydrogen bonding 46

#### CONCEPT 3.2 Four emergent properties of water contribute to Earth's suitability for life 47

- Cohesion of Water Molecules 47
- Moderation of Temperature by Water 48
- Floating of Ice on Liquid Water 49
- Water: The Solvent of Life 50
- Possible Evolution of Life on Other Planets with Water 52

#### CONCEPT 3.3 Acidic and basic conditions affect living organisms 52

- Acids and Bases 53
- The pH Scale 53
- Buffers 54
- Acidification: A Threat to Water Quality 55

## 4

### Carbon and the Molecular Diversity of Life 58

#### OVERVIEW Carbon: The Backbone of Life 58

#### CONCEPT 4.1 Organic chemistry is the study of carbon compounds 58

- Organic Molecules and the Origin of Life on Earth 59

#### CONCEPT 4.2 Carbon atoms can form diverse molecules by bonding to four other atoms 60

- The Formation of Bonds with Carbon 60
- Molecular Diversity Arising from Carbon Skeleton Variation 61

#### CONCEPT 4.3 A few chemical groups are key to the functioning of biological molecules 63

- The Chemical Groups Most Important in the Processes of Life 63
- ATP: An Important Source of Energy for Cellular Processes 66
- The Chemical Elements of Life: A Review 66



## 5

## The Structure and Function of Large Biological Molecules 68

**OVERVIEW** The Molecules of Life 68

**CONCEPT 5.1** Macromolecules are polymers, built from monomers 68

The Synthesis and Breakdown of Polymers 68  
The Diversity of Polymers 69

**CONCEPT 5.2** Carbohydrates serve as fuel and building material 69

Sugars 69  
Polysaccharides 70

**CONCEPT 5.3** Lipids are a diverse group of hydrophobic molecules 74

Fats 74  
Phospholipids 76  
Steroids 77

**CONCEPT 5.4** Proteins include a diversity of structures, resulting in a wide range of functions 77

Polypeptides 77  
Protein Structure and Function 80

**CONCEPT 5.5** Nucleic acids store, transmit, and help express hereditary information 86

The Roles of Nucleic Acids 86  
The Components of Nucleic Acids 87  
Nucleotide Polymers 88  
The Structures of DNA and RNA Molecules 88  
DNA and Proteins as Tape Measures of Evolution 89  
The Theme of Emergent Properties in the Chemistry of Life: A Review 89

UNIT

## 2

## The Cell 92

Interview: Bonnie L. Bassler

## 6

## A Tour of the Cell 94

**OVERVIEW** The Fundamental Units of Life 94

**CONCEPT 6.1** Biologists use microscopes and the tools of biochemistry to study cells 94

Microscopy 94  
Cell Fractionation 97

**CONCEPT 6.2** Eukaryotic cells have internal membranes that compartmentalize their functions 98

Comparing Prokaryotic and Eukaryotic Cells 98  
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 in the cell 104

The Endoplasmic Reticulum: Biosynthetic Factory 104  
The Golgi Apparatus: Shipping and Receiving Center 105

Lysosomes: Digestive Compartments 106  
Vacuoles: Diverse Maintenance Compartments 107  
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 111

**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 119  
Cell Junctions 120  
The Cell: A Living Unit Greater Than the Sum of Its Parts 122

## 7

## Membrane Structure and Function 125

**OVERVIEW** Life at the Edge 125

**CONCEPT 7.1** Cellular membranes are fluid mosaics of lipids and proteins 125

Membrane Models: *Scientific Inquiry* 125  
The Fluidity of Membranes 127  
Evolution of Differences in Membrane Lipid Composition 128  
Membrane Proteins and Their Functions 129  
The Role of Membrane Carbohydrates in Cell-Cell Recognition 130  
Synthesis and Sidedness of Membranes 130

**CONCEPT 7.2** Membrane structure results in selective permeability 131

The Permeability of the Lipid Bilayer 131  
Transport Proteins 131

**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 134

**CONCEPT 7.4** Active transport uses energy to move solutes against their gradients 135

The Need for Energy in Active Transport 135  
How Ion Pumps Maintain Membrane Potential 136  
Cotransport: Coupled Transport by a Membrane Protein 137

**CONCEPT 7.5** Bulk transport across the plasma membrane occurs by exocytosis and endocytosis 138

Exocytosis 138  
Endocytosis 138



## 8 An Introduction to Metabolism 142

### OVERVIEW The Energy of Life 142

#### CONCEPT 8.1 An organism's metabolism transforms matter and energy, subject to the laws of thermodynamics 142

Organization of the Chemistry of Life into Metabolic Pathways 142

Forms of Energy 143

The Laws of Energy Transformation 144

#### CONCEPT 8.2 The free-energy change of a reaction tells us whether or not the reaction occurs spontaneously 146

Free-Energy Change,  $\Delta G$  146

Free Energy, Stability, and Equilibrium 146

Free Energy and Metabolism 147

#### CONCEPT 8.3 ATP powers cellular work by coupling exergonic reactions to endergonic reactions 149

The Structure and Hydrolysis of ATP 149

How the Hydrolysis of ATP Performs Work 150

The Regeneration of ATP 151

#### CONCEPT 8.4 Enzymes speed up metabolic reactions by lowering energy barriers 152

The Activation Energy Barrier 152

How Enzymes Lower the  $E_A$  Barrier 153

Substrate Specificity of Enzymes 153

Catalysis in the Enzyme's Active Site 154

Effects of Local Conditions on Enzyme Activity 155

The Evolution of Enzymes 157

#### CONCEPT 8.5 Regulation of enzyme activity helps control metabolism 158

Allosteric Regulation of Enzymes 158

Specific Localization of Enzymes Within the Cell 160



## 9 Cellular Respiration and Fermentation 163

### OVERVIEW Life Is Work 163

#### CONCEPT 9.1 Catabolic pathways yield energy by oxidizing organic fuels 164

Catabolic Pathways and Production of ATP 164

Redox Reactions: Oxidation and Reduction 164

The Stages of Cellular Respiration: A Preview 167

#### CONCEPT 9.2 Glycolysis harvests chemical energy by oxidizing glucose to pyruvate 168

#### CONCEPT 9.3 After pyruvate is oxidized, the citric acid cycle completes the energy-yielding oxidation of organic molecules 170

Oxidation of Pyruvate to Acetyl CoA 170

The Citric Acid Cycle 170

#### CONCEPT 9.4 During oxidative phosphorylation, chemiosmosis couples electron transport to ATP synthesis 172

The Pathway of Electron Transport 172

Chemiosmosis: The Energy-Coupling Mechanism 173

An Accounting of ATP Production by Cellular Respiration 174

#### CONCEPT 9.5 Fermentation and anaerobic respiration enable cells to produce ATP without the use of oxygen 177

Types of Fermentation 177

Comparing Fermentation with Anaerobic and Aerobic Respiration 178

The Evolutionary Significance of Glycolysis 179

#### CONCEPT 9.6 Glycolysis and the citric acid cycle connect to many other metabolic pathways 179

The Versatility of Catabolism 179

Biosynthesis (Anabolic Pathways) 180

Regulation of Cellular Respiration via Feedback Mechanisms 181

## 10 Photosynthesis 184

### OVERVIEW The Process That Feeds the Biosphere 184

#### CONCEPT 10.1 Photosynthesis converts light energy to the chemical energy of food 186

Chloroplasts: The Sites of Photosynthesis in Plants 186

Tracking Atoms Through Photosynthesis: *Scientific Inquiry* 187

The Two Stages of Photosynthesis: A Preview 188

#### CONCEPT 10.2 The light reactions convert solar energy to the chemical energy of ATP and NADPH 189

The Nature of Sunlight 189

Photosynthetic Pigments: The Light Receptors 190

Excitation of Chlorophyll by Light 192

A Photosystem: A Reaction-Center Complex Associated with Light-Harvesting Complexes 192

Linear Electron Flow 193

Cyclic Electron Flow 195

A Comparison of Chemiosmosis in Chloroplasts and Mitochondria 196

#### CONCEPT 10.3 The Calvin cycle uses the chemical energy of ATP and NADPH to reduce $\text{CO}_2$ to sugar 198

#### CONCEPT 10.4 Alternative mechanisms of carbon fixation have evolved in hot, arid climates 199

Photorespiration: An Evolutionary Relic? 199

$\text{C}_4$  Plants 200

CAM Plants 201

The Importance of Photosynthesis: A Review 203

## 11 Cell Communication 206

### OVERVIEW Cellular Messaging 206

#### CONCEPT 11.1 External signals are converted to responses within the cell 206

- Evolution of Cell Signaling 206
- Local and Long-Distance Signaling 208
- The Three Stages of Cell Signaling: A Preview 209

#### CONCEPT 11.2 Reception: A signaling molecule binds to a receptor protein, causing it to change shape 210

- Receptors in the Plasma Membrane 210
- Intracellular Receptors 214

#### CONCEPT 11.3 Transduction: Cascades of molecular interactions relay signals from receptors to target molecules in the cell 214

- Signal Transduction Pathways 215
- Protein Phosphorylation and Dephosphorylation 215
- Small Molecules and Ions as Second Messengers 216

#### CONCEPT 11.4 Response: Cell signaling leads to regulation of transcription or cytoplasmic activities 219

- Nuclear and Cytoplasmic Responses 219
- Fine-Tuning of the Response 220

#### CONCEPT 11.5 Apoptosis integrates multiple cell-signaling pathways 223

- Apoptosis in the Soil Worm *Caenorhabditis elegans* 224
- Apoptotic Pathways and the Signals That Trigger Them 224

## 12 The Cell Cycle 228

### OVERVIEW The Key Roles of Cell Division 228

#### CONCEPT 12.1 Most cell division results in genetically identical daughter cells 229

- Cellular Organization of the Genetic Material 229
- Distribution of Chromosomes During Eukaryotic Cell Division 229

#### CONCEPT 12.2 The mitotic phase alternates with interphase in the cell cycle 230

- Phases of the Cell Cycle 231
- The Mitotic Spindle: A Closer Look 231
- Cytokinesis: A Closer Look 234
- Binary Fission in Bacteria 236
- The Evolution of Mitosis 237

#### CONCEPT 12.3 The eukaryotic cell cycle is regulated by a molecular control system 238

- Evidence for Cytoplasmic Signals 238
- The Cell Cycle Control System 238
- Loss of Cell Cycle Controls in Cancer Cells 242

### UNIT

## 3

## Genetics 246

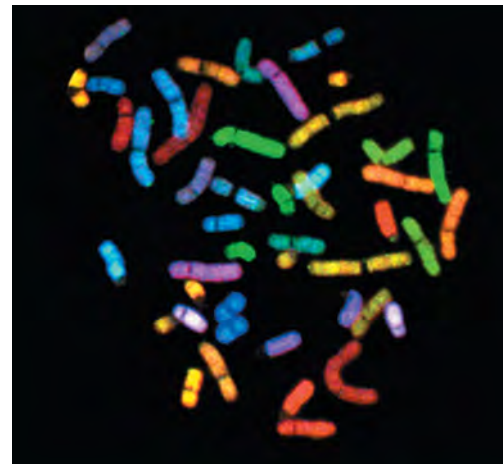
Interview: Joan A. Steitz

## 13 Meiosis and Sexual Life Cycles 248

### OVERVIEW Variations on a Theme 248

#### CONCEPT 13.1 Offspring acquire genes from parents by inheriting chromosomes 248

- Inheritance of Genes 249
- Comparison of Asexual and Sexual Reproduction 249



#### CONCEPT 13.2 Fertilization and meiosis alternate in sexual life cycles 250

- Sets of Chromosomes in Human Cells 250
- Behavior of Chromosome Sets in the Human Life Cycle 251
- The Variety of Sexual Life Cycles 252

#### CONCEPT 13.3 Meiosis reduces the number of chromosome sets from diploid to haploid 253

- The Stages of Meiosis 253
- A Comparison of Mitosis and Meiosis 257

#### CONCEPT 13.4 Genetic variation produced in sexual life cycles contributes to evolution 257

- Origins of Genetic Variation Among Offspring 257
- The Evolutionary Significance of Genetic Variation Within Populations 259

## 14 Mendel and the Gene Idea 262

### OVERVIEW Drawing from the Deck of Genes 262

#### CONCEPT 14.1 Mendel used the scientific approach to identify two laws of inheritance 262

- Mendel's Experimental, Quantitative Approach 262
- The Law of Segregation 264
- The Law of Independent Assortment 267

#### CONCEPT 14.2 The laws of probability govern Mendelian inheritance 269

- The Multiplication and Addition Rules Applied to Monohybrid Crosses 269
- Solving Complex Genetics Problems with the Rules of Probability 270

#### CONCEPT 14.3 Inheritance patterns are often more complex than predicted by simple Mendelian genetics 271

- Extending Mendelian Genetics for a Single Gene 271
- Extending Mendelian Genetics for Two or More Genes 273
- Nature and Nurture: The Environmental Impact on Phenotype 274
- Integrating a Mendelian View of Heredity and Variation 275

#### CONCEPT 14.4 Many human traits follow Mendelian patterns of inheritance 275

- Pedigree Analysis 275
- Recessively Inherited Disorders 276
- Dominantly Inherited Disorders 278
- Multifactorial Disorders 279
- Genetic Testing and Counseling 279

## 15

## The Chromosomal Basis of Inheritance 286

**OVERVIEW** Locating Genes Along Chromosomes 286

**CONCEPT 15.1** Mendelian inheritance has its physical basis in the behavior of chromosomes 286

Morgan's Experimental Evidence: *Scientific Inquiry* 288

**CONCEPT 15.2** Sex-linked genes exhibit unique patterns of inheritance 289

The Chromosomal Basis of Sex 289

Inheritance of X-Linked Genes 290

X Inactivation in Female Mammals 291

**CONCEPT 15.3** Linked genes tend to be inherited together because they are located near each other on the same chromosome 292

How Linkage Affects Inheritance 292

Genetic Recombination and Linkage 294

Mapping the Distance Between Genes Using

Recombination Data: *Scientific Inquiry* 296

**CONCEPT 15.4** Alterations of chromosome number or structure cause some genetic disorders 297

Abnormal Chromosome Number 297

Alterations of Chromosome Structure 298

Human Disorders Due to Chromosomal Alterations 299

**CONCEPT 15.5** Some inheritance patterns are exceptions to standard Mendelian inheritance 300

Genomic Imprinting 300

Inheritance of Organelle Genes 301

## 16

## The Molecular Basis of Inheritance 305

**OVERVIEW** Life's Operating Instructions 305

**CONCEPT 16.1** DNA is the genetic material 305

The Search for the Genetic Material: *Scientific Inquiry* 305

Building a Structural Model of DNA: *Scientific Inquiry* 308

**CONCEPT 16.2** Many proteins work together in DNA replication and repair 311

The Basic Principle: Base Pairing to a Template Strand 311

DNA Replication: *A Closer Look* 312

Proofreading and Repairing DNA 316

Evolutionary Significance of Altered DNA Nucleotides 318

Replicating the Ends of DNA Molecules 318

**CONCEPT 16.3** A chromosome consists of a DNA molecule packed together with proteins 320

## 17

## From Gene to Protein 325

**OVERVIEW** The Flow of Genetic Information 325

**CONCEPT 17.1** Genes specify proteins via transcription and translation 325

Evidence from the Study of Metabolic Defects 326

Basic Principles of Transcription and Translation 328

The Genetic Code 328

**CONCEPT 17.2** Transcription is the DNA-directed synthesis of RNA: *a closer look* 331

Molecular Components of Transcription 331

Synthesis of an RNA Transcript 332

**CONCEPT 17.3** Eukaryotic cells modify RNA after transcription 334

Alteration of mRNA Ends 334

Split Genes and RNA Splicing 334

xxxvi Detailed Contents

**CONCEPT 17.4** Translation is the RNA-directed synthesis of a polypeptide: *a closer look* 337

Molecular Components of Translation 337

Building a Polypeptide 340

Completing and Targeting the Functional Protein 342

**CONCEPT 17.5** Mutations of one or a few nucleotides can affect protein structure and function 344

Types of Small-Scale Mutations 344

Mutagens 346

**CONCEPT 17.6** While gene expression differs among the domains of life, the concept of a gene is universal 346

Comparing Gene Expression in Bacteria, Archaea, and Eukarya 346

What Is a Gene? *Revisiting the Question* 347

## 18

## Regulation of Gene Expression 351

**OVERVIEW** Conducting the Genetic Orchestra 351

**CONCEPT 18.1** Bacteria often respond to environmental change by regulating transcription 351

Operons: The Basic Concept 352

Repressible and Inducible Operons: Two Types of Negative Gene Regulation 353

Positive Gene Regulation 355

**CONCEPT 18.2** Eukaryotic gene expression is regulated at many stages 356

Differential Gene Expression 356

Regulation of Chromatin Structure 357

Regulation of Transcription Initiation 358

Mechanisms of Post-Transcriptional Regulation 362

**CONCEPT 18.3** Noncoding RNAs play multiple roles in controlling gene expression 364

Effects on mRNAs by MicroRNAs and Small Interfering RNAs 365

Chromatin Remodeling and Effects on Transcription by ncRNAs 366

The Evolutionary Significance of Small ncRNAs 366

**CONCEPT 18.4** A program of differential gene expression leads to the different cell types in a multicellular organism 366

A Genetic Program for Embryonic Development 366

Cytoplasmic Determinants and Inductive Signals 367

Sequential Regulation of Gene Expression During Cellular Differentiation 367

Pattern Formation: Setting Up the Body Plan 369

**CONCEPT 18.5** Cancer results from genetic changes that affect cell cycle control 373

Types of Genes Associated with Cancer 373

Interference with Normal Cell-Signaling Pathways 374

The Multistep Model of Cancer Development 376

Inherited Predisposition and Other Factors Contributing to Cancer 376

## 19

## Viruses 381

**OVERVIEW** A Borrowed Life 381

**CONCEPT 19.1** A virus consists of a nucleic acid surrounded by a protein coat 381

The Discovery of Viruses: *Scientific Inquiry* 381

Structure of Viruses 382



**CONCEPT 19.2** Viruses replicate only in host cells 384

General Features of Viral Replicative Cycles 384  
Replicative Cycles of Phages 385  
Replicative Cycles of Animal Viruses 387  
Evolution of Viruses 390

**CONCEPT 19.3** Viruses, viroids, and prions are formidable pathogens in animals and plants 390

Viral Diseases in Animals 391  
Emerging Viruses 391  
Viral Diseases in Plants 393  
Viroids and Prions: The Simplest Infectious Agents 393

## 20 Biotechnology 396

**OVERVIEW** The DNA Toolbox 396

**CONCEPT 20.1** DNA cloning yields multiple copies of a gene or other DNA segment 396

DNA Cloning and Its Applications: *A Preview* 397  
Using Restriction Enzymes to Make Recombinant DNA 398  
Cloning a Eukaryotic Gene in a Bacterial Plasmid 398  
Expressing Cloned Eukaryotic Genes 402  
Amplifying DNA *in Vitro*: The Polymerase Chain Reaction (PCR) 403

**CONCEPT 20.2** DNA technology allows us to study the sequence, expression, and function of a gene 405

Gel Electrophoresis and Southern Blotting 405  
DNA Sequencing 407  
Analyzing Gene Expression 409  
Determining Gene Function 410

**CONCEPT 20.3** Cloning organisms may lead to production of stem cells for research and other applications 412

Cloning Plants: Single-Cell Cultures 412  
Cloning Animals: Nuclear Transplantation 413  
Stem Cells of Animals 415

**CONCEPT 20.4** The practical applications of DNA technology affect our lives in many ways 417

Medical Applications 417  
Forensic Evidence and Genetic Profiles 420  
Environmental Cleanup 421  
Agricultural Applications 421  
Safety and Ethical Questions Raised by DNA Technology 422

## 21 Genomes and Their Evolution 426

**OVERVIEW** Reading the Leaves from the Tree of Life 426

**CONCEPT 21.1** New approaches have accelerated the pace of genome sequencing 427

Three-Stage Approach to Genome Sequencing 427  
Whole-Genome Shotgun Approach to Genome Sequencing 428

**CONCEPT 21.2** Scientists use bioinformatics to analyze genomes and their functions 429

Centralized Resources for Analyzing Genome Sequences 429  
Identifying Protein-Coding Genes and Understanding Their Functions 429  
Understanding Genes and Gene Expression at the Systems Level 430

**CONCEPT 21.3** Genomes vary in size, number of genes, and gene density 432

Genome Size 432  
Number of Genes 433  
Gene Density and Noncoding DNA 434

**CONCEPT 21.4** Multicellular eukaryotes have much noncoding DNA and many multigene families 434

Transposable Elements and Related Sequences 434  
Other Repetitive DNA, Including Simple Sequence DNA 436  
Genes and Multigene Families 437

**CONCEPT 21.5** Duplication, rearrangement, and mutation of DNA contribute to genome evolution 438

Duplication of Entire Chromosome Sets 438  
Alterations of Chromosome Structure 438  
Duplication and Divergence of Gene-Sized Regions of DNA 439  
Rearrangements of Parts of Genes: Exon Duplication and Exon Shuffling 441  
How Transposable Elements Contribute to Genome Evolution 441

**CONCEPT 21.6** Comparing genome sequences provides clues to evolution and development 442

Comparing Genomes 442  
Comparing Developmental Processes 445

UNIT



## Mechanisms of Evolution 450

Interview: Geerat J. Vermeij

## 22

## Descent with Modification: A Darwinian View of Life 452

**OVERVIEW** Endless Forms Most Beautiful 452

**CONCEPT 22.1** The Darwinian revolution challenged traditional views of a young Earth inhabited by unchanging species 453

*Scala Naturae* and Classification of Species 453  
Ideas About Change over Time 454  
Lamarck's Hypothesis of Evolution 454

**CONCEPT 22.2** Descent with modification by natural selection explains the adaptations of organisms and the unity and diversity of life 455

Darwin's Research 455  
*The Origin of Species* 457

**CONCEPT 22.3** Evolution is supported by an overwhelming amount of scientific evidence 460

Direct Observations of Evolutionary Change 460  
Homology 462  
The Fossil Record 465  
Biogeography 466  
What Is Theoretical About Darwin's View of Life? 467



## 23 The Evolution of Populations 469

**OVERVIEW** The Smallest Unit of Evolution 469

**CONCEPT 23.1** Genetic variation makes evolution possible 469

Genetic Variation 470

Sources of Genetic Variation 471

**CONCEPT 23.2** The Hardy-Weinberg equation can be used to test whether a population is evolving 473

Gene Pools and Allele Frequencies 473

The Hardy-Weinberg Principle 473

**CONCEPT 23.3** Natural selection, genetic drift, and gene flow can alter allele frequencies in a population 476

Natural Selection 476

Genetic Drift 477

Gene Flow 479

**CONCEPT 23.4** Natural selection is the only mechanism that consistently causes adaptive evolution 480

A Closer Look at Natural Selection 480

The Key Role of Natural Selection in Adaptive Evolution 482

Sexual Selection 482

The Preservation of Genetic Variation 483

Why Natural Selection Cannot Fashion Perfect Organisms 484

## 24 The Origin of Species 488

**OVERVIEW** That “Mystery of Mysteries” 488

**CONCEPT 24.1** The biological species concept emphasizes reproductive isolation 488

The Biological Species Concept 489

Other Definitions of Species 492

**CONCEPT 24.2** Speciation can take place with or without geographic separation 493

Allopatric (“Other Country”) Speciation 493

Sympatric (“Same Country”) Speciation 495

Allopatric and Sympatric Speciation: A Review 497

**CONCEPT 24.3** Hybrid zones reveal factors that cause reproductive isolation 498

Patterns Within Hybrid Zones 498

Hybrid Zones over Time 499

**CONCEPT 24.4** Speciation can occur rapidly or slowly and can result from changes in few or many genes 501

The Time Course of Speciation 501

Studying the Genetics of Speciation 503

From Speciation to Macroevolution 504

## 25 The History of Life on Earth 507

**OVERVIEW** Lost Worlds 507

**CONCEPT 25.1** Conditions on early Earth made the origin of life possible 507

Synthesis of Organic Compounds on Early Earth 508

Abiotic Synthesis of Macromolecules 509

Protocells 509

Self-Replicating RNA and the Dawn of Natural Selection 509

**CONCEPT 25.2** The fossil record documents the history of life 510

The Fossil Record 510

How Rocks and Fossils Are Dated 512

The Origin of New Groups of Organisms 512

**CONCEPT 25.3** Key events in life’s history include the origins of single-celled and multicelled organisms and the colonization of land 514

The First Single-Celled Organisms 514

The Origin of Multicellularity 517

The Colonization of Land 518

**CONCEPT 25.4** The rise and fall of groups of organisms reflect differences in speciation and extinction rates 519

Plate Tectonics 519

Mass Extinctions 521

Adaptive Radiations 524

**CONCEPT 25.5** Major changes in body form can result from changes in the sequences and regulation of developmental genes 525

Effects of Developmental Genes 525

The Evolution of Development 526

**CONCEPT 25.6** Evolution is not goal oriented 529

Evolutionary Novelties 529

Evolutionary Trends 530

UNIT

## 5 The Evolutionary History of Biological Diversity 534

Interview: W. Ford Doolittle

## 26 Phylogeny and the Tree of Life 536

**OVERVIEW** Investigating the Tree of Life 536

**CONCEPT 26.1** Phylogenies show evolutionary relationships 537

Binomial Nomenclature 537

Hierarchical Classification 537

Linking Classification and Phylogeny 538

What We Can and Cannot Learn from Phylogenetic Trees 539

Applying Phylogenies 539

**CONCEPT 26.2** Phylogenies are inferred from morphological and molecular data 540

Morphological and Molecular Homologies 540

Sorting Homology from Analogy 540

Evaluating Molecular Homologies 541

**CONCEPT 26.3** Shared characters are used to construct phylogenetic trees 542

Cladistics 542

Phylogenetic Trees with Proportional Branch Lengths 544

Maximum Parsimony and Maximum Likelihood 544

Phylogenetic Trees as Hypotheses 547

**CONCEPT 26.4** An organism’s evolutionary history is documented in its genome 548

Gene Duplications and Gene Families 548

Genome Evolution 548

**CONCEPT 26.5** Molecular clocks help track evolutionary time 549

Molecular Clocks 549

Applying a Molecular Clock: The Origin of HIV 550

**CONCEPT 26.6** New information continues to revise our understanding of the tree of life 551

From Two Kingdoms to Three Domains 551

A Simple Tree of All Life 552

Is the Tree of Life Really a Ring? 553

## 27 Bacteria and Archaea 556

### OVERVIEW Masters of Adaptation 556

#### CONCEPT 27.1 Structural and functional adaptations contribute to prokaryotic success 556

- Cell-Surface Structures 557
- Motility 558
- Internal Organization and DNA 559
- Reproduction and Adaptation 560

#### CONCEPT 27.2 Rapid reproduction, mutation, and genetic recombination promote genetic diversity in prokaryotes 561

- Rapid Reproduction and Mutation 561
- Genetic Recombination 561

#### CONCEPT 27.3 Diverse nutritional and metabolic adaptations have evolved in prokaryotes 564

- The Role of Oxygen in Metabolism 564
- Nitrogen Metabolism 564
- Metabolic Cooperation 565

#### CONCEPT 27.4 Molecular systematics is illuminating prokaryotic phylogeny 565

- Lessons from Molecular Systematics 566
- Archaea 566
- Bacteria 567

#### CONCEPT 27.5 Prokaryotes play crucial roles in the biosphere 570

- Chemical Recycling 570
- Ecological Interactions 570

#### CONCEPT 27.6 Prokaryotes have both beneficial and harmful impacts on humans 571

- Mutualistic Bacteria 571
- Pathogenic Bacteria 571
- Prokaryotes in Research and Technology 572

## 28 Protists 575

### OVERVIEW Living Small 575

#### CONCEPT 28.1 Most eukaryotes are single-celled organisms 575

- Structural and Functional Diversity in Protists 576
- Endosymbiosis in Eukaryotic Evolution 576
- Five Supergroups of Eukaryotes 576

#### CONCEPT 28.2 Excavates include protists with modified mitochondria and protists with unique flagella 580

- Diplomonads and Parabasalids 580
- Euglenozoans 580

#### CONCEPT 28.3 Chromalveolates may have originated by secondary endosymbiosis 582

- Alveolates 582
- Stramenopiles 585

#### CONCEPT 28.4 Rhizarians are a diverse group of protists defined by DNA similarities 589

- Radiolarians 589
- Forams 589
- Cercozoans 590

#### CONCEPT 28.5 Red algae and green algae are the closest relatives of land plants 590

- Red Algae 590
- Green Algae 591

#### CONCEPT 28.6 Unikonts include protists that are closely related to fungi and animals 593

- Amoebozoans 593
- Opisthokonts 596

#### CONCEPT 28.7 Protists play key roles in ecological communities 596

- Symbiotic Protists 596
- Photosynthetic Protists 597

## 29 Plant Diversity I: How Plants Colonized Land 600

### OVERVIEW The Greening of Earth 600

#### CONCEPT 29.1 Land plants evolved from green algae 600

- Morphological and Molecular Evidence 600
- Adaptations Enabling the Move to Land 601
- Derived Traits of Plants 601
- The Origin and Diversification of Plants 604

#### CONCEPT 29.2 Mosses and other nonvascular plants have life cycles dominated by gametophytes 606

- Bryophyte Gametophytes 606
- Bryophyte Sporophytes 609
- The Ecological and Economic Importance of Mosses 609

#### CONCEPT 29.3 Ferns and other seedless vascular plants were the first plants to grow tall 610

- Origins and Traits of Vascular Plants 610
- Classification of Seedless Vascular Plants 613
- The Significance of Seedless Vascular Plants 615

## 30 Plant Diversity II: The Evolution of Seed Plants 618

### OVERVIEW Transforming the World 618

#### CONCEPT 30.1 Seeds and pollen grains are key adaptations for life on land 618

- Advantages of Reduced Gametophytes 618
- Heterospory: The Rule Among Seed Plants 619
- Ovules and Production of Eggs 619
- Pollen and Production of Sperm 620
- The Evolutionary Advantage of Seeds 620

#### CONCEPT 30.2 Gymnosperms bear “naked” seeds, typically on cones 621

- Gymnosperm Evolution 621
- The Life Cycle of a Pine: *A Closer Look* 625

#### CONCEPT 30.3 The reproductive adaptations of angiosperms include flowers and fruits 625

- Characteristics of Angiosperms 625
- Angiosperm Evolution 628
- Angiosperm Diversity 630
- Evolutionary Links Between Angiosperms and Animals 632

#### CONCEPT 30.4 Human welfare depends greatly on seed plants 632

- Products from Seed Plants 633
- Threats to Plant Diversity 633



## 31 Fungi 636

### OVERVIEW Mighty Mushrooms 636

#### CONCEPT 31.1 Fungi are heterotrophs that feed by absorption 636

- Nutrition and Ecology 636
- Body Structure 637
- Specialized Hyphae in Mycorrhizal Fungi 638



**CONCEPT 31.2 Fungi produce spores through sexual or asexual life cycles 638**

Sexual Reproduction 639  
Asexual Reproduction 639

**CONCEPT 31.3 The ancestor of fungi was an aquatic, single-celled, flagellated protist 640**

The Origin of Fungi 640  
Are Microsporidia Fungi? 641  
The Move to Land 641

**CONCEPT 31.4 Fungi have radiated into a diverse set of lineages 641**

Chytrids 641  
Zygomycetes 643  
Glomeromycetes 644  
Ascomycetes 644  
Basidiomycetes 646

**CONCEPT 31.5 Fungi play key roles in nutrient cycling, ecological interactions, and human welfare 648**

Fungi as Decomposers 648  
Fungi as Mutualists 648  
Fungi as Pathogens 650  
Practical Uses of Fungi 651

## 32 An Overview of Animal Diversity 654

**OVERVIEW Welcome to Your Kingdom 654**

**CONCEPT 32.1 Animals are multicellular, heterotrophic eukaryotes with tissues that develop from embryonic layers 654**

Nutritional Mode 654  
Cell Structure and Specialization 654  
Reproduction and Development 655

**CONCEPT 32.2 The history of animals spans more than half a billion years 656**

Neoproterozoic Era (1 Billion–542 Million Years Ago) 656  
Paleozoic Era (542–251 Million Years Ago) 657  
Mesozoic Era (251–65.5 Million Years Ago) 658  
Cenozoic Era (65.5 Million Years Ago to the Present) 658

**CONCEPT 32.3 Animals can be characterized by “body plans” 658**

Symmetry 658  
Tissues 659  
Body Cavities 660  
Protostome and Deuterostome Development 660

**CONCEPT 32.4 New views of animal phylogeny are emerging from molecular data 662**

Points of Agreement 662  
Progress in Resolving Bilaterian Relationships 663  
Future Directions in Animal Systematics 664

## 33 An Introduction to Invertebrates 666

**OVERVIEW Life Without a Backbone 666**

**CONCEPT 33.1 Sponges are basal animals that lack true tissues 670**

**CONCEPT 33.2 Cnidarians are an ancient phylum of eumetazoans 671**

Hydrozoans 672  
Scyphozoans 672  
Cubozoans 672  
Anthozoans 673

**CONCEPT 33.3 Lophotrochozoans, a clade identified by molecular data, have the widest range of animal body forms 674**

Flatworms 674

Rotifers 676

Lophophorates: Ectoprocts and Brachiopods 677

Molluscs 677

Annelids 681

**CONCEPT 33.4 Ecdysozoans are the most species-rich animal group 683**

Nematodes 683  
Arthropods 684

**CONCEPT 33.5 Echinoderms and chordates are deuterostomes 692**

Echinoderms 692  
Chordates 694

## 34 The Origin and Evolution of Vertebrates 697

**OVERVIEW Half a Billion Years of Backbones 697**

**CONCEPT 34.1 Chordates have a notochord and a dorsal, hollow nerve cord 697**

Derived Characters of Chordates 698  
Lancelets 699  
Tunicates 700  
Early Chordate Evolution 700

**CONCEPT 34.2 Craniates are chordates that have a head 701**

Derived Characters of Craniates 701  
The Origin of Craniates 702  
Hagfishes 702

**CONCEPT 34.3 Vertebrates are craniates that have a backbone 703**

Derived Characters of Vertebrates 703  
Lampreys 703  
Fossils of Early Vertebrates 703  
Origins of Bone and Teeth 704

**CONCEPT 34.4 Gnathostomes are vertebrates that have jaws 704**

Derived Characters of Gnathostomes 704  
Fossil Gnathostomes 705  
Chondrichthyans (Sharks, Rays, and Their Relatives) 705  
Ray-Finned Fishes and Lobe-Fins 707

**CONCEPT 34.5 Tetrapods are gnathostomes that have limbs 709**

Derived Characters of Tetrapods 709  
The Origin of Tetrapods 709  
Amphibians 710

**CONCEPT 34.6 Amniotes are tetrapods that have a terrestrially adapted egg 713**

Derived Characters of Amniotes 713  
Early Amniotes 714  
Reptiles 715

**CONCEPT 34.7 Mammals are amniotes that have hair and produce milk 720**

Derived Characters of Mammals 720  
Early Evolution of Mammals 721  
Monotremes 721  
Marsupials 722  
Eutherians (Placental Mammals) 723

**CONCEPT 34.8 Humans are mammals that have a large brain and bipedal locomotion 728**

Derived Characters of Humans 728  
The Earliest Hominins 728  
Australopiths 729  
Bipedalism 730  
Tool Use 730  
Early *Homo* 731  
Neanderthals 731  
*Homo sapiens* 732

# Plant Form and Function 736

Interview: Luis Herrera-Estrella

## 35

### Plant Structure, Growth, and Development 738

**OVERVIEW** Are Plants Computers? 738

**CONCEPT 35.1** Plants have a hierarchical organization consisting of organs, tissues, and cells 738

The Three Basic Plant Organs: Roots, Stems, and Leaves 739

Dermal, Vascular, and Ground Tissues 742

Common Types of Plant Cells 743

**CONCEPT 35.2** Meristems generate cells for primary and secondary growth 746

**CONCEPT 35.3** Primary growth lengthens roots and shoots 747

Primary Growth of Roots 747

Primary Growth of Shoots 749

**CONCEPT 35.4** Secondary growth increases the diameter of stems and roots in woody plants 751

The Vascular Cambium and Secondary Vascular Tissue 751

The Cork Cambium and the Production of Periderm 754

Evolution of Secondary Growth 754

**CONCEPT 35.5** Growth, morphogenesis, and cell differentiation produce the plant body 755

Model Organisms: Revolutionizing the Study of Plants 755

Growth: Cell Division and Cell

Expansion 756

Morphogenesis and Pattern Formation

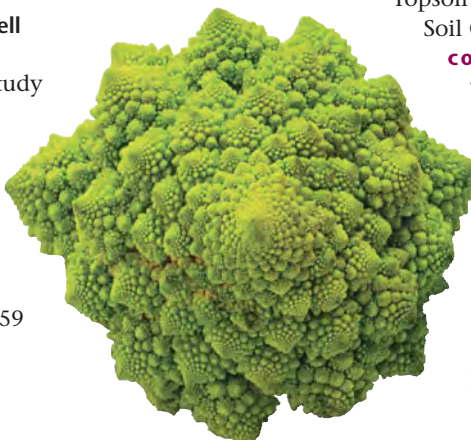
758

Gene Expression and Control of Cell

Differentiation 759

Shifts in Development: Phase Changes 759

Genetic Control of Flowering 760



## 36

### Resource Acquisition and Transport in Vascular Plants 764

**OVERVIEW** Underground Plants 764

**CONCEPT 36.1** Adaptations for acquiring resources were key steps in the evolution of vascular plants 764

Shoot Architecture and Light Capture 765

Root Architecture and Acquisition of Water and Minerals 766

**CONCEPT 36.2** Different mechanisms transport substances over short or long distances 767

The Apoplast and Symplast: Transport Continuums 767

Short-Distance Transport of Solutes Across Plasma Membranes 768

Short-Distance Transport of Water Across Plasma Membranes 768

Long-Distance Transport: The Role of Bulk Flow 771

**CONCEPT 36.3** Transpiration drives the transport of water and minerals from roots to shoots via the xylem 772

Absorption of Water and Minerals by Root Cells 772

Transport of Water and Minerals into the Xylem 772

Bulk Flow Transport via the Xylem 772

Xylem Sap Ascent by Bulk Flow: A Review 776

**CONCEPT 36.4** The rate of transpiration is regulated by stomata 776

Stomata: Major Pathways for Water Loss 776

Mechanisms of Stomatal Opening and Closing 777

Stimuli for Stomatal Opening and Closing 777

Effects of Transpiration on Wilting and Leaf

Temperature 778

Adaptations That Reduce Evaporative Water Loss 778

**CONCEPT 36.5** Sugars are transported from sources to sinks via the phloem 779

Movement from Sugar Sources to Sugar Sinks 779

Bulk Flow by Positive Pressure: The Mechanism of Translocation in Angiosperms 780

**CONCEPT 36.6** The symplast is highly dynamic 781

Changes in Plasmodesmata 782

Phloem: An Information Superhighway 782

Electrical Signaling in the Phloem 782

## 37

### Soil and Plant Nutrition 785

**OVERVIEW** A Horrifying Discovery 785

**CONCEPT 37.1** Soil contains a living, complex ecosystem 785

Soil Texture 786

Topsoil Composition 786

Soil Conservation and Sustainable Agriculture 787

**CONCEPT 37.2** Plants require essential elements to complete their life cycle 789

Macronutrients and Micronutrients 790

Symptoms of Mineral Deficiency 790

Improving Plant Nutrition by Genetic

Modification: Some Examples 792

**CONCEPT 37.3** Plant nutrition often involves relationships with other organisms 792

Soil Bacteria and Plant Nutrition 793

Fungi and Plant Nutrition 795

Epiphytes, Parasitic Plants, and Carnivorous Plants 797

## 38

### Angiosperm Reproduction and Biotechnology 801

**OVERVIEW** Flowers of Deceit 801

**CONCEPT 38.1** Flowers, double fertilization, and fruits are unique features of the angiosperm life cycle 801

Flower Structure and Function 802

Double Fertilization 806

Seed Development, Form, and Function 807

Fruit Form and Function 809

**CONCEPT 38.2** Flowering plants reproduce sexually, asexually, or both 812

Mechanisms of Asexual Reproduction 812

Advantages and Disadvantages of Asexual Versus Sexual Reproduction 812

Mechanisms That Prevent Self-Fertilization 813

Vegetative Propagation and Agriculture 814

**CONCEPT 38.3** Humans modify crops by breeding and genetic engineering 815

Plant Breeding 815

Plant Biotechnology and Genetic Engineering 816

The Debate over Plant Biotechnology 817

## 39 Plant Responses to Internal and External Signals 821

**OVERVIEW** Stimuli and a Stationary Life 821

**CONCEPT 39.1** Signal transduction pathways link signal reception to response 821

- Reception 822
- Transduction 822
- Response 823

**CONCEPT 39.2** Plant hormones help coordinate growth, development, and responses to stimuli 824

- The Discovery of Plant Hormones 825
- A Survey of Plant Hormones 826
- Systems Biology and Hormone Interactions 834

**CONCEPT 39.3** Responses to light are critical for plant success 835

- Blue-Light Photoreceptors 836
- Phytochromes as Photoreceptors 836
- Biological Clocks and Circadian Rhythms 838
- The Effect of Light on the Biological Clock 838
- Photoperiodism and Responses to Seasons 839

**CONCEPT 39.4** Plants respond to a wide variety of stimuli other than light 841

- Gravity 841
- Mechanical Stimuli 842
- Environmental Stresses 843

**CONCEPT 39.5** Plants respond to attacks by herbivores and pathogens 845

- Defenses Against Herbivores 845
- Defenses Against Pathogens 846

### UNIT

## 7

## Animal Form and Function 850

Interview: Baldomero M. Olivera

## 40 Basic Principles of Animal Form and Function 852

**OVERVIEW** Diverse Forms, Common Challenges 852

**CONCEPT 40.1** Animal form and function are correlated at all levels of organization 852

- Evolution of Animal Size and Shape 853
- Exchange with the Environment 853
- Hierarchical Organization of Body Plans 855
- Coordination and Control 859

**CONCEPT 40.2** Feedback control maintains the internal environment in many animals 860

- Regulating and Conforming 860
- Homeostasis 860

**CONCEPT 40.3** Homeostatic processes for thermoregulation involve form, function, and behavior 862

- Endothermy and Ectothermy 863
- Variation in Body Temperature 863
- Balancing Heat Loss and Gain 864
- Acclimatization in Thermoregulation 867
- Physiological Thermostats and Fever 867

**CONCEPT 40.4** Energy requirements are related to animal size, activity, and environment 868

- Energy Allocation and Use 868

Quantifying Energy Use 869

Minimum Metabolic Rate and Thermoregulation 869

Influences on Metabolic Rate 870

Energy Budgets 871

Torpor and Energy Conservation 871

## 41 Animal Nutrition 875

**OVERVIEW** The Need to Feed 875

**CONCEPT 41.1** An animal's diet must supply chemical energy, organic molecules, and essential nutrients 875

- Essential Nutrients 876
- Dietary Deficiencies 878
- Assessing Nutritional Needs 879

**CONCEPT 41.2** The main stages of food processing are ingestion, digestion, absorption, and elimination 880

- Digestive Compartments 880

**CONCEPT 41.3** Organs specialized for sequential stages of food processing form the mammalian digestive system 883

- The Oral Cavity, Pharynx, and Esophagus 883
- Digestion in the Stomach 885
- Digestion in the Small Intestine 887
- Absorption in the Small Intestine 887
- Absorption in the Large Intestine 888

**CONCEPT 41.4** Evolutionary adaptations of vertebrate digestive systems correlate with diet 889

- Dental Adaptations 889
- Stomach and Intestinal Adaptations 890
- Mutualistic Adaptations 890

**CONCEPT 41.5** Feedback circuits regulate digestion, energy storage, and appetite 891

- Regulation of Digestion 891
- Regulation of Energy Storage 892
- Regulation of Appetite and Consumption 893
- Obesity and Evolution 894

## 42 Circulation and Gas Exchange 897

**OVERVIEW** Trading Places 897

**CONCEPT 42.1** Circulatory systems link exchange surfaces with cells throughout the body 897

- Gastrovascular Cavities 898
- Evolutionary Variation in Circulatory Systems 898
- Organization of Vertebrate Circulatory Systems 899

**CONCEPT 42.2** Coordinated cycles of heart contraction drive double circulation in mammals 902

- Mammalian Circulation 902
- The Mammalian Heart: A Closer Look 902
- Maintaining the Heart's Rhythmic Beat 904

**CONCEPT 42.3** Patterns of blood pressure and flow reflect the structure and arrangement of blood vessels 905

- Blood Vessel Structure and Function 905
- Blood Flow Velocity 905
- Blood Pressure 906
- Capillary Function 908
- Fluid Return by the Lymphatic System 909

**CONCEPT 42.4** Blood components function in exchange, transport, and defense 910

- Blood Composition and Function 910
- Cardiovascular Disease 913



**CONCEPT 42.5 Gas exchange occurs across specialized respiratory surfaces 915**

Partial Pressure Gradients in Gas Exchange 915  
Respiratory Media 915  
Respiratory Surfaces 916  
Gills in Aquatic Animals 916  
Tracheal Systems in Insects 917  
Lungs 918

**CONCEPT 42.6 Breathing ventilates the lungs 920**

How an Amphibian Breathes 920  
How a Bird Breathes 920  
How a Mammal Breathes 921  
Control of Breathing in Humans 922

**CONCEPT 42.7 Adaptations for gas exchange include pigments that bind and transport gases 923**

Coordination of Circulation and Gas Exchange 923  
Respiratory Pigments 923  
Respiratory Adaptations of Diving Mammals 925

## 43 The Immune System 929

**OVERVIEW Recognition and Response 929**

**CONCEPT 43.1 In innate immunity, recognition and response rely on traits common to groups of pathogens 930**

Innate Immunity of Invertebrates 930  
Innate Immunity of Vertebrates 932  
Evasion of Innate Immunity by Pathogens 934

**CONCEPT 43.2 In adaptive immunity, receptors provide pathogen-specific recognition 935**

Antigen Recognition by B Cells and Antibodies 935  
Antigen Recognition by T Cells 936  
B Cell and T Cell Development 937

**CONCEPT 43.3 Adaptive immunity defends against infection of body fluids and body cells 940**

Helper T Cells: A Response to Nearly All Antigens 940  
Cytotoxic T Cells: A Response to Infected Cells 941  
B Cells and Antibodies: A Response to Extracellular Pathogens 942  
Summary of the Humoral and Cell-Mediated Immune Responses 944  
Active and Passive Immunization 944  
Antibodies as Tools 945  
Immune Rejection 945

**CONCEPT 43.4 Disruptions in immune system function can elicit or exacerbate disease 946**

Exaggerated, Self-Directed, and Diminished Immune Responses 946  
Evolutionary Adaptations of Pathogens That Underlie Immune System Avoidance 948  
Cancer and Immunity 950

## 44 Osmoregulation and Excretion 953

**OVERVIEW A Balancing Act 953**

**CONCEPT 44.1 Osmoregulation balances the uptake and loss of water and solutes 953**

Osmosis and Osmolarity 953  
Osmotic Challenges 954  
Energetics of Osmoregulation 956  
Transport Epithelia in Osmoregulation 957



**CONCEPT 44.2 An animal's nitrogenous wastes reflect its phylogeny and habitat 958**

Forms of Nitrogenous Waste 958  
The Influence of Evolution and Environment on Nitrogenous Wastes 959

**CONCEPT 44.3 Diverse excretory systems are variations on a tubular theme 960**

Excretory Processes 960  
Survey of Excretory Systems 960

**CONCEPT 44.4 The nephron is organized for stepwise processing of blood filtrate 963**

From Blood Filtrate to Urine: A Closer Look 964  
Solute Gradients and Water Conservation 965  
Adaptations of the Vertebrate Kidney to Diverse Environments 967

**CONCEPT 44.5 Hormonal circuits link kidney function, water balance, and blood pressure 968**

Antidiuretic Hormone 969  
The Renin-Angiotensin-Aldosterone System 970  
Homeostatic Regulation of the Kidney 971

## 45 Hormones and the Endocrine System 974

**OVERVIEW The Body's Long-Distance Regulators 974**

**CONCEPT 45.1 Hormones and other signaling molecules bind to target receptors, triggering specific response pathways 975**

Inter cellular Communication 975  
Endocrine Tissues and Organs 976  
Chemical Classes of Hormones 976  
Cellular Response Pathways 977  
Multiple Effects of Hormones 978  
Signaling by Local Regulators 979  
Coordination of Neuroendocrine and Endocrine Signaling 980

**CONCEPT 45.2 Feedback regulation and antagonistic hormone pairs are common in endocrine systems 981**

Simple Hormone Pathways 981  
Feedback Regulation 982  
Insulin and Glucagon: Control of Blood Glucose 982

**CONCEPT 45.3 The hypothalamus and pituitary are central to endocrine regulation 984**

Coordination of Endocrine and Nervous Systems in Vertebrates 984  
Thyroid Regulation: A Hormone Cascade Pathway 987  
Evolution of Hormone Function 988  
Tropic and Nontropic Hormones 989

**CONCEPT 45.4 Endocrine glands respond to diverse stimuli in regulating homeostasis, development, and behavior 989**

Parathyroid Hormone and Vitamin D: Control of Blood Calcium 989  
Adrenal Hormones: Response to Stress 990  
Gonadal Sex Hormones 992  
Melatonin and Biorhythms 993



## 46 Animal Reproduction 996

**OVERVIEW** Pairing Up for Sexual Reproduction 996

**CONCEPT 46.1** Both asexual and sexual reproduction occur in the animal kingdom 996

Mechanisms of Asexual Reproduction 996

Sexual Reproduction: An Evolutionary Enigma 997

Reproductive Cycles 998

Variation in Patterns of Sexual Reproduction 998

**CONCEPT 46.2** Fertilization depends on mechanisms that bring together sperm and eggs of the same species 999

Ensuring the Survival of Offspring 1000

Gamete Production and Delivery 1000

**CONCEPT 46.3** Reproductive organs produce and transport gametes 1002

Female Reproductive Anatomy 1002

Male Reproductive Anatomy 1004

Gametogenesis 1005

**CONCEPT 46.4** The interplay of tropic and sex hormones regulates mammalian reproduction 1008

Hormonal Control of Female Reproductive Cycles 1008

Hormonal Control of the Male Reproductive System 1010

Human Sexual Response 1011

**CONCEPT 46.5** In placental mammals, an embryo develops fully within the mother's uterus 1011

Conception, Embryonic Development, and Birth 1012

Maternal Immune Tolerance of the Embryo and Fetus 1015

Contraception and Abortion 1015

Modern Reproductive Technologies 1017

## 47 Animal Development 1021

**OVERVIEW** A Body-Building Plan 1021

**CONCEPT 47.1** Fertilization and cleavage initiate embryonic development 1022

Fertilization 1022

Cleavage 1025

**CONCEPT 47.2** Morphogenesis in animals involves specific changes in cell shape, position, and survival 1027

Gastrulation 1027

Developmental Adaptations of Amniotes 1031

Organogenesis 1031

Mechanisms of Morphogenesis 1033

**CONCEPT 47.3** Cytoplasmic determinants and inductive signals contribute to cell fate specification 1035

Fate Mapping 1035

Cell Fate Determination and Pattern Formation by

Inductive Signals 1039

## 48 Neurons, Synapses, and Signaling 1045

**OVERVIEW** Lines of Communication 1045

**CONCEPT 48.1** Neuron organization and structure reflect function in information transfer 1045

Introduction to Information Processing 1046

Neuron Structure and Function 1046

**CONCEPT 48.2** Ion pumps and ion channels establish the resting potential of a neuron 1048

Formation of the Resting Potential 1048

Modeling the Resting Potential 1049

**CONCEPT 48.3** Action potentials are the signals conducted by axons 1050

Hyperpolarization and Depolarization 1050

Graded Potentials and Action Potentials 1050

Generation of Action Potentials: *A Closer Look* 1051

Conduction of Action Potentials 1053

**CONCEPT 48.4** Neurons communicate with other cells at synapses 1055

Generation of Postsynaptic Potentials 1056

Summation of Postsynaptic Potentials 1056

Modulated Signaling at Synapses 1057

Neurotransmitters 1057

## 49 Nervous Systems 1062

**OVERVIEW** Command and Control Center 1062

**CONCEPT 49.1** Nervous systems consist of circuits of neurons and supporting cells 1062

Organization of the Vertebrate Nervous System 1063

Glia 1065

The Peripheral Nervous System 1066

**CONCEPT 49.2** The vertebrate brain is regionally specialized 1067

Arousal and Sleep 1067

Biological Clock Regulation 1070

Emotions 1071

**CONCEPT 49.3** The cerebral cortex controls voluntary movement and cognitive functions 1072

Language and Speech 1072

Lateralization of Cortical Function 1073

Information Processing 1074

Frontal Lobe Function 1075

Evolution of Cognition in Vertebrates 1075

**CONCEPT 49.4** Changes in synaptic connections underlie memory and learning 1076

Neural Plasticity 1076

Memory and Learning 1077

Long-Term Potentiation 1077

Stem Cells in the Brain 1078

**CONCEPT 49.5** Many nervous system disorders can be explained in molecular terms 1079

Schizophrenia 1079

Depression 1080

Drug Addiction and the Brain's Reward System 1080

Alzheimer's Disease 1081

Parkinson's Disease 1081





## 50

### Sensory and Motor Mechanisms 1085

#### OVERVIEW Sensing and Acting 1085

##### CONCEPT 50.1 Sensory receptors transduce stimulus energy and transmit signals to the central nervous system 1085

Sensory Pathways 1086

Types of Sensory Receptors 1088

##### CONCEPT 50.2 The mechanoreceptors responsible for hearing and equilibrium detect moving fluid or settling particles 1090

Sensing of Gravity and Sound in Invertebrates 1090

Hearing and Equilibrium in Mammals 1090

Hearing and Equilibrium in Other Vertebrates 1094

##### CONCEPT 50.3 Visual receptors in diverse animals depend on light-absorbing pigments 1095

Evolution of Visual Perception 1095

The Vertebrate Visual System 1097

##### CONCEPT 50.4 The senses of taste and smell rely on similar sets of sensory receptors 1101

Taste in Mammals 1101

Smell in Humans 1102

##### CONCEPT 50.5 The physical interaction of protein filaments is required for muscle function 1103

Vertebrate Skeletal Muscle 1104

Other Types of Muscle 1109

##### CONCEPT 50.6 Skeletal systems transform muscle contraction into locomotion 1110

Types of Skeletal Systems 1111

Types of Locomotion 1113

Energy Costs of Locomotion 1114

## 51

### Animal Behavior 1118

#### OVERVIEW The How and Why of Animal Activity 1118

##### CONCEPT 51.1 Discrete sensory inputs can stimulate both simple and complex behaviors 1118

Fixed Action Patterns 1119

Migration 1119

Behavioral Rhythms 1120

Animal Signals and Communication 1120

##### CONCEPT 51.2 Learning establishes specific links between experience and behavior 1123

Experience and Behavior 1123

Learning 1123

##### CONCEPT 51.3 Selection for individual survival and reproductive success can explain most behaviors 1128

Foraging Behavior 1128

Mating Behavior and Mate Choice 1129

##### CONCEPT 51.4 Inclusive fitness can account for the evolution of behavior, including altruism 1134

Genetic Basis of Behavior 1134

Genetic Variation and the Evolution of Behavior 1135

Altruism 1137

Inclusive Fitness 1137

Evolution and Human Culture 1139

## UNIT

## 8

### Ecology 1142

Interview: Camille Parmesan

## 52

### An Introduction to Ecology and the Biosphere 1144

#### OVERVIEW Discovering Ecology 1144

##### CONCEPT 52.1 Earth's climate varies by latitude and season and is changing rapidly 1144

Global Climate Patterns 1147

Regional and Local Effects on Climate 1147

Microclimate 1149

Global Climate Change 1149

##### CONCEPT 52.2 The structure and distribution of terrestrial biomes are controlled by climate and disturbance 1150

Climate and Terrestrial Biomes 1151

General Features of Terrestrial Biomes 1151

Disturbance and Terrestrial Biomes 1152

##### CONCEPT 52.3 Aquatic biomes are diverse and dynamic systems that cover most of Earth 1157

Zonation in Aquatic Biomes 1157

##### CONCEPT 52.4 Interactions between organisms and the environment limit the distribution of species 1163

Dispersal and Distribution 1164

Behavior and Habitat Selection 1165

Biotic Factors 1165

Abiotic Factors 1166



## 53

### Population Ecology 1170

#### OVERVIEW Counting Sheep 1170

##### CONCEPT 53.1 Dynamic biological processes influence population density, dispersion, and demographics 1170

Density and Dispersion 1171

Demographics 1173

##### CONCEPT 53.2 The exponential model describes population growth in an idealized, unlimited environment 1175

Per Capita Rate of Increase 1175

Exponential Growth 1176



**CONCEPT 53.3** The logistic model describes how a population grows more slowly as it nears its carrying capacity 1177

The Logistic Growth Model 1177

The Logistic Model and Real Populations 1178

**CONCEPT 53.4** Life history traits are products of natural selection 1179

Evolution and Life History Diversity 1180

“Trade-offs” and Life Histories 1180

**CONCEPT 53.5** Many factors that regulate population growth are density dependent 1182

Population Change and Population Density 1182

Mechanisms of Density-Dependent Population

Regulation 1182

Population Dynamics 1184

**CONCEPT 53.6** The human population is no longer growing exponentially but is still increasing rapidly 1187

The Global Human Population 1187

Global Carrying Capacity 1190

## 54 Community Ecology 1194

**OVERVIEW** Communities in Motion 1194

**CONCEPT 54.1** Community interactions are classified by whether they help, harm, or have no effect on the species involved 1194

Competition 1195

Predation 1197

Herbivory 1198

Symbiosis 1198

Facilitation 1200

**CONCEPT 54.2** Diversity and trophic structure characterize biological communities 1200

Species Diversity 1200

Diversity and Community Stability 1201

Trophic Structure 1202

Species with a Large Impact 1204

Bottom-Up and Top-Down Controls 1206

**CONCEPT 54.3** Disturbance influences species diversity and composition 1207

Characterizing Disturbance 1207

Ecological Succession 1208

Human Disturbance 1210

**CONCEPT 54.4** Biogeographic factors affect community diversity 1211

Latitudinal Gradients 1211

Area Effects 1211

Island Equilibrium Model 1212

**CONCEPT 54.5** Pathogens alter community structure locally and globally 1213

Pathogens and Community Structure 1214

Community Ecology and Zoonotic Diseases 1214

## 55 Ecosystems and Restoration Ecology 1218

**OVERVIEW** Cool Ecosystem 1218

**CONCEPT 55.1** Physical laws govern energy flow and chemical cycling in ecosystems 1219

Conservation of Energy 1219

Conservation of Mass 1219

Energy, Mass, and Trophic Levels 1219

**CONCEPT 55.2** Energy and other limiting factors control primary production in ecosystems 1220

Ecosystem Energy Budgets 1221

Primary Production in Aquatic Ecosystems 1223

Primary Production in Terrestrial Ecosystems 1224

**CONCEPT 55.3** Energy transfer between trophic levels is typically only 10% efficient 1225

Production Efficiency 1225

Trophic Efficiency and Ecological Pyramids 1225

**CONCEPT 55.4** Biological and geochemical processes cycle nutrients and water in ecosystems 1227

Biogeochemical Cycles 1227

Decomposition and Nutrient Cycling Rates 1230

*Case Study:* Nutrient Cycling in the Hubbard Brook

Experimental Forest 1231

**CONCEPT 55.5** Restoration ecologists help return degraded ecosystems to a more natural state 1232

Bioremediation 1232

Biological Augmentation 1233

Restoration Projects Worldwide 1233

## 56 Conservation Biology and Global Change 1238

**OVERVIEW** Striking Gold 1238

**CONCEPT 56.1** Human activities threaten Earth's biodiversity 1239

Three Levels of Biodiversity 1239

Biodiversity and Human Welfare 1240

Threats to Biodiversity 1241

**CONCEPT 56.2** Population conservation focuses on population size, genetic diversity, and critical habitat 1244

Small-Population Approach 1245

Declining-Population Approach 1247

Weighing Conflicting Demands 1249

**CONCEPT 56.3** Landscape and regional conservation help sustain biodiversity 1249

Landscape Structure and Biodiversity 1249

Establishing Protected Areas 1251

**CONCEPT 56.4** Earth is changing rapidly as a result of human actions 1254

Nutrient Enrichment 1254

Toxins in the Environment 1255

Greenhouse Gases and Global Warming 1256

Depletion of Atmospheric Ozone 1258

**CONCEPT 56.5** Sustainable development can improve human lives while conserving biodiversity 1260

Sustainable Biosphere Initiative 1260

The Future of the Biosphere 1261

[Appendix A](#) Answers A–1

[Appendix B](#) Periodic Table of the Elements B–1

[Appendix C](#) The Metric System C–1

[Appendix D](#) A Comparison of the Light Microscope and the Electron Microscope D–1

[Appendix E](#) Classification of Life E–1

[Credits](#) CR–1

[Glossary](#) G–1

[Index](#) I–1

# 1

## Introduction: Themes in the Study of Life



▲ **Figure 1.1** How is the mother-of-pearl plant adapted to its environment?

### KEY CONCEPTS

- 1.1 The themes of this book make connections across different areas of biology
- 1.2 The Core Theme: Evolution accounts for the unity and diversity of life
- 1.3 In studying nature, scientists make observations and then form and test hypotheses
- 1.4 Science benefits from a cooperative approach and diverse viewpoints

### OVERVIEW

## Inquiring About Life

The mother-of-pearl plant, or ghost plant (**Figure 1.1** and cover), is native to a single mountain in northeastern Mexico. Its fleshy, succulent leaves and other features allow this plant to store and conserve water. Even when rain falls, the plant's access to water is limited because it grows in crevices

of vertical rock walls, where little soil is present to hold rain-water (**Figure 1.2**). The plant's water-conserving characteristics help it survive and thrive in these nooks and crannies. Similar features are found in many plants that live in dry environments, allowing them to eke out a living where rain is unpredictable.

An organism's adaptations to its environment, such as adaptations for conserving water, are the result of **evolution**, the process of change that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. Evolution is the fundamental organizing principle of biology and the core theme of this book.

Although biologists know a great deal about life on Earth, many mysteries remain. For instance, what exactly led to the origin of flowering among plants such as the one pictured here? Posing questions about the living world and seeking science-based answers—scientific inquiry—are the central activities of **biology**, the scientific study of life. Biologists' questions can be ambitious. They may ask how a single tiny cell becomes a tree or a dog, how the human mind works, or how the different forms of life in a forest interact. Most people wonder about the organisms living around them, and many interesting questions probably occur to you when you are out-of-doors, surrounded by the natural world. When they do, you are already thinking like a biologist. More than anything else, biology is a quest, an ongoing inquiry about the nature of life.

What is life? Even a small child realizes that a dog or a plant is alive, while a rock or a lawn mower is not. Yet the phenomenon we call life defies a simple, one-sentence definition. We recognize life by what living things do. **Figure 1.3**, on the next page, highlights some of the properties and processes we associate with life.

While limited to a handful of images, Figure 1.3 reminds us that the living world is wondrously varied. How do biologists



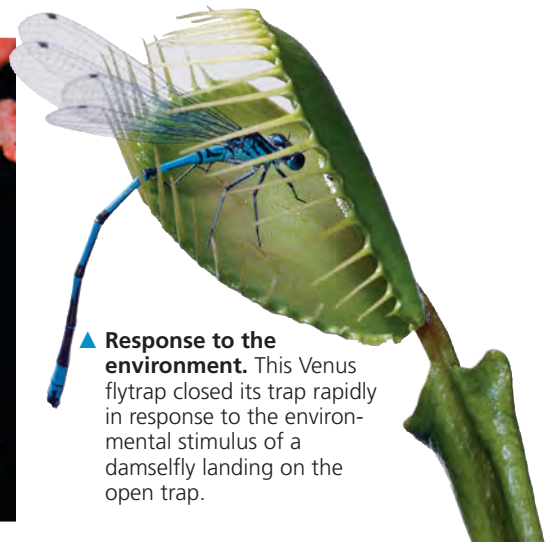
▲ **Figure 1.2** The mother-of-pearl plant (*Graptopetalum paraguayense*). This plant's thick leaves hold water, enabling it to live where soil is scarce. The leaves vary in color, as seen here.



▼ **Order.** This close-up of a sunflower illustrates the highly ordered structure that characterizes life.



▲ **Evolutionary adaptation.** The appearance of this pygmy sea horse camouflages the animal in its environment. Such adaptations evolve over many generations by the reproductive success of those individuals with heritable traits that are best suited to their environments.



▲ **Response to the environment.** This Venus flytrap closed its trap rapidly in response to the environmental stimulus of a damselfly landing on the open trap.



▲ **Regulation.** The regulation of blood flow through the blood vessels of this jackrabbit's ears helps maintain a constant body temperature by adjusting heat exchange with the surrounding air.



▲ **Energy processing.** This hummingbird obtains fuel in the form of nectar from flowers. The hummingbird will use chemical energy stored in its food to power flight and other work.

► **Reproduction.** Organisms (living things) reproduce their own kind. Here, a baby giraffe stands close to its mother.



◀ **Growth and development.** Inherited information carried by genes controls the pattern of growth and development of organisms, such as this Nile crocodile.

▲ **Figure 1.3** Some properties of life.

make sense of this diversity and complexity? This opening chapter sets up a framework for answering this question. The first part of the chapter provides a panoramic view of the biological “landscape,” organized around some unifying themes. We then focus on biology’s core theme, evolution, with an introduction to the reasoning that led Charles Darwin to his explanatory theory. Next, we look at scientific inquiry—how scientists raise and attempt to answer questions about the natural world. Finally, we address the culture of science and its effects on society.

## CONCEPT 1.1

### The themes of this book make connections across different areas of biology

Biology is a subject of enormous scope, and news reports reveal exciting new biological discoveries being made every day. Simply memorizing the factual details of this huge subject is most likely not the best way to develop a coherent view of