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BIOLOGY

NINTH EDITION

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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

PEARSON

www.pearsonhighered.com

3 4 5 6 7 8 9 10—CRK—14 13 12 11
Manufactured in the United States of America.

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Brief Contents

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 Microbiology 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 developmental 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 postdoctoral 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 numerous 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.

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:

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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.

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

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.

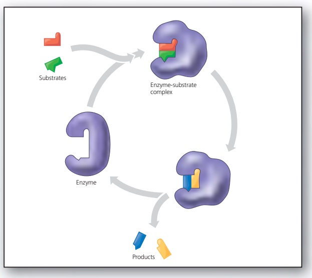
CONCEPT CHECK 52.1

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_3 and C_4 plants. Focusing just on the effects of temperature, would you expect the global distribution of C_4 plants to expand or contract as Earth becomes warmer? Why?

For suggested answers, see Appendix A.

Make connections across biology.

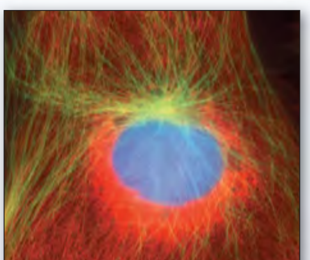
By relating the content of a chapter to material you learned earlier in the course, new **Make Connections Questions** help you develop a deeper understanding of biological principles.



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.

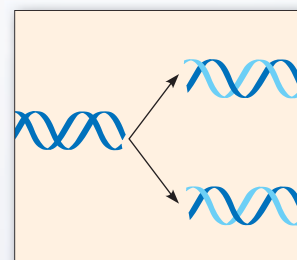
Enzymes (Chapter 8) — **Animal nutrition** (Chapter 41)

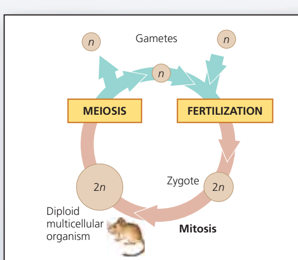


CONCEPT CHECK 16.2

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)

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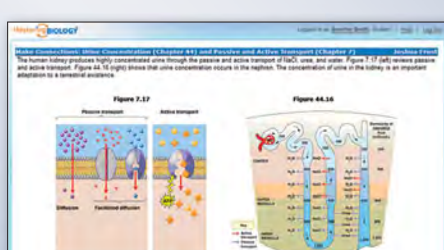
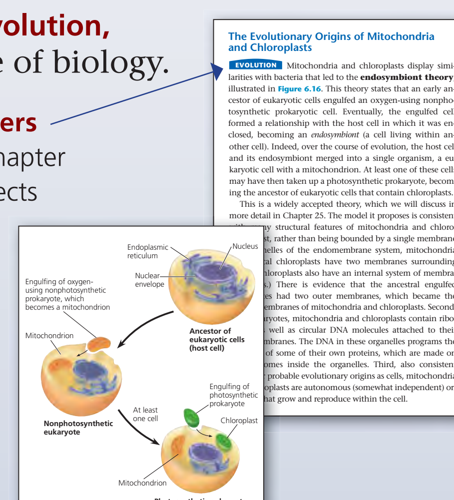


New **Make Connections Tutorials** help you connect biological concepts across chapters in an interactive way.

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.



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.

▼ 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 explains the relevance of the research. ▶

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 directs you to articles to explore. ▶

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).

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

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?

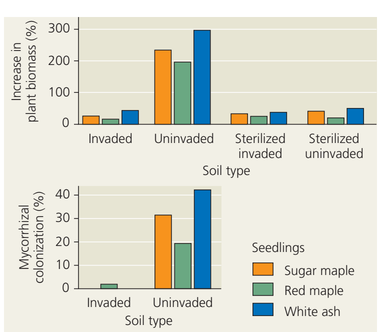
Inquiry Figures reveal "how we know what we know" by highlighting how researchers designed an experiment, interpreted their results, and drew conclusions.
▼

▼ Figure 37.14
INQUIRY

Does the invasive weed garlic mustard disrupt mutualistic associations between native tree seedlings and arbuscular mycorrhizal fungi?

EXPERIMENT Kristina Stinson, of Harvard University, and colleagues investigated the effect of invasive garlic mustard on the growth of native tree seedlings and associated mycorrhizal fungi. In one experiment, they grew seedlings of three North American trees—sugar maple, red maple, and white ash—in four different soils. Two of the soil samples were collected from a location where garlic mustard was growing, and one of these samples was sterilized. The other two soil samples were collected from a location devoid of garlic mustard, and one was then sterilized. After four months of growth, the researchers harvested the shoots and roots and determined the dried biomass. The roots were also analyzed for percent colonization by arbuscular mycorrhizal fungi.

RESULTS Native tree seedlings grew more slowly and were less able to form mycorrhizal associations when grown either in sterilized soil or in unsterilized soil collected from a location that had been invaded by garlic mustard.



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.

◀ 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.***

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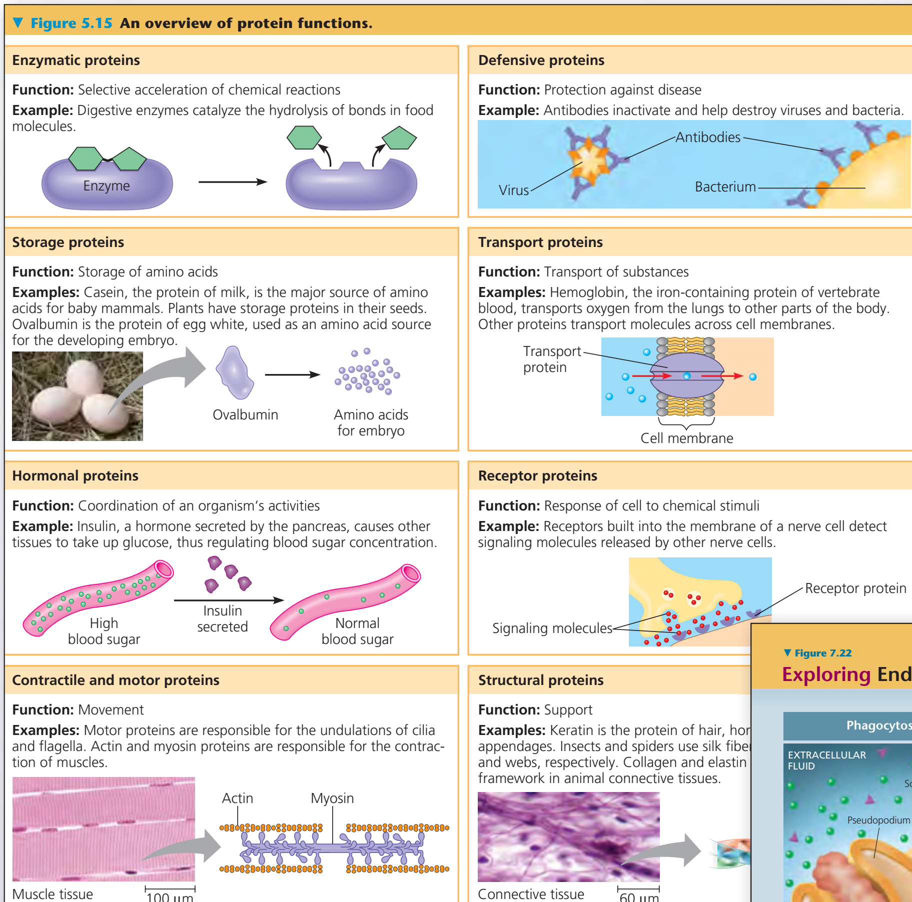
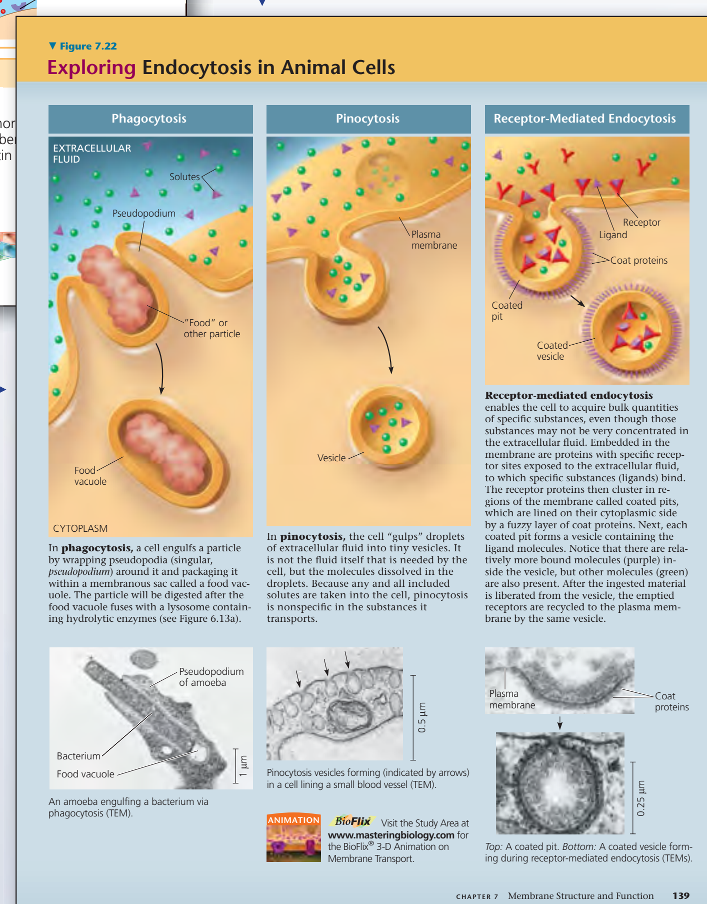
New **Experimental Inquiry Tutorials** give you practice analyzing experimental design and data and drawing conclusions.

Study the figures as you read the text.



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

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



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

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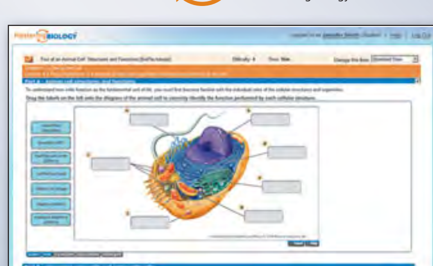


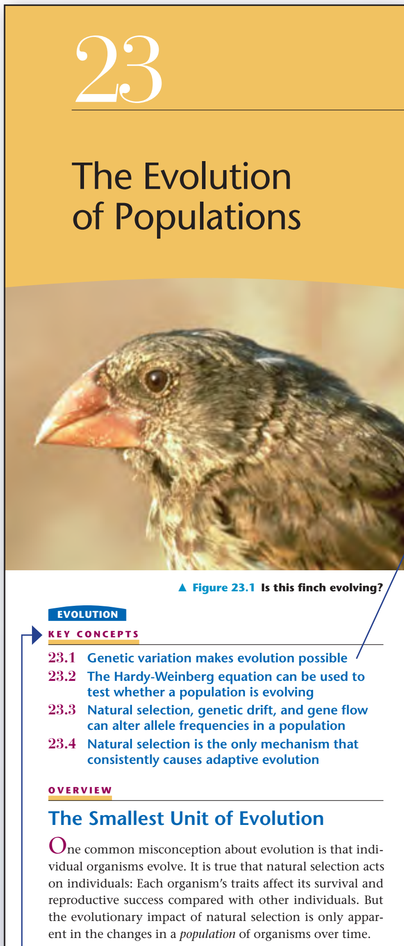
Many **Tutorials** and **Activities** integrate art from the textbook, providing a unified learning experience.

▲ **BioFlix®** icons direct you to high-impact 3-D animations in the Study Area at www.masteringbiology.com.

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

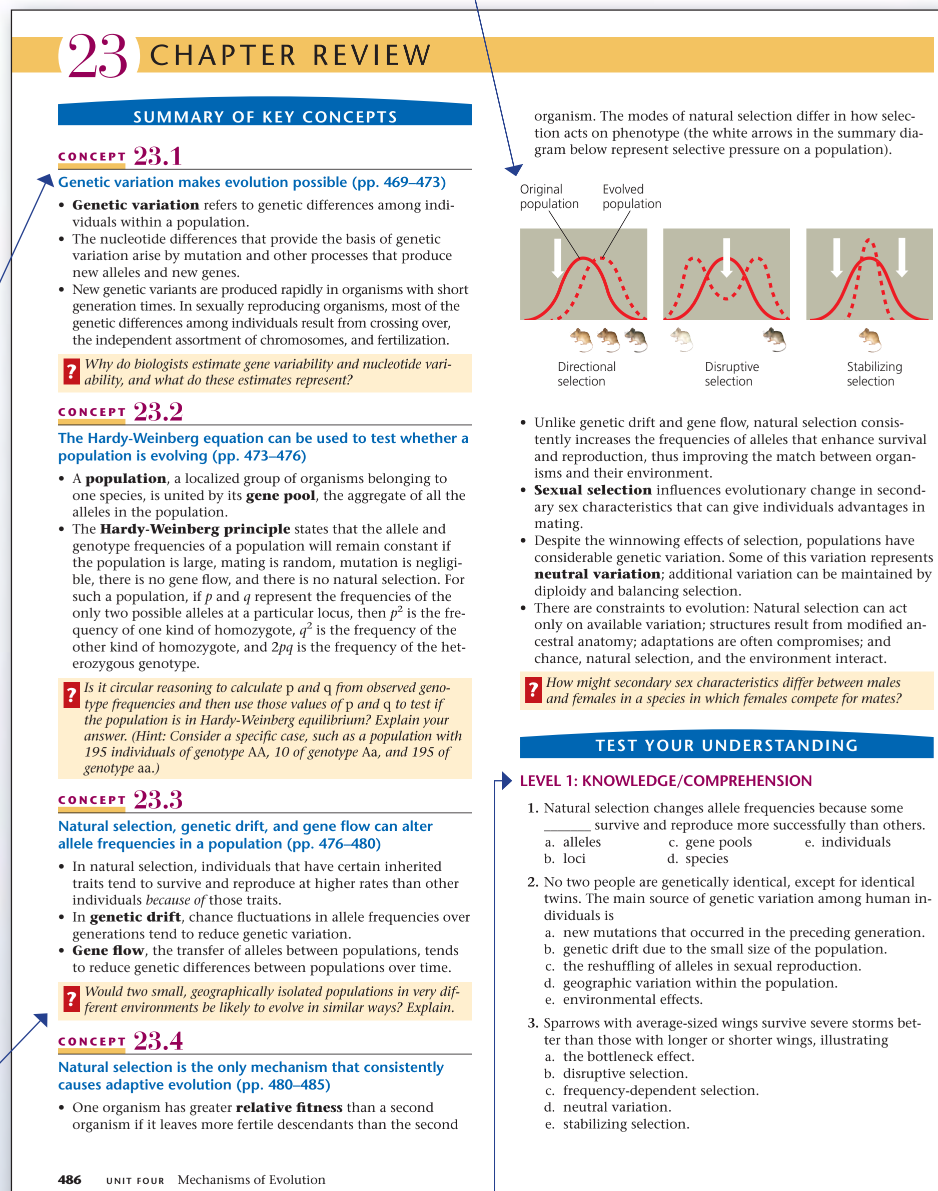
KEY CONCEPTS

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.


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).

- 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.

486 UNIT FOUR Mechanisms of Evolution

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.

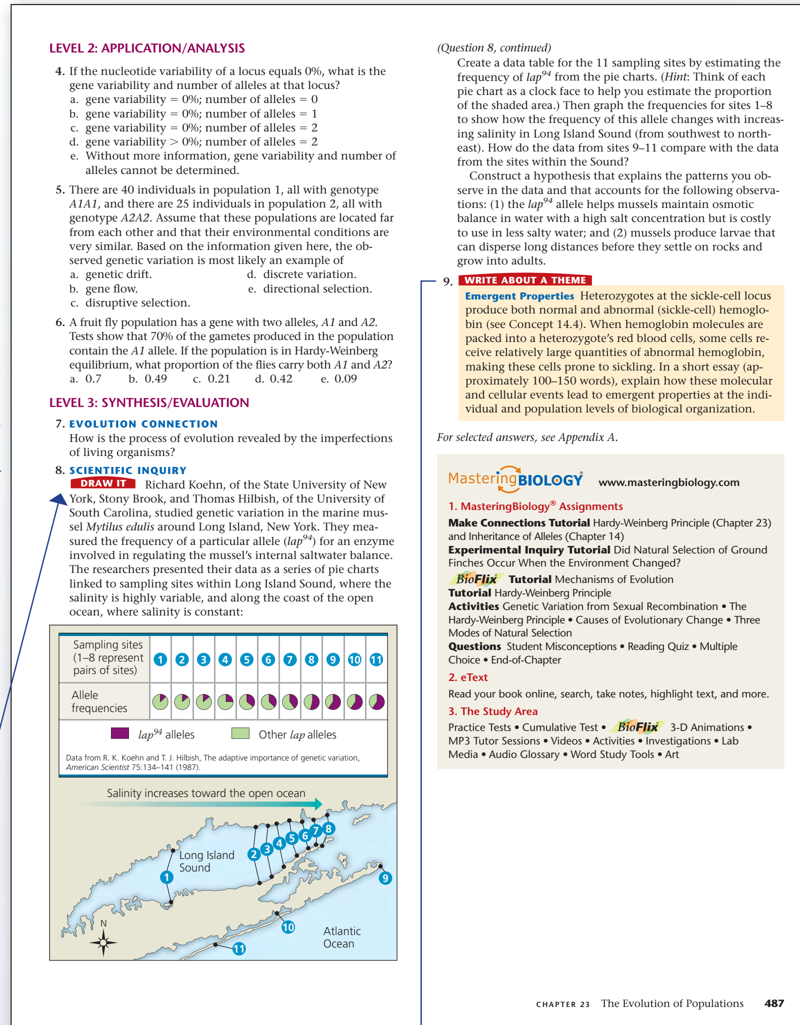
To help you prepare for the various kinds of questions that may appear on a test, the end-of-chapter questions are now organized into three levels based on Bloom's Taxonomy:

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 *A1A1*, and there are 25 individuals in population 2, all with genotype *A2A2*. 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, *A1* and *A2*. Tests show that 70% of the gametes produced in the population contain the *A1* allele. If the population is in Hardy-Weinberg equilibrium, what proportion of the flies carry both *A1* and *A2*?
   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*[94]) 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*[94] 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*[94] 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.

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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

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CHAPTER 23 The Evolution of Populations 487

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.

To the Student: How to Effectively

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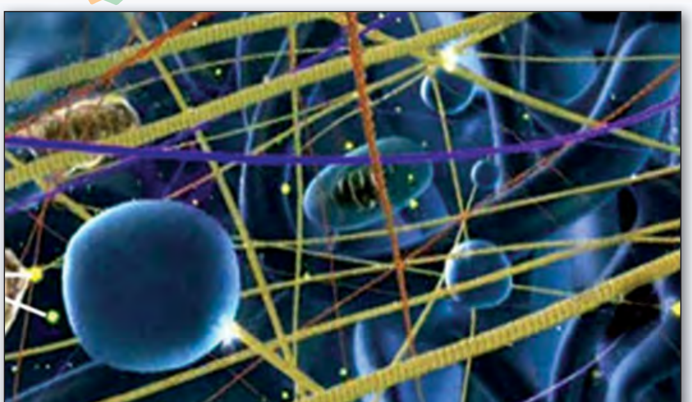

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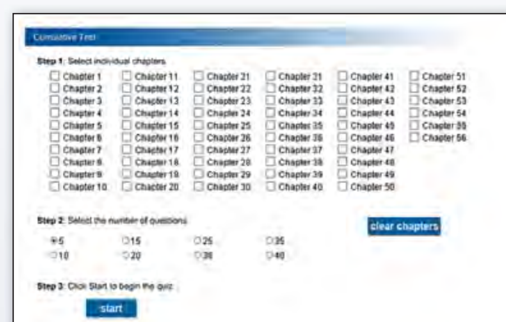

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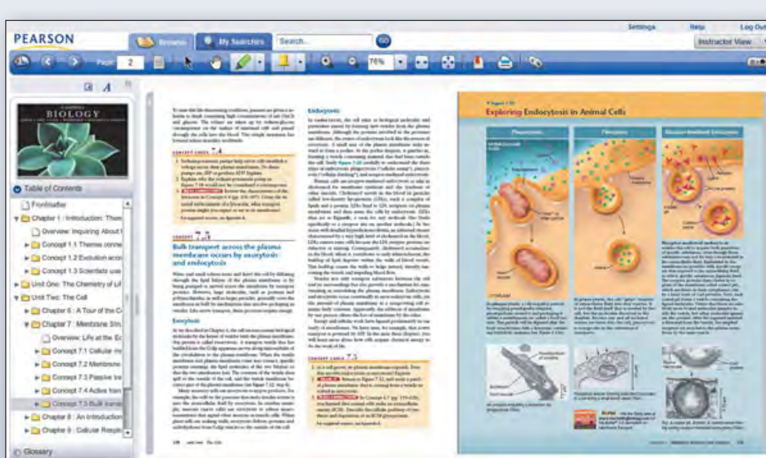

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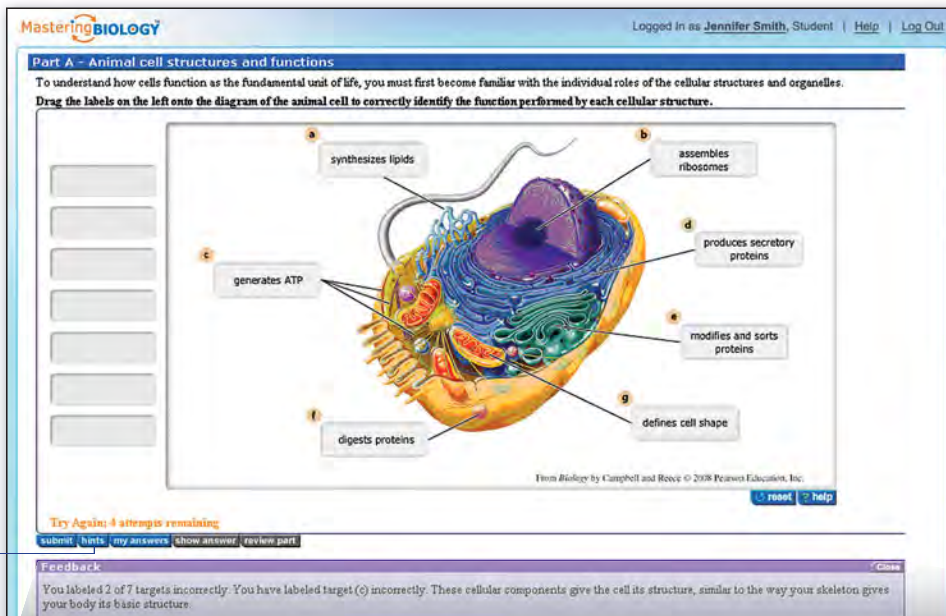
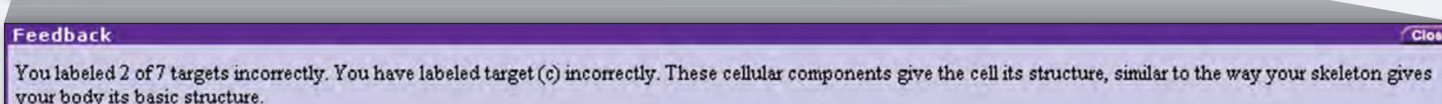
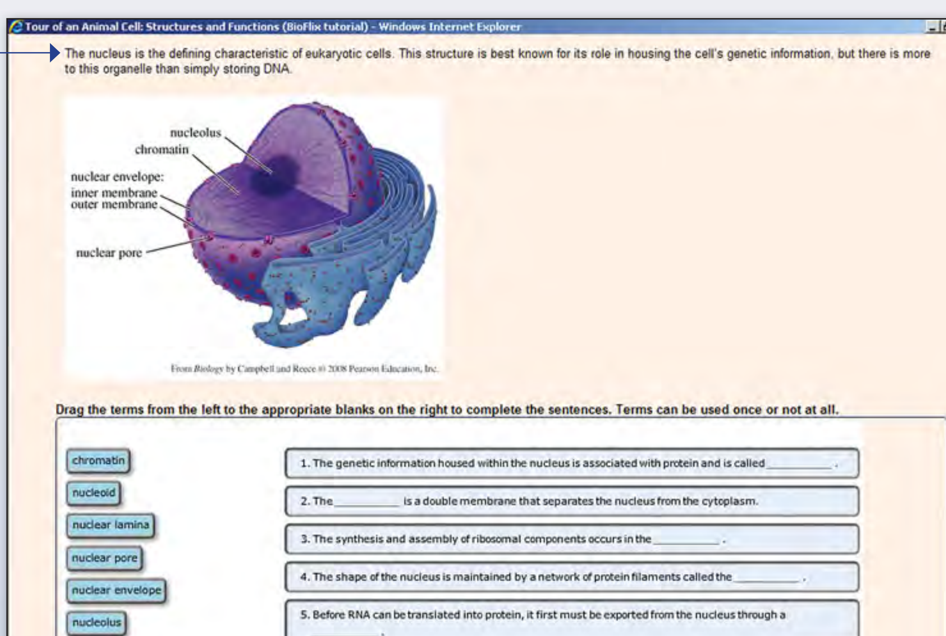




1 If you get stuck…



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

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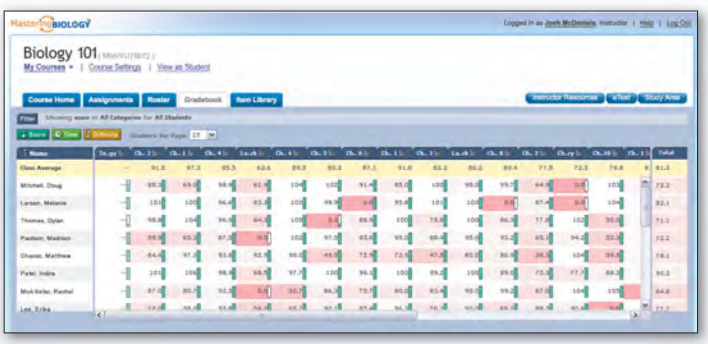

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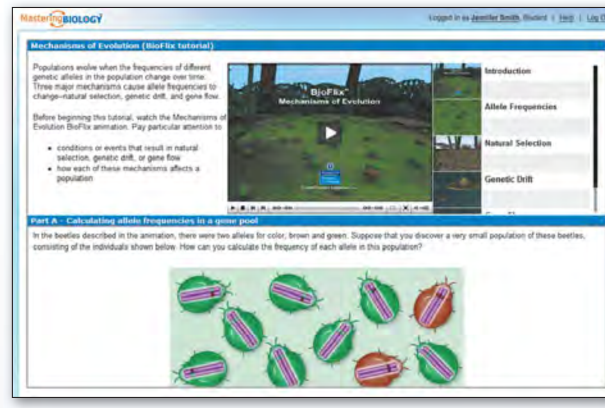

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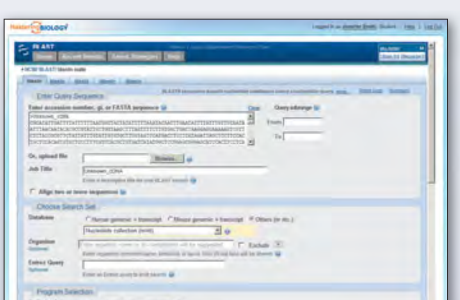
- Muscle Contraction
- Population Ecology
- The Carbon Cycle



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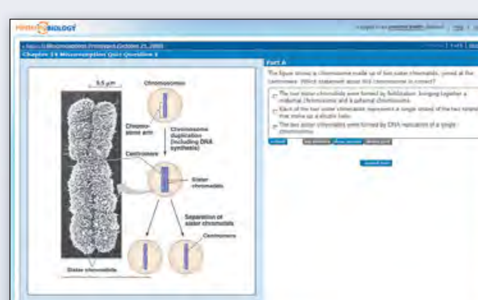

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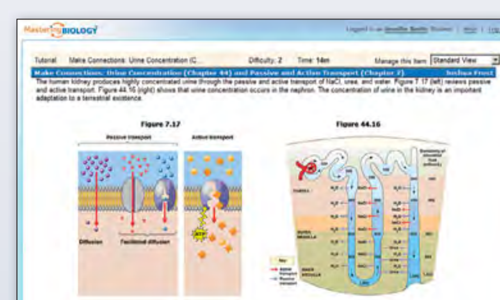

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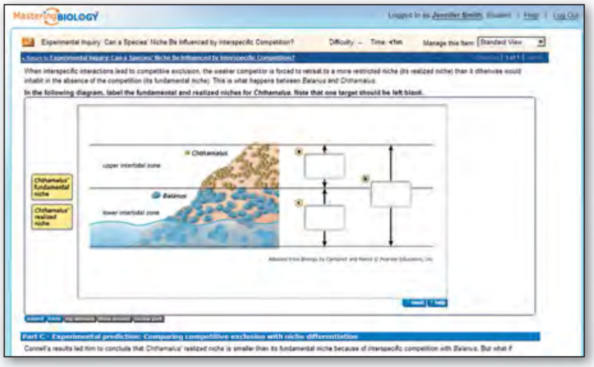

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- Does DNA Replication Follow the Conservative, Semiconservative, or Dispersive Model?
- Did Natural Selection of Ground Finches Occur When the Environment Changed?
- What Effect Does Auxin Have on Coleoptile Growth?
- What Role Do Genes Play in Appetite 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:

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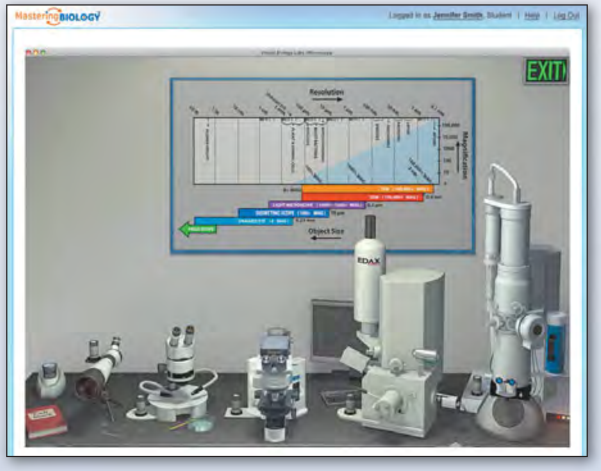

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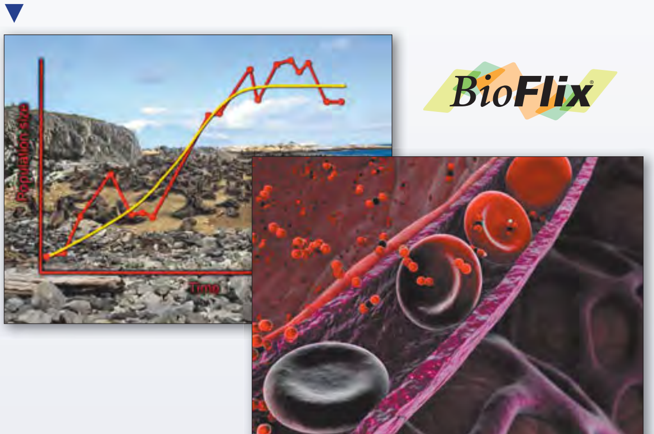

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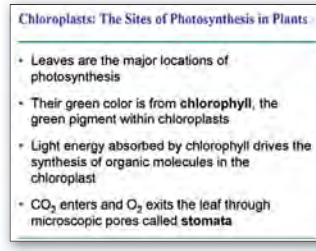

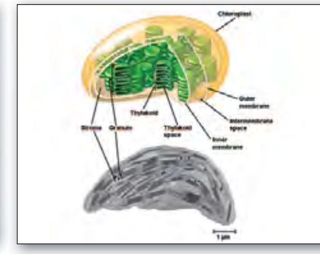

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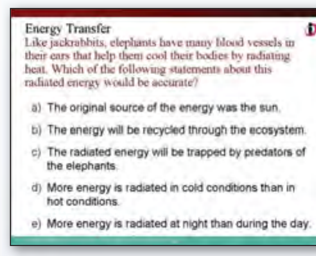

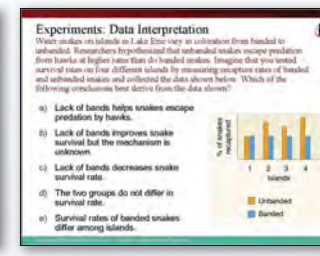

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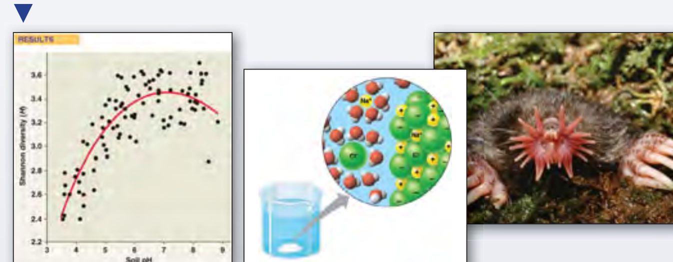

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Research Method Figures

Interviews

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 Cowlishaw, 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 Simione 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 Hespenheide; 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.

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Zai Ming Zhao *(University of Texas, Austin)*
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Miriam Zolan *(Indiana University)*
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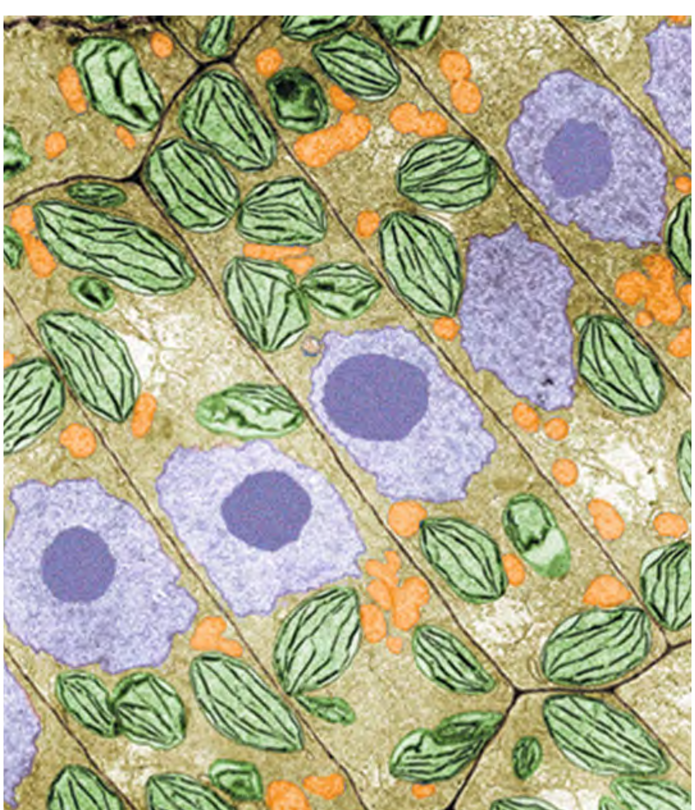

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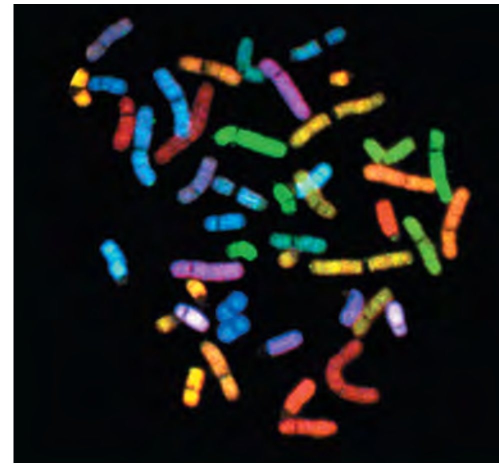

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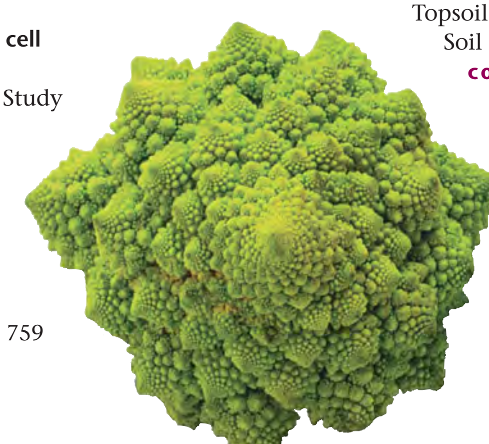

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1

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

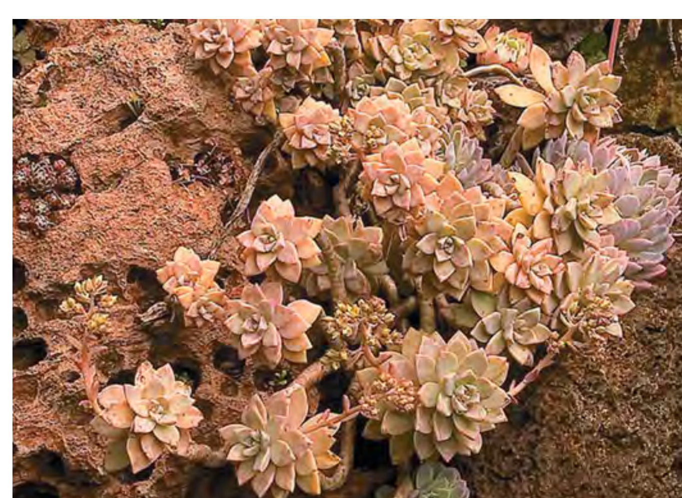
The mother-of-pearl plant, or ghost plant (**Figure 1.1** and cover), is native to a single mountain in northeastern Mexico. Its fleshy, succulent leaves and other features allow this plant to store and conserve water. Even when rain falls, the plant's access to water is limited because it grows in crevices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

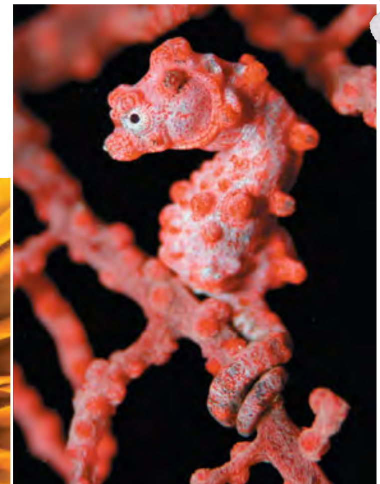
What is life? Even a small child realizes that a dog or a plant is alive, while a rock or a lawn mower is not. Yet the phenomenon we call life defies a simple, one-sentence definition. We recognize life by what living things do. **Figure 1.3**, on the next page, highlights some of the properties and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

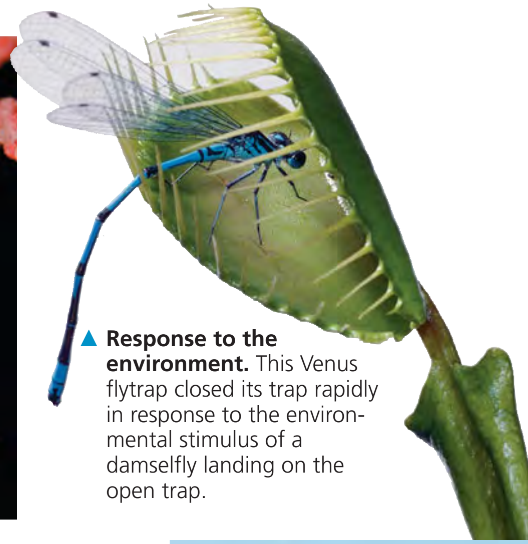


▲ **Figure 1.2 The mother-of-pearl plant (*Graptopetalum paraguayense*).** This plant's thick leaves hold water, enabling it to live where soil is scarce. The leaves vary in color, as seen here.

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



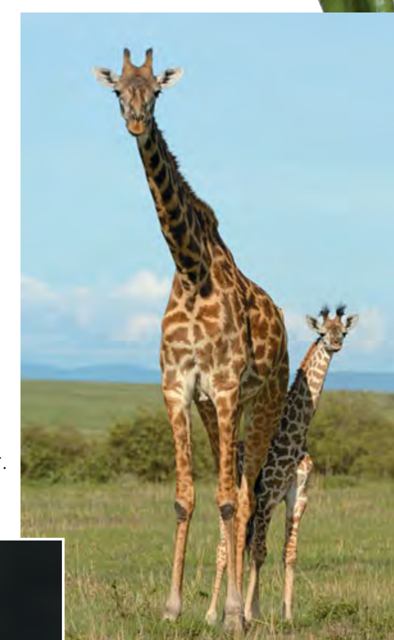
▲ **Evolutionary adaptation.** The appearance of this pygmy sea horse camouflages the animal in its environment. Such adaptations evolve over many generations by the reproductive success of those individuals with heritable traits that are best suited to their environments.



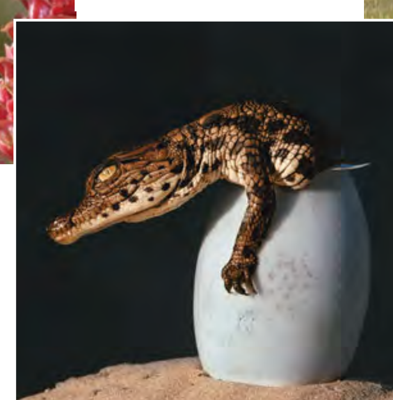
▲ **Response to the environment.** This Venus flytrap closed its trap rapidly in response to the environmental stimulus of a damselfly landing on the open trap.

▲ **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