TWELFTH EDITION

CAMPBELL BIOLOGY

URRY • CAIN • WASSERMAN
MINORSKY • ORR

Brief Contents

Students: Campbell offers many tools to help you succeed

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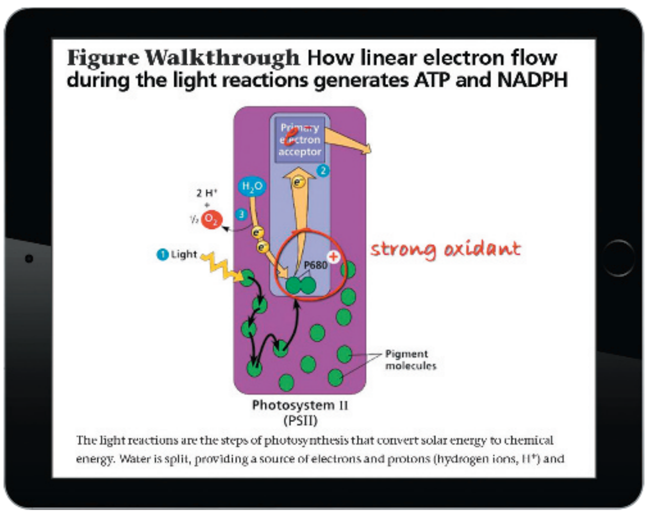
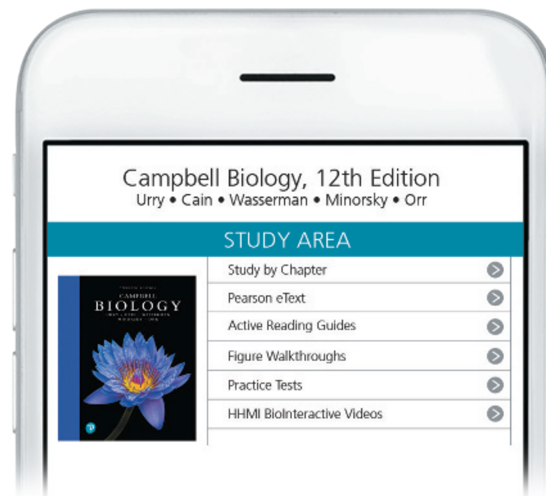
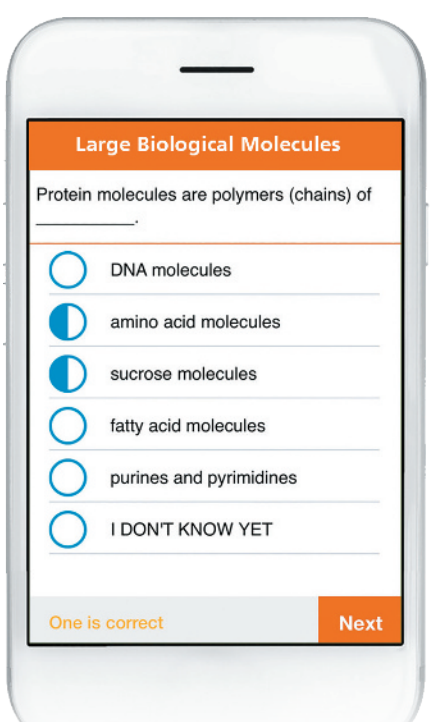


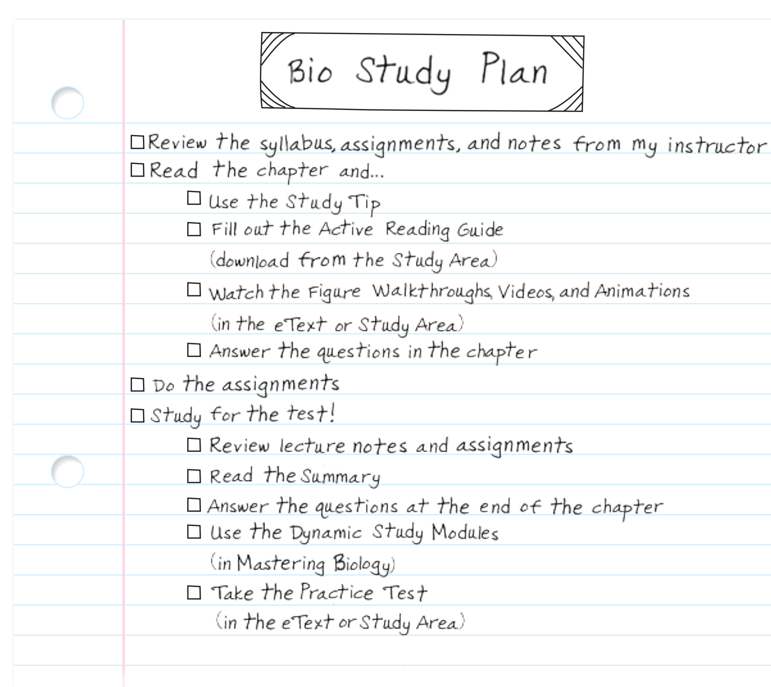
✔ Strengthen your knowledge in **the Mastering Biology Study Area**



✔ Prepare for your exams with **the Dynamic Study Modules**



✔ Use the tools in *Campbell Biology* and **Mastering Biology** to create a **Study Plan**. Your Study Plan might include:



CAMPBELL

BIOLOGY

TWELFTH EDITION

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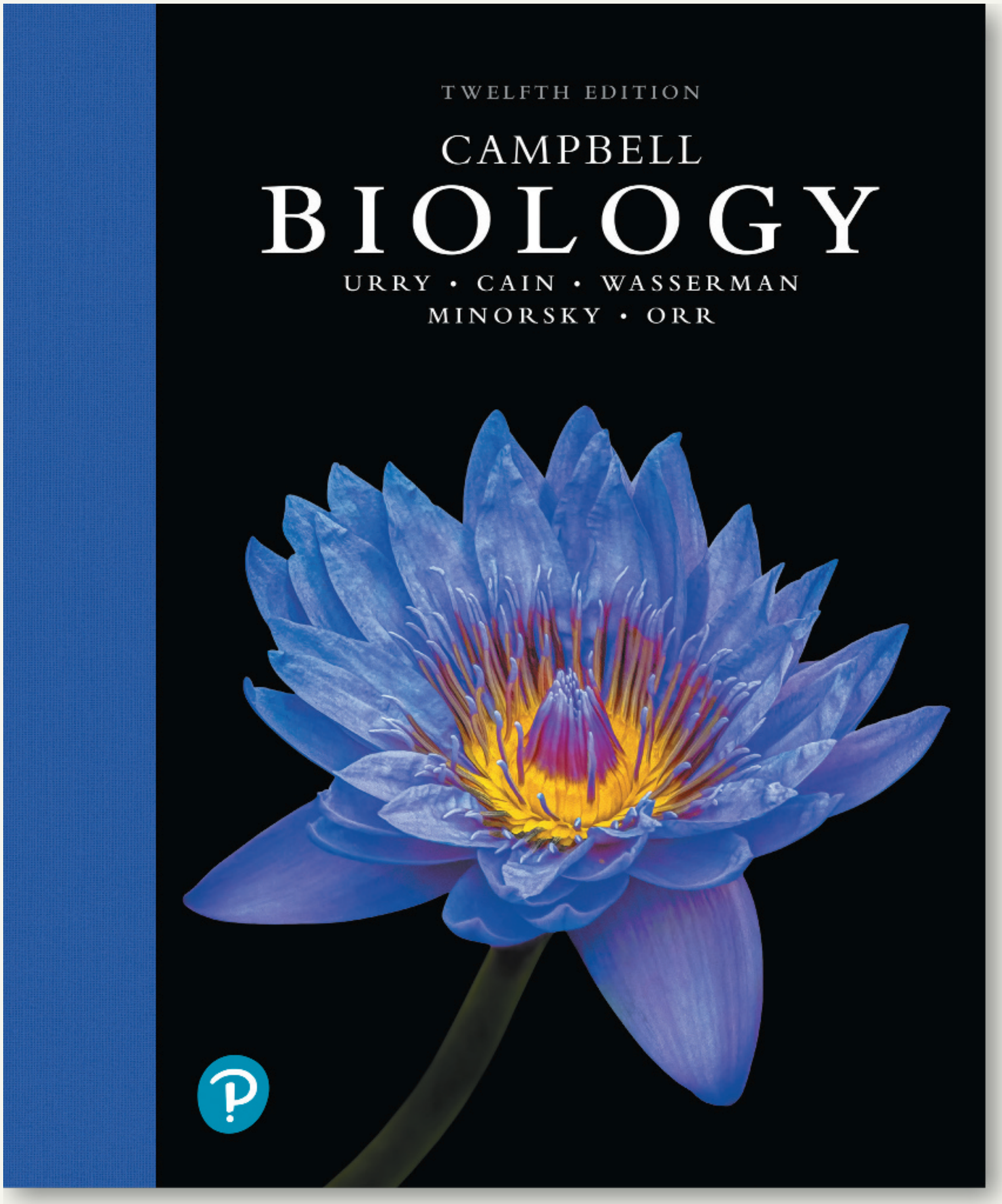
Setting the Standard for Excellence, Accuracy, and Innovation

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



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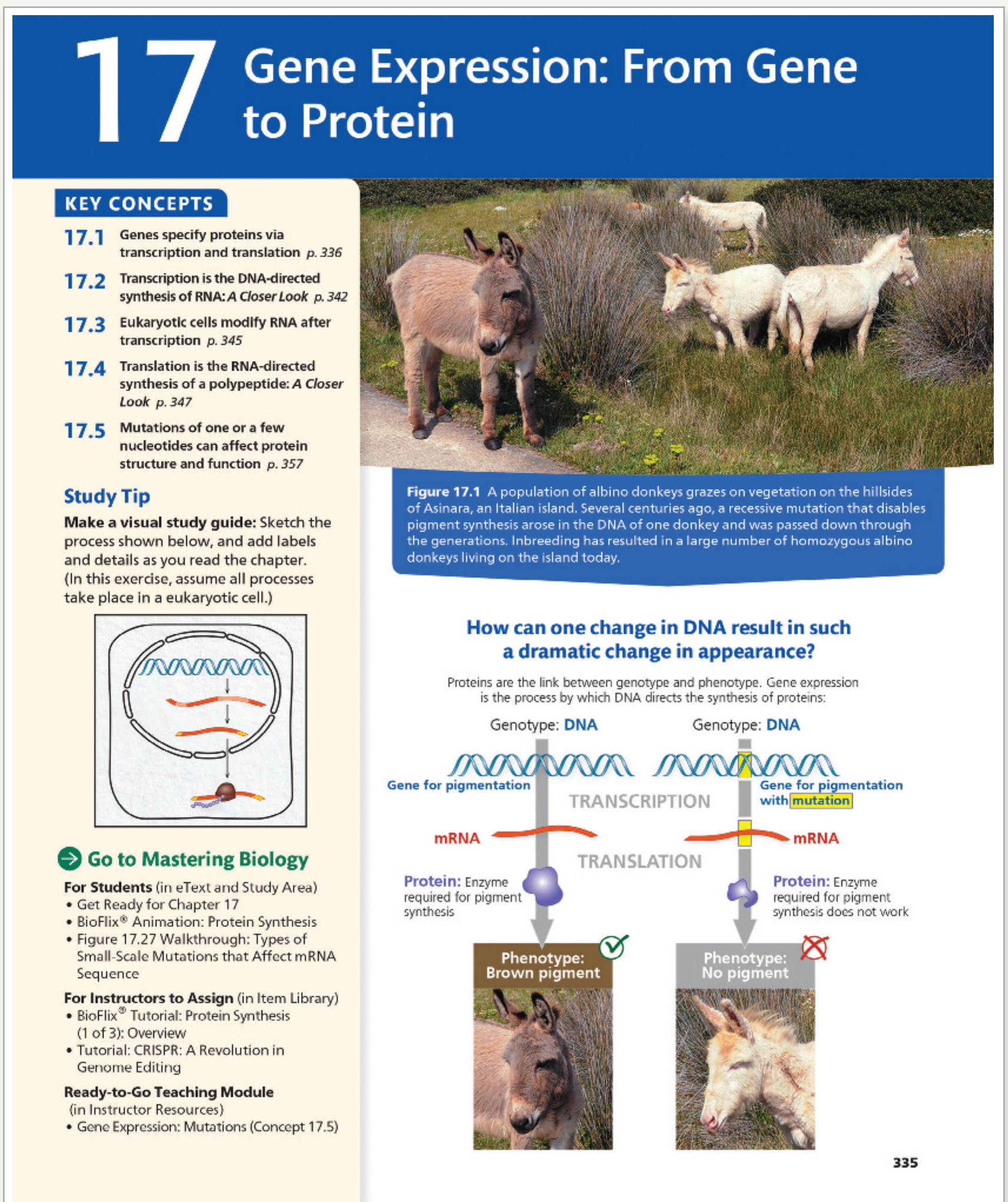
A New Visual Experience for Every Chapter

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



17 Gene Expression: From Gene to Protein

KEY CONCEPTS

Study Tip

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

Go to Mastering Biology

For Students (in eText and Study Area)
- Get Ready for Chapter 17
- BioFlix® Animation: Protein Synthesis
- Figure 17.27 Walkthrough: Types of Small-Scale Mutations that Affect mRNA Sequence

For Instructors to Assign (in Item Library)
- BioFlix® Tutorial: Protein Synthesis (1 of 3): Overview
- Tutorial: CRISPR: A Revolution in Genome Editing

Ready-to-Go Teaching Module (in Instructor Resources)
- Gene Expression: Mutations (Concept 17.5)

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

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

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

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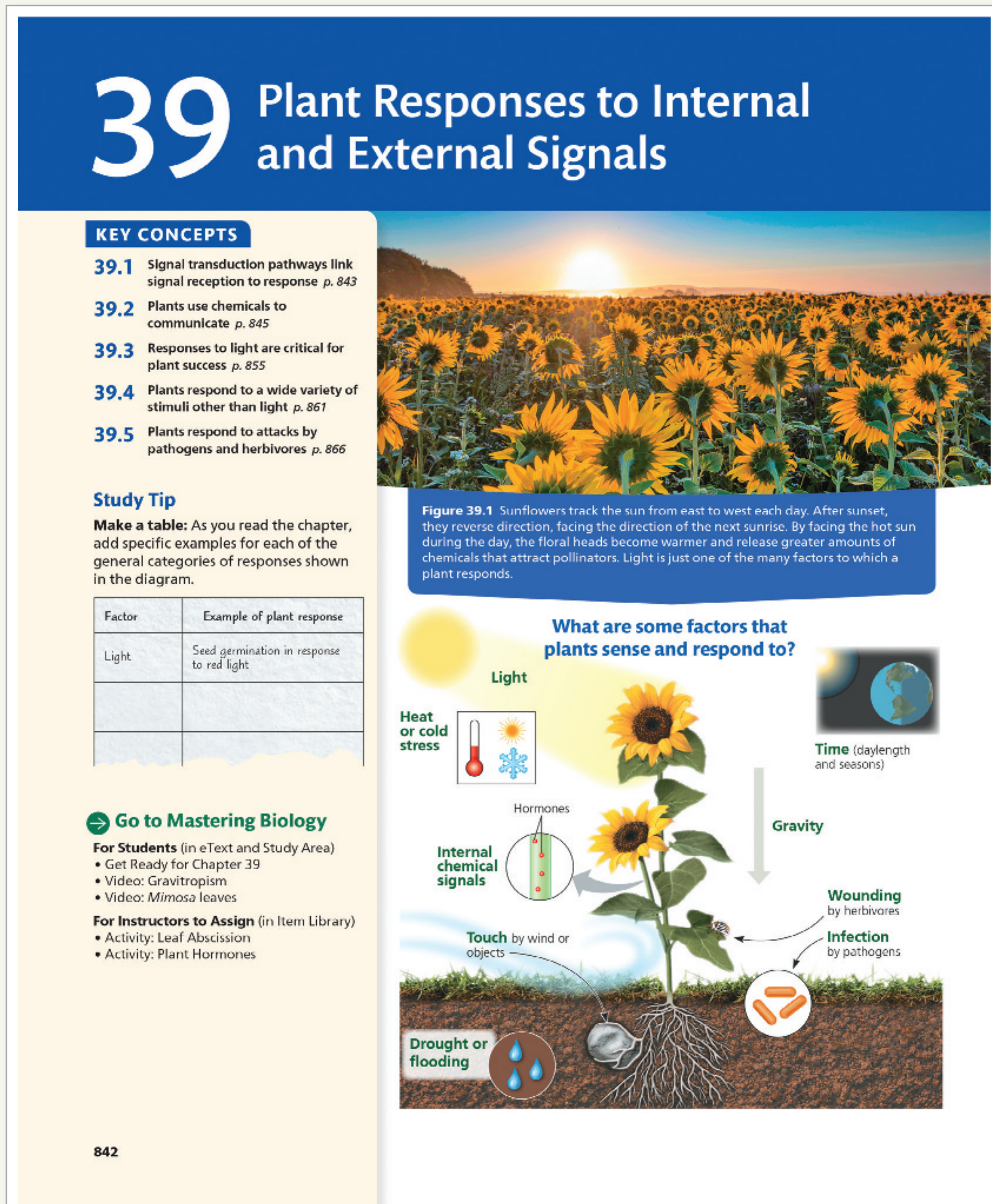
NEW! A Visual Overview helps students start with the big picture.

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

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



39 Plant Responses to Internal and External Signals

KEY CONCEPTS

39.1 Signal transduction pathways link signal reception to response *p. 843*

39.2 Plants use chemicals to communicate *p. 845*

39.3 Responses to light are critical for plant success *p. 855*

39.4 Plants respond to a wide variety of stimuli other than light *p. 861*

39.5 Plants respond to attacks by pathogens and herbivores *p. 866*

Study Tip

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

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

Go to Mastering Biology

For Students (in eText and Study Area)
- Get Ready for Chapter 39
- Video: Gravitropism
- Video: *Mimosa* leaves

For Instructors to Assign (in Item Library)
- Activity: Leaf Abscission
- Activity: Plant Hormones

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

What are some factors that plants sense and respond to?

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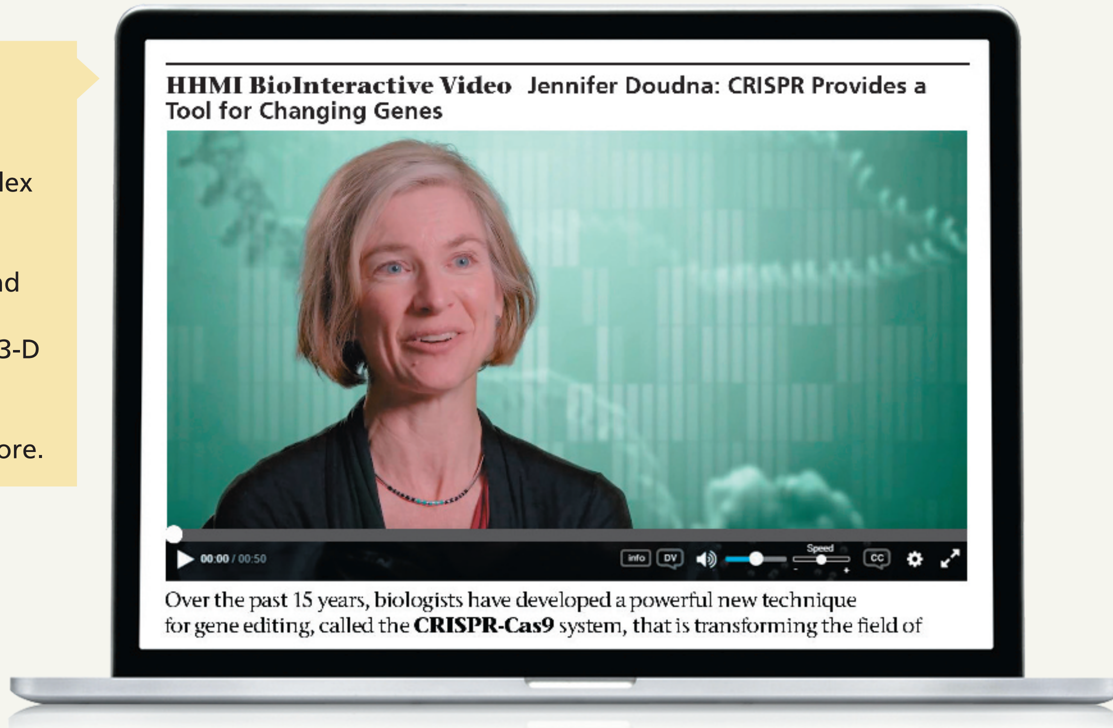
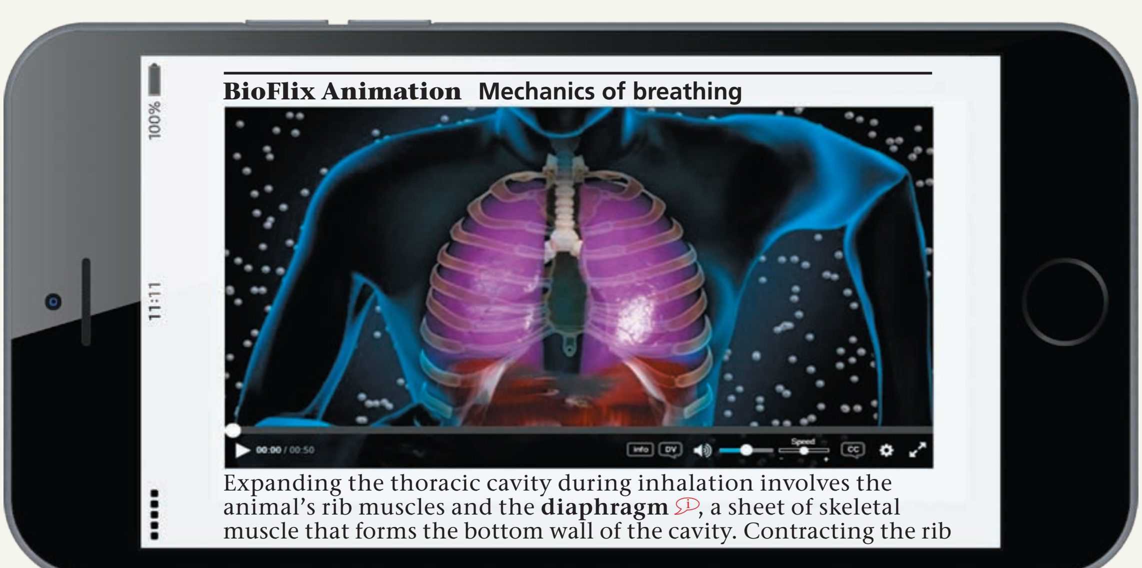
Pearson eText for *Campbell Biology*:

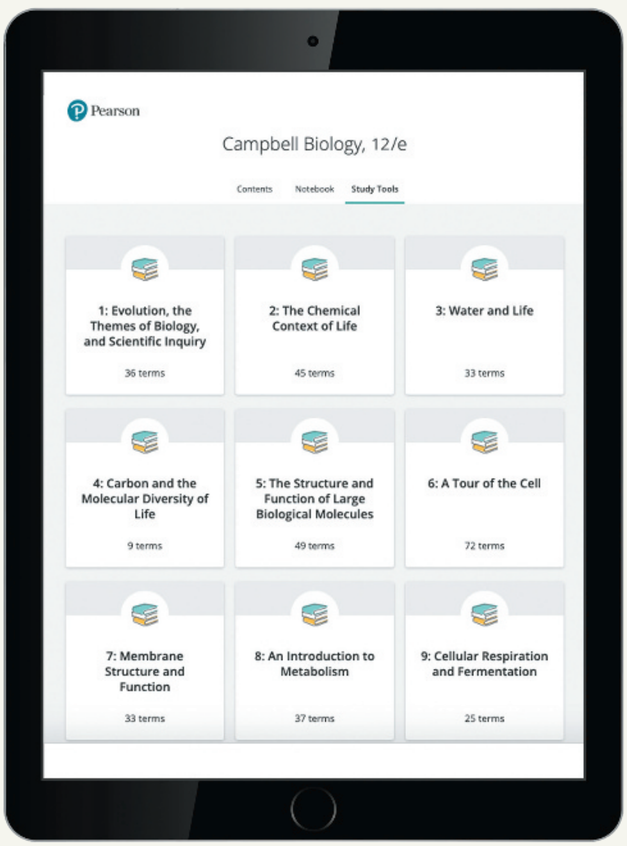
EXPANDED! 500 embedded Videos & Animations help students visualize complex biology topics. These include: new HHMI BioInteractive Videos and Animations, new Figure Walkthroughs, BioFlix® 3-D Animations, Galápagos Videos by Peter and Rosemary Grant, and more.

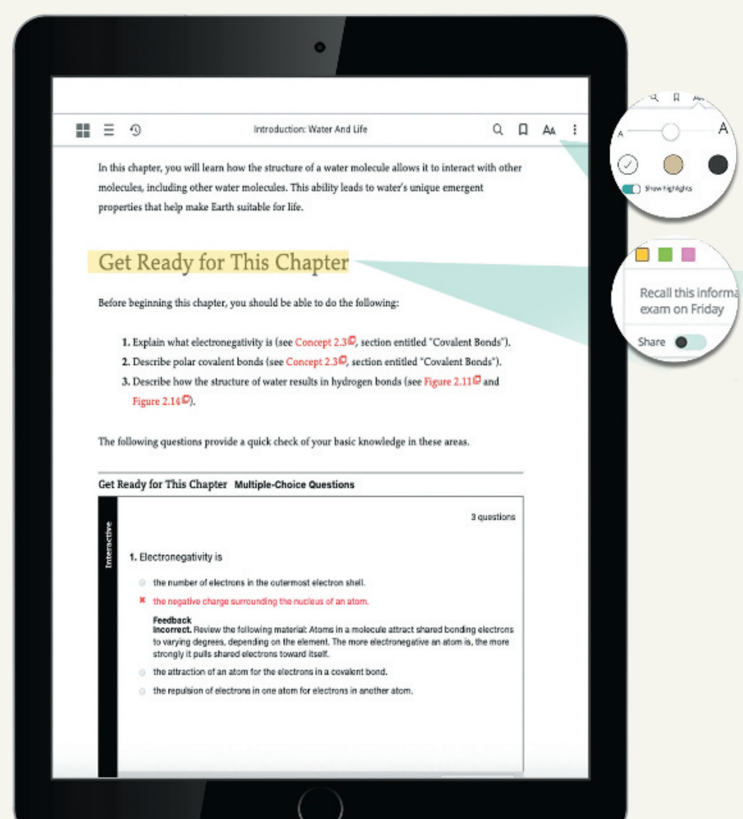




A Whole New Reading Experience

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

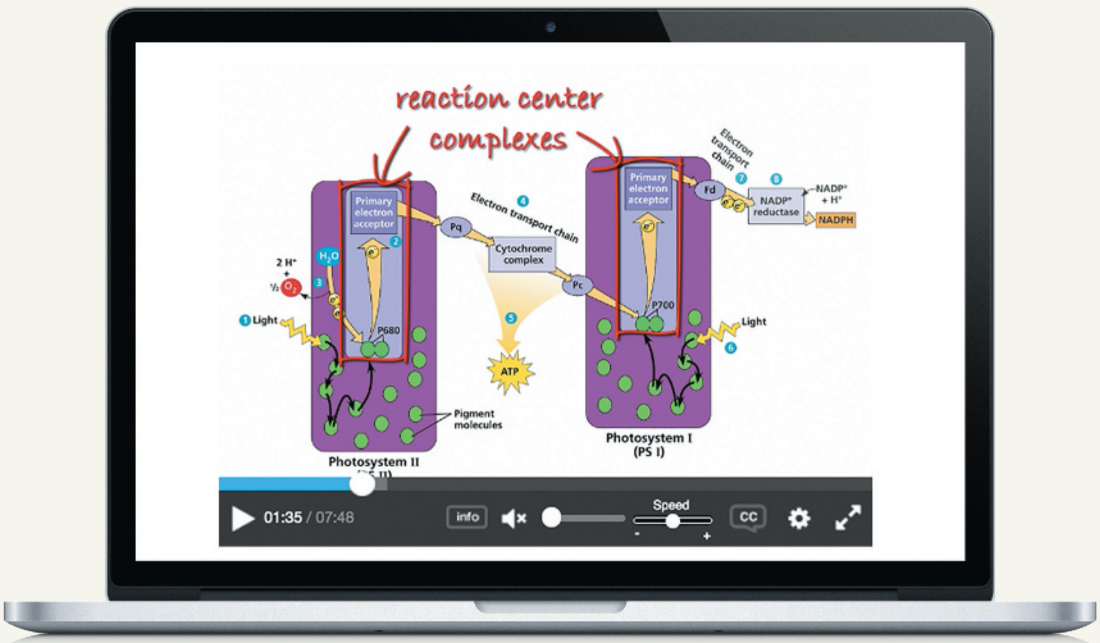


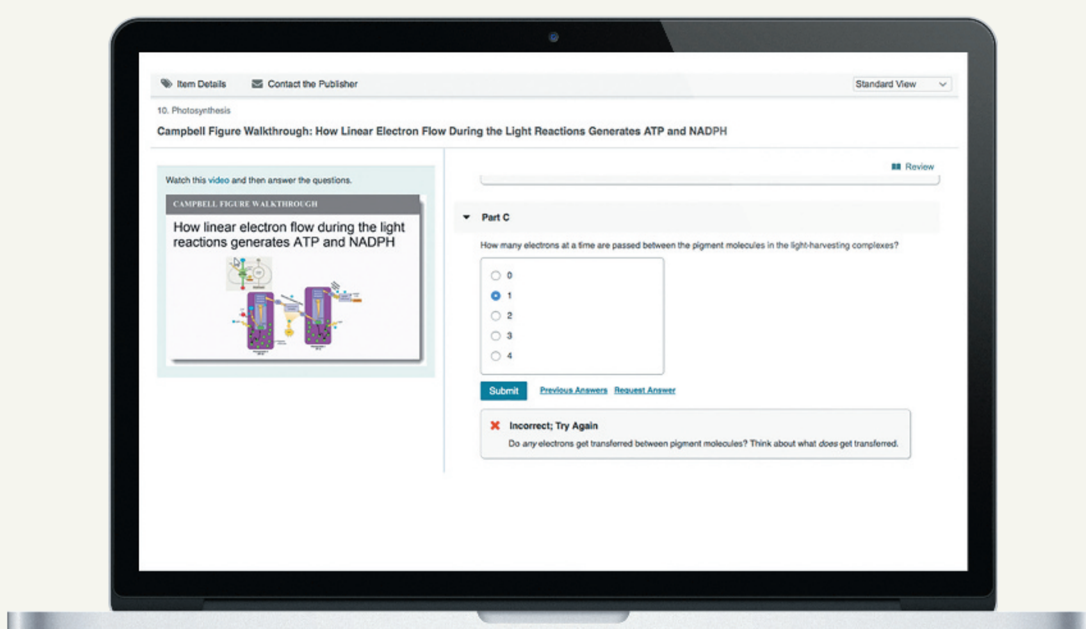


The Pearson eText app is available for download in the app store for approved devices.

Bringing Innovative Art to Life

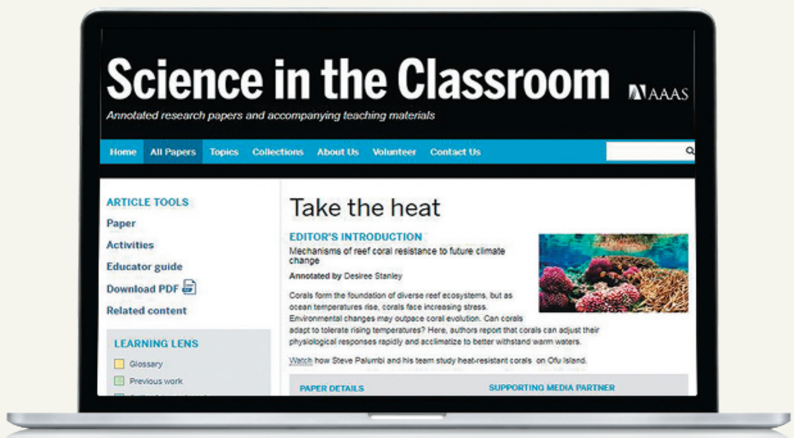
NEW! An expanded collection of Figure Walkthroughs guide students through key figures with narrated explanations and figure mark-ups that reinforce important points. **These are embedded in the eText and available for assignment in Mastering Biology**.





Giving Students the Tools They Need to Succeed

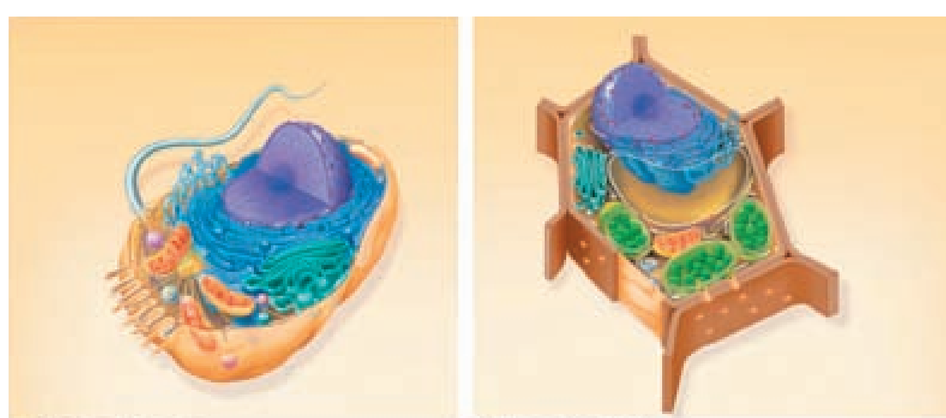
Explore Scientific Papers with Science in the Classroom AAAS
How are coral reefs responding to climate change?
Go to "Take the Heat" at www.scienceintheclassroom.org.
Instructors: Questions can be assigned in Mastering Biology.



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

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

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



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

36. What is the cytoskeleton?

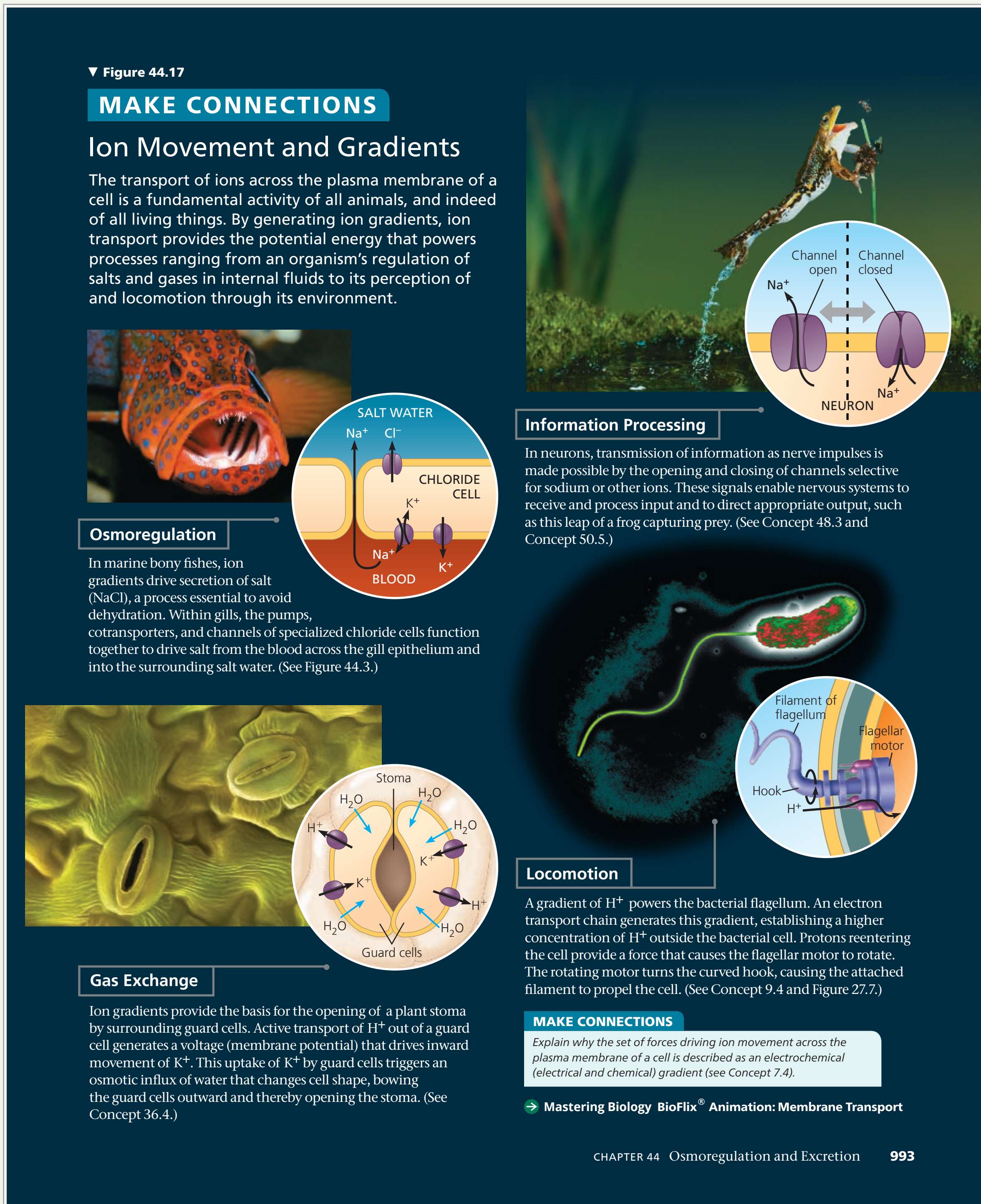
37. What are the three roles of the cytoskeleton?

38. There are three main types of fibers that make up the cytoskeleton. Name them.

39. *Microtubules* are hollow rods made of a globular protein called tubulin. Each tubulin protein is a dimer made of two subunits. These are easily assembled and disassembled. What are four functions of microtubules?

Make Connections Across Multiple Concepts

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



▼ **Figure 44.17**

MAKE CONNECTIONS

Ion Movement and Gradients

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

Osmoregulation

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

Gas Exchange

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

Information Processing

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

Locomotion

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

MAKE CONNECTIONS

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

Mastering Biology BioFlix® Animation: Membrane Transport

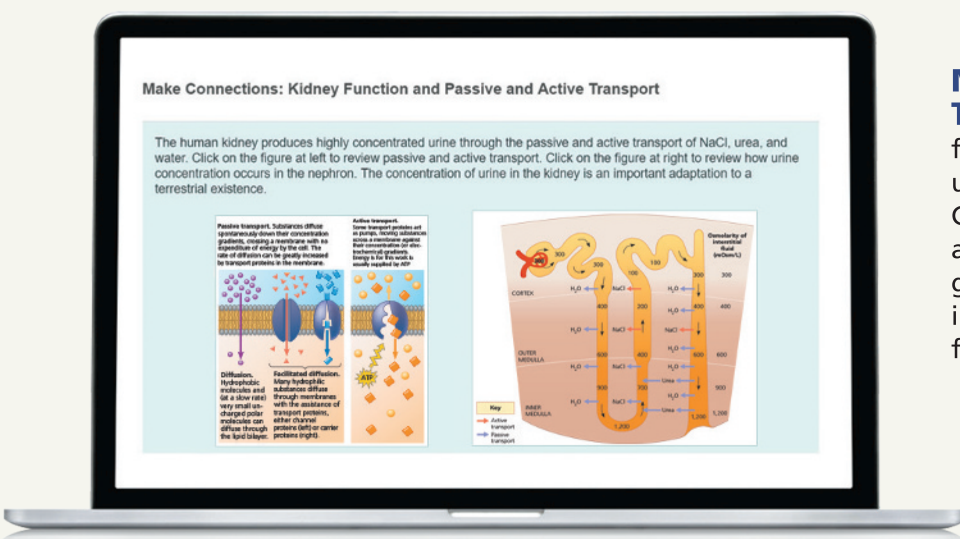
CHAPTER 44 Osmoregulation and Excretion **993**

CONCEPT CHECK 24.2

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

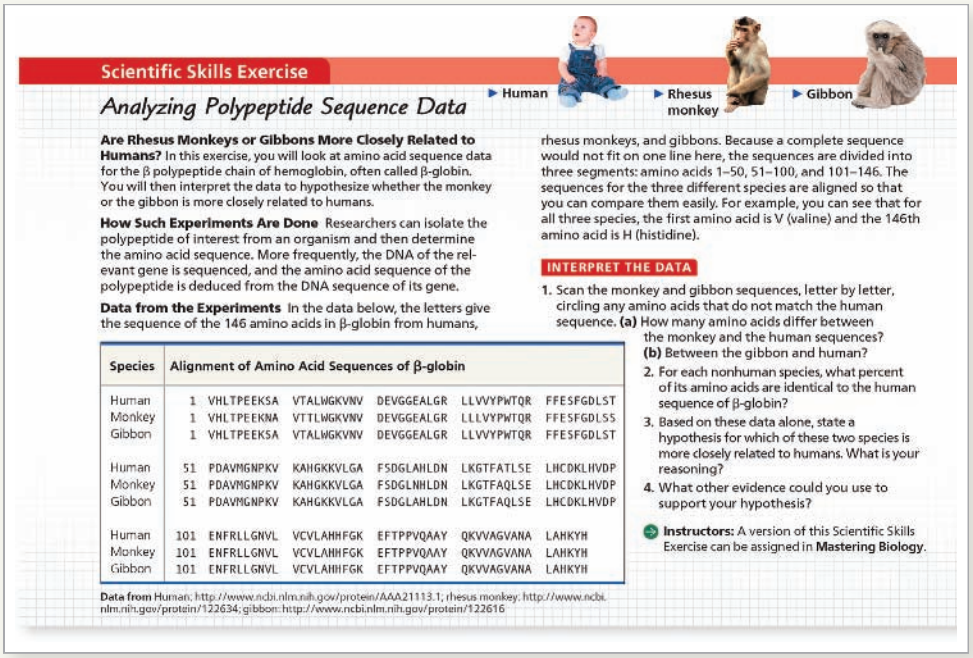
For suggested answers, see Appendix A.

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



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

Develop Scientific Skills



Scientific Skills Exercise

Human Rhesus monkey Gibbon

Analyzing Polypeptide Sequence Data

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

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

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

Species	Alignment of Amino Acid Sequences of β-globin
Human	1 VHLTPEEKSA VTALWGKVNV DEVGGEALGR LLVVYPWTQR FFESFGDLST
Monkey	1 VHLTPEEKNA VTTLWGKVNV DEVGGEALGR LLLVYPWTQR FFESFGDLSS
Gibbon	1 VHLTPEEKSA VTALWGKVNV DEVGGEALGR LLVVYPWTQR FFESFGDLST
Human	51 PDAVMGNPKV KAHGKKVLGA FSDGLAHLDN LKGTFATLSE LHCDKLHVDP
Monkey	51 PDAVMGNPKV KAHGKKVLGA FSDGLNHLDN LKGTFAQLSE LHCDKLHVDP
Gibbon	51 PDAVMGNPKV KAHGKKVLGA FSDGLAHLDN LKGTFAQLSE LHCDKLHVDP
Human	101 ENFRLLGNVL VCVLAHHFGK EFTPPVQAAY QKVVAGVANA LAHKYH
Monkey	101 ENFRLLGNVL VCVLAHHFGK EFTPPVQAAY QKVVAGVANA LAHKYH
Gibbon	101 ENFRLLGNVL VCVLAHHFGK EFTPPVQAAY QKVVAGVANA LAHKYH

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

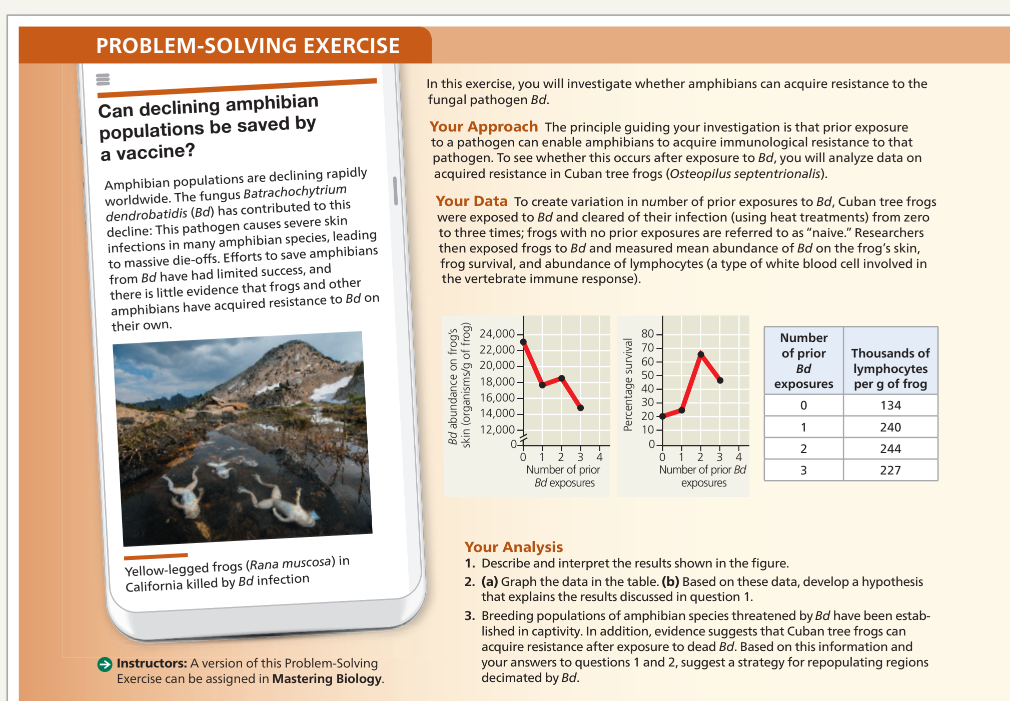
INTERPRET THE DATA

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

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

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

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



PROBLEM-SOLVING EXERCISE

Can declining amphibian populations be saved by a vaccine?

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

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

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

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

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

Bd abundance on frog's skin (organisms/g of frog)
24,000
22,000
20,000
18,000
16,000
14,000
12,000
0
0 1 2 3 4
Number of prior *Bd* exposures

Percentage survival
80
70
60
50
40
30
20
10
0
0 1 2 3 4
Number of prior *Bd* exposures

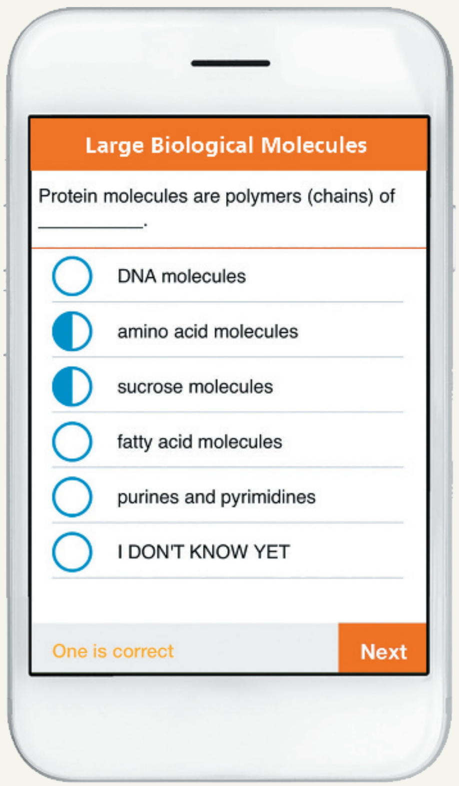
Number of prior *Bd* exposures	Thousands of lymphocytes per g of frog
0	134
1	240
2	244
3	227

Your Analysis

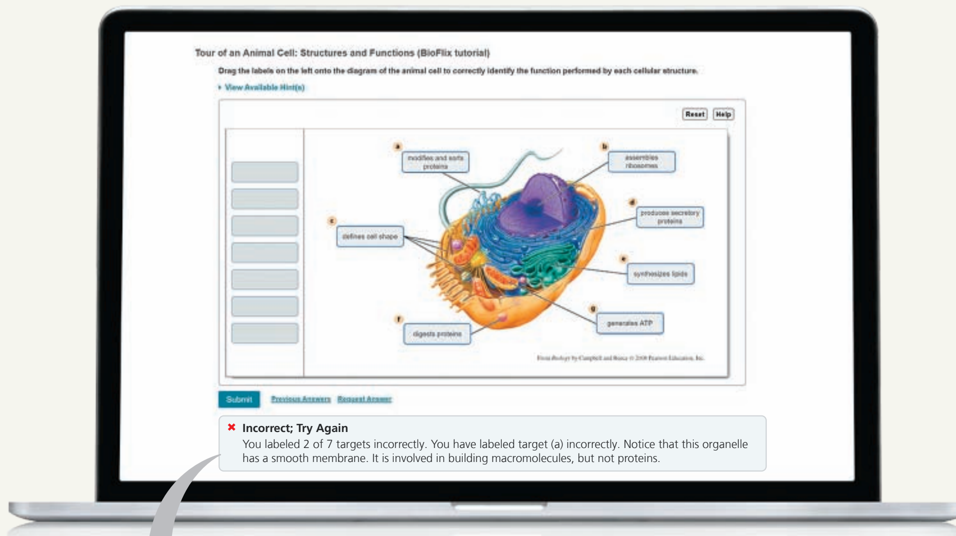
1. Describe and interpret the results shown in the figure.
2. **(a)** Graph the data in the table. **(b)** Based on these data, develop a hypothesis that explains the results discussed in question 1.
3. Breeding populations of amphibian species threatened by *Bd* have been established in captivity. In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

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

Innovation in Assessment



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



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

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

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

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

—Student, University of Texas at Arlington

Innovation in Instructor Resources

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

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

About the Authors

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

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

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

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

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

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

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

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

Preface

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

Our goals for the Twelfth Edition include:

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

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

New to This Edition

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

- **NEW! Chapter Openers Re-envisioned.** Catalyzed by feedback from students and instructors, informed by data analytics, and building on the results of science education research, we have redesigned the opening of every chapter of the text. The result is more visual, more interactive, and more engaging. In place of an opening narrative, the first page of each chapter is organized around three new elements that provide students with the specific tools and approaches needed to achieve the learning objectives of that chapter:
  - **NEW! Visual Overview.** Centered on a basic biological question related to the opening photo and legend, the Visual Overview illustrates a core idea of the chapter with straightforward art and text. Students get an immediate sense of what the chapter is about and what kinds of thinking will underlie its exploration.
  - **NEW! Study Tip.** Just as the Visual Overview introduces students to *what* they will learn, the study tip offers guidance in *how* to learn. It encourages students to learn actively through such proven strategies as drawing a flow chart, labeling a diagram, or making a table. Each tip provides an effective strategy for tackling important content in the chapter.
  - **NEW! Highlights of Digital Resources.** In conversations with users of the textbook, we often encounter a limited awareness of the digital tools the text provides to facilitate instruction and learning. We therefore created *Go to Mastering Biology*, a chapter opener section where we highlight some of the tutorials, animations, and other interactives available for students to explore on their own or for instructors to assign. These resources include Get Ready for This Chapter questions, Figure Walkthroughs, HHMI BioInteractive videos, Ready-to-Go Teaching Modules, and more.
- **NEW! Updated Content.** As in each new edition of *Campbell Biology*, the Twelfth Edition incorporates new content, summarized on pages xviii–xx. Content updates reflect rapid, ongoing changes in knowledge about climate change, genomics, gene-editing technology (CRISPR), evolutionary biology, microbiome-based therapies, and more. In addition, Unit 7 includes a new section on "Biological Sex, Gender Identity, and Sexual Orientation in Human Sexuality," which provides instructors and students with a thoughtful, clear, and current introduction to topics of tremendous relevance to biology, to student lives, and to current public discourse and events.
- **NEW! Active Reading Guides.** These worksheets provide students with self-assessment activities to complete as they read each chapter. Students can download the Active Reading Guides from the Mastering Biology Study Area.
- **5 NEW! Ready-to-Go Teaching Modules.** The Ready-to-Go Teaching Modules provide instructors with active learning exercises and questions to use in class, plus Mastering Biology assignments that can be assigned before and after class. A total of 15 modules are now available in the Instructor Resources area of Mastering Biology.

Pearson eText

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

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

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

For more information, see pages vi–ix.

Mastering Biology

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

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

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

Our Hallmark Features

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

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

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

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

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

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

Our Partnership with Instructors and Students

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

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

Highlights of New Content

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

Unit 1 THE CHEMISTRY OF LIFE

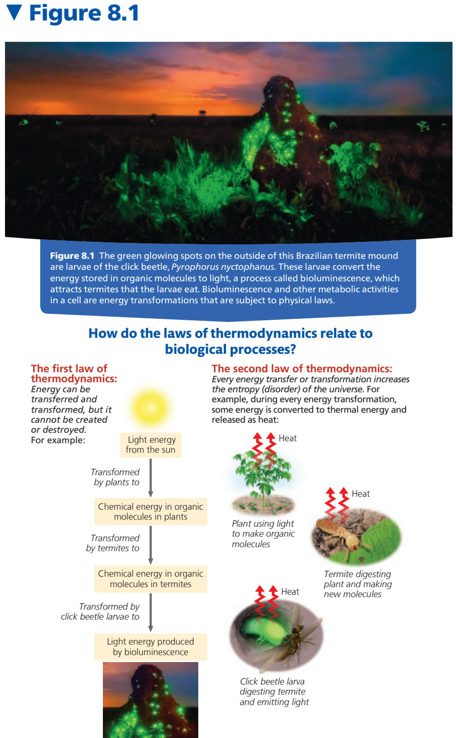
In Unit 1, new content engages students in learning foundational chemistry. Chapter 2 includes a new micrograph of the tiny hairs on a gecko's foot that allow it to walk up a wall. The opening photo for Chapter 3 features a ringed seal, a species endangered by the melting of Arctic sea ice due to climate change. Chapter 3 also has added coverage on the discovery of a large subsurface reservoir of liquid water on Mars and the first CO_2 enhancement study done on an unconfined natural coral reef (both reported in 2018). Chapter 4 now includes the discovery of carbon-based compounds on Mars reported by NASA in 2018. In Chapter 5, the technique of cryo-electron microscopy is introduced, due to its increasing importance in the determination of molecular structure.

Unit 2 THE CELL

Our main goal for this unit was to make the material more accessible, inviting, and exciting to students. Chapter 6 includes a new text description of cryo-electron microscopy (cryo-EM) and a new cryo-EM image in Figure 6.3. Art has been added to Figure 6.17 to illustrate the dynamic nature of mitochondrial networks. Chapter 7 begins with a new chapter-opening image showing neurotransmitter release during exocytosis. **Figure 8.1** includes a new photo of bioluminescent click beetle larvae on the outside of a termite mound and a new Visual Overview that illustrates how the laws of thermodynamics apply to metabolic reactions like bioluminescence.

Chapter 9 includes new information on human brown fat usage, the role of fermentation during the production of chocolate, and recent research on the role of lactate in mammalian metabolism. Chapter 10 begins with a new concept that puts photosynthesis into a big-picture ecological context. Chapter 10 also includes a discussion of the 2018 discovery of a new form of chlorophyll found in cyanobacteria that can carry out photosynthesis using far-red light. In Chapter 11, the relevance of synaptic signaling is underscored by mentioning that it is a target for treatment of depression, anxiety, and PTSD. In Chapter 12, the cell cycle figure (Figure 12.6) now includes cell images and labels describing the events of each phase.

▼ Figure 8.1



Unit 3 GENETICS

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

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

▼ Figure 18.8 Examples of epigenetic inheritance.

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

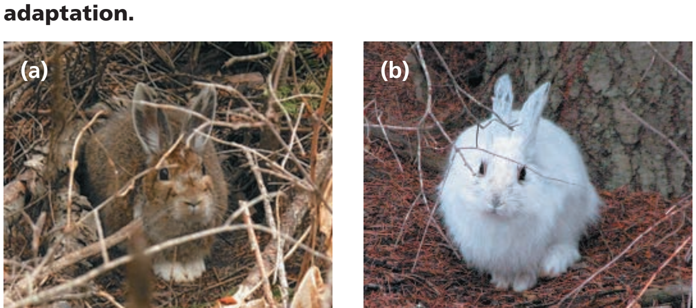
(b) The Dutch Hunger Winter.

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

Unit 4 MECHANISMS OF EVOLUTION

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

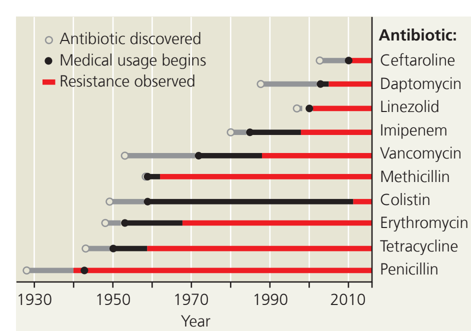
▼ Figure 23.19 Lack of variation in a population can limit adaptation.



Unit 5 THE EVOLUTIONARY HISTORY OF BIOLOGICAL DIVERSITY

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

► Figure 27.22 The rise of antibiotic resistance.



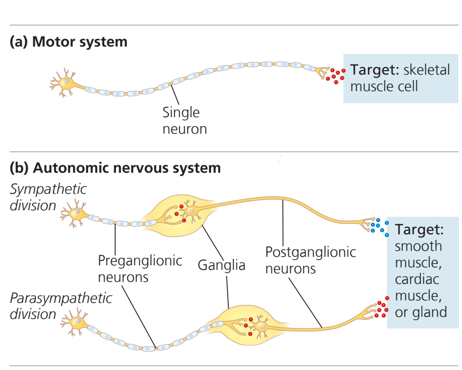
Unit 6 PLANT FORM AND FUNCTION

In Chapter 35, greater emphasis is placed on how structure fits function in vascular plants by way of a new Visual Overview. In Chapter 36, a new Visual Skills Question provides a quantitative exercise in estimating stomatal density. Chapter 37 begins with an emphasis on the importance of crop fertilization in feeding the world. To increase student engagement, renewed emphasis is placed on the link between the nutrition of plants and the nutrition of the organisms, including humans, that feed on them. Table 37.1 concerning plant essential elements has been expanded to include micronutrients as well as macronutrients. In Concept 37.2, a new subsection titled “Global Climate Change and Food Quality” discusses new evidence that global climate change may be negatively impacting the nutritional mineral content of crops. In Chapter 38, the discussion of genetic engineering and agriculture has been enhanced by a discussion of biofortification and by updates concerning “Golden Rice.” Chapter 39 includes new updates on the location of the IAA receptor in plant cells and the role of abscisic acid in bud dormancy. The introduction to Concept 39.2 has been revised to emphasize that plants use many classes of chemicals in addition to the classic hormones to communicate information.

Unit 7 ANIMAL FORM AND FUNCTION

The Unit 7 revisions feature pedagogical innovations coupled with updates for currency. A striking new underwater image of Emperor penguins (Figure 40.1) opens the unit and highlights the contributions of form, function, and behavior to homeostasis in general as well as to the specific topic of thermoregulation. The artwork used to introduce and explore homeostasis throughout the unit (Figures 40.8, 40.17, 41.23, 42.28, 44.19, 44.21, and 45.18) has been improved and refined to provide a clear and consistent presentation of the role of perturbation in triggering a response. In Chapter 43, the introduction of the adaptive immune response has been shifted to later in the chapter, allowing students to build on the features of innate immunity before tackling the more demanding topic of the adaptive response. In Chapter 46, a new section of text in Concept 46.4 provides a clear and current introduction to “Biological Sex, Gender Identity, and Sexual Orientation in Human Sexuality.” In Chapter 48, the structural overview of neurons is now completed before the introduction of information processing. A new illustration, **Figure 49.8**, provides a concise visual comparison of sympathetic and parasympathetic neurons with each other and with motor neurons of the CNS. In addition, in-depth consideration of glia is now provided in Concept 49.1, where it is more logically integrated into the overview of nervous systems. At the end of the unit, an eye-catching photograph of the male frigatebird’s courtship display (Figure 51.1) introduces the topic of animal behavior. Among the content updates that enhance currency and student engagement throughout the unit are discussions of phage therapy and fecal transplantation, state-of-the-art treatments that both rely on microbiome data, and chronic traumatic encephalopathy (CTE), as well as the latest findings on dinosaur locomotion (Concept 40.1), the awarding of a Nobel Prize in 2017 in the field of circadian rhythms (Concept 40.2), and reference to the ongoing public health crisis of opioid addiction in the context of considering the brain’s reward system (Concept 49.5).

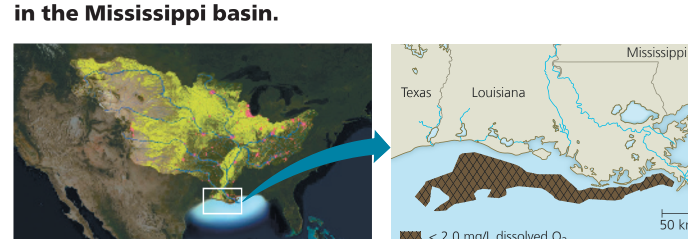
▶ Figure 49.8 Comparison of pathways in the motor and autonomic nervous systems.



Unit 8 ECOLOGY

Complementary goals of the Unit 8 revision were to strengthen our coverage of core concepts while also increasing our coverage of how human actions affect ecological communities. Revisions include a new section of text and a new figure (Figure 52.7) on how plants (and deforestation) can affect the local or regional climate; a new section of text in Concept 55.1 that summarizes how ecosystems work; new text and a new figure (Figure 52.25) illustrating how rapid evolution can cause rapid ecological change; new material in Concept 55.2 on eutrophication and how it can cause the formation of large “dead zones” in aquatic ecosystems; and new text and a new figure (Figure 54.22) on how the abundance of organisms at each trophic level can be controlled by bottom-up or top-down control. A new figure **(Figure 56.23)** shows the extent of the record-breaking 2017 dead zone in the Gulf of Mexico and the watershed that contributes to its nutrient load. In addition, Concept 56.1 includes a new section that describes attempts to use cloning to resurrect species lost to extinction, while Concept 56.4 includes a new section of text and two new figures (Figure 56.27 and 56.28) on plastic waste, a major and growing environmental problem. In keeping with our book-wide goal of expanding our coverage of climate change, Chapter 56 has a new Scientific Skills Exercise in which students interpret changes in atmospheric CO_2 concentrations. Chapter 55 describes how climate warming is causing large regions of tundra in Alaska to release more CO_2 than they absorb (thereby contributing to further climate warming); a new figure (Figure 56.32) describes human and natural factors that contribute to rising global temperatures; and a new section of text in Concept 56.4 describes how global climate change models are developed and why they are valuable.

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



(a) Nutrients drain from agricultural land (green) and cities (red) through the vast Mississippi watershed to the Gulf of Mexico.

(b) The 2017 dead zone, represented here, was the largest yet measured. It occupied 22,730 km^2 (8,776 mi^2), an area slightly larger than New Jersey.

Skills Exercises

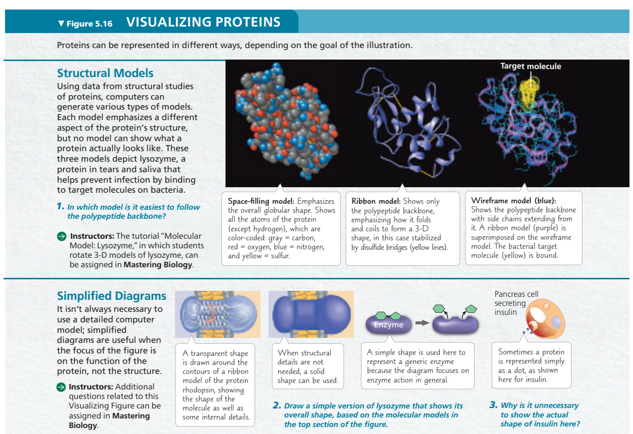
Scientific Skills Exercises

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

Problem-Solving Exercises

Featured Figures

Visualizing Figures



Make Connections Figures

Exploring Figures

Inquiry Figures

Research Method Figures

*The Inquiry Figure, original research paper, and a worksheet to guide you through the paper are provided in *Inquiry in Action: Interpreting Scientific Papers*, Fourth Edition.
†A related Experimental Inquiry Tutorial can be assigned in Mastering Biology.

Student and Lab Supplements

For Students

NEW! *Active Reading Guides*, Twelfth Edition

by Fred and Theresa Holtzclaw, The Webb School of Knoxville

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

Study Guide, Eleventh Edition

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

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

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

Study Card, Eleventh Edition

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

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

Inquiry in Action: Interpreting Scientific Papers, Fourth Edition*

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

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

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

Practicing Biology: A Student Workbook, Sixth Edition*

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

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

This workbook offers a variety of activities to suit different learning styles. Activities such as modeling and concept mapping allow students to visualize and understand biological processes. Other activities focus on basic skills, such as reading and drawing graphs.

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

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

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

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

Spanish Glossary for Biology

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

Into the Jungle: Great Adventures in the Search for Evolution

by Sean B. Carroll, University of Wisconsin, Madison

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

Get Ready for Biology

by Lori K. Garrett, Parkland College

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

A Short Guide to Writing About Biology, Ninth Edition

by Jan A. Pechenik, Tufts University

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

An Introduction to Chemistry for Biology Students, Ninth Edition

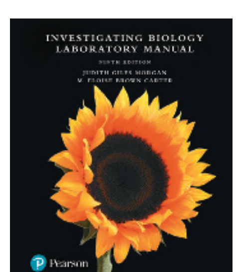
by George I. Sackheim, University of Illinois, Chicago

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

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

For Lab

Investigating Biology Laboratory Manual, Ninth Edition



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

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

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

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

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

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

Preparation Guide for Investigating Biology, Ninth Edition

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

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

Pearson Collections Custom Library

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

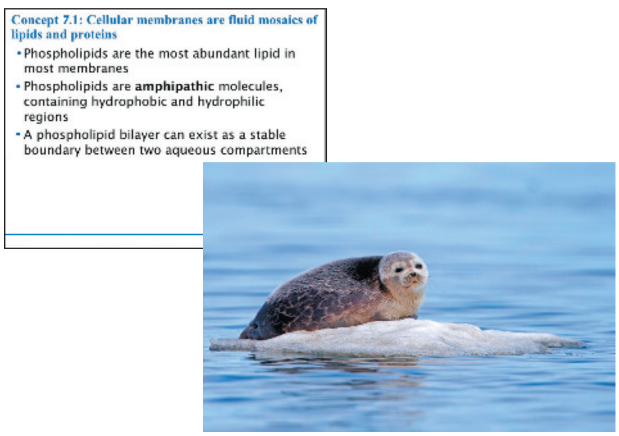
NEW! Mastering Biology LabBench

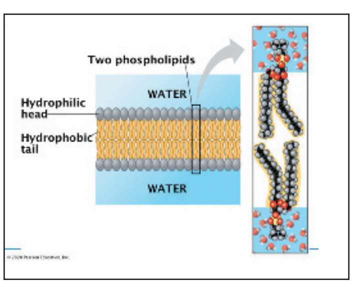
The LabBench pre-labs feature 13 online tutorials in Mastering Biology that will both prepare students for their lab work and reinforce key biological principles.

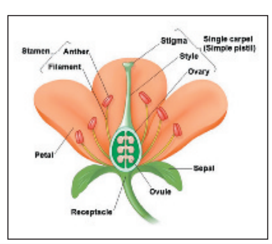
Instructor Resources

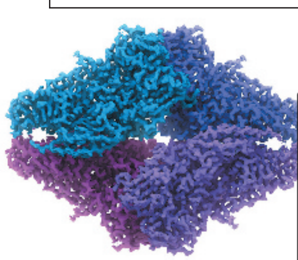
The Instructor Resources Area of Mastering Biology

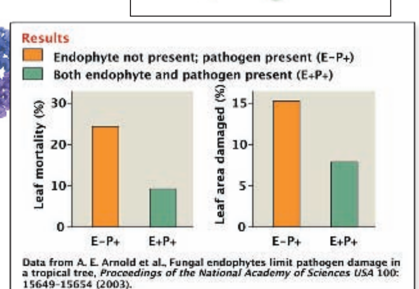
- **5 NEW! Ready-to-Go Teaching Modules** help instructors efficiently make use of the available teaching tools for the toughest topics. Before-class assignments, in-class activities, and after-class assignments are provided for ease of use. Instructors can incorporate active learning into their course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



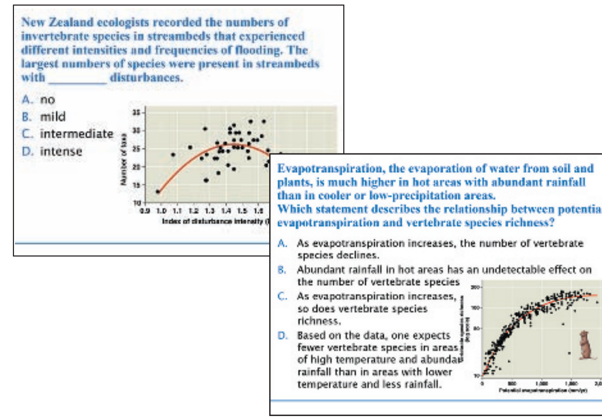








- **Accessible Lecture Presentations in PowerPoint** with alt text for every image; students can access alt text with a screen reader if needed
- **Editable Images in PowerPoint** (all art and photos from the text) and all tables from the text in PowerPoint with enlarged, customizable labels
- **Labeled and Unlabeled JPEG Images,** including art, photos from the text, and extra photos
- **Clicker Questions in PowerPoint,** which can be used to stimulate effective classroom discussions (for use with or without clickers):



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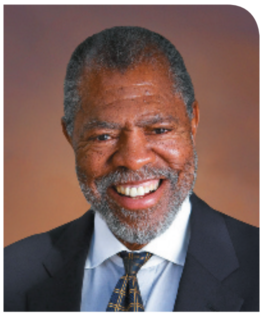

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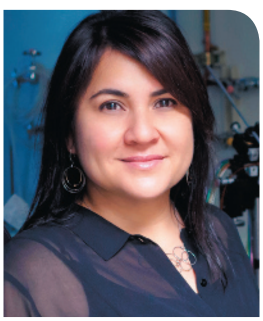

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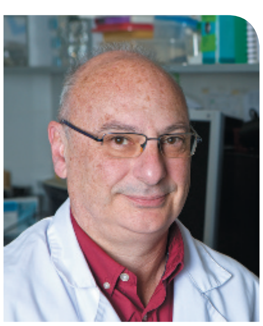

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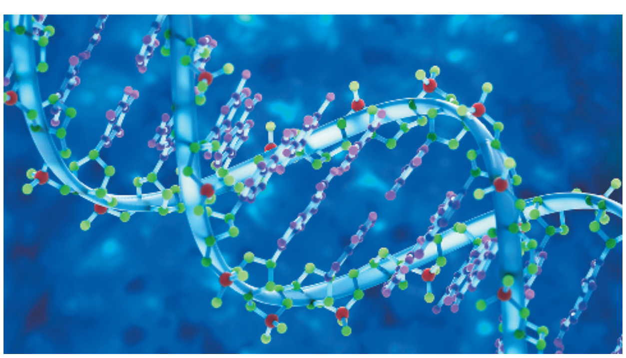
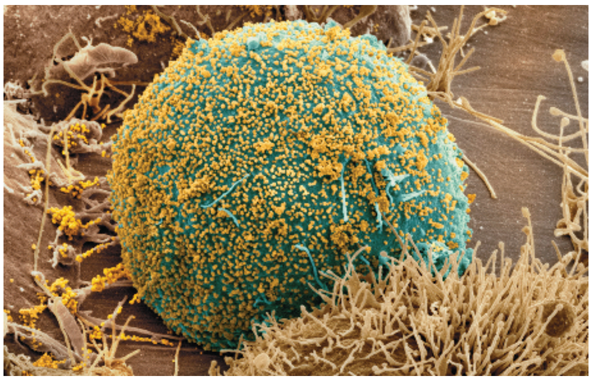
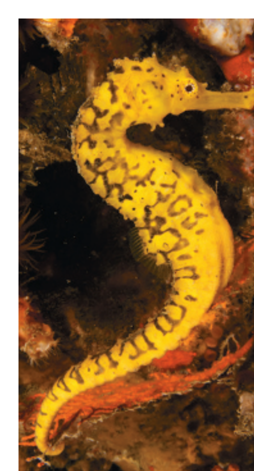
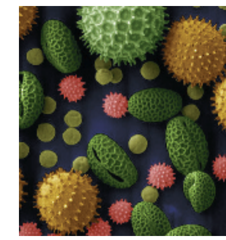
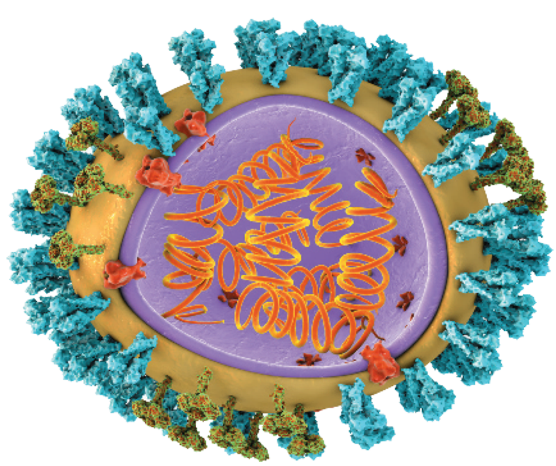
Detailed Contents











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1 Evolution, the Themes of Biology, and Scientific Inquiry

KEY CONCEPTS

Study Tip

Make a table: List the five unifying themes of biology across the top. Enter at least three examples of each theme as you read this chapter. One example is filled in for you. To help you focus on these big ideas, continue adding examples throughout your study of biology.

Evolution	Organization			
Beach mouse's coat color matches its sandy habitat.				

Go to Mastering Biology

For Students (in eText and Study Area)
- Get Ready for Chapter 1
- Figure 1.8 Walkthrough: Gene Expression: Cells Use Information Encoded in a Gene to Synthesize a Functional Protein
- Video: Galápagos Biodiversity by Peter and Rosemary Grant

For Instructors to Assign (in Item Library)
- Scientific Skills Exercise: Interpreting a Pair of Bar Graphs
- Tutorial: The Scientific Method

Figure 1.1 The light, dappled color of this beach mouse (*Peromyscus polionotus*) allows it to blend into its habitat—brilliant white sand dunes dotted with sparse clumps of beach grass along the Florida seashore. Mice of the same species that inhabit nearby inland areas are much darker, blending with the soil and vegetation where they live.

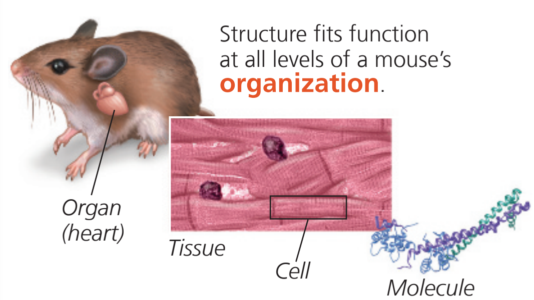
How do these mice illustrate the unifying themes of biology?

Beach mouse

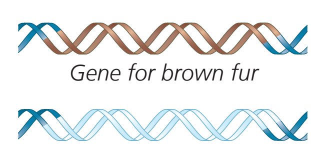
As a result of **evolution** through natural selection over long periods of time, the fur colors of these two populations of mice resemble their surroundings, providing protection from predators.

Inland mouse

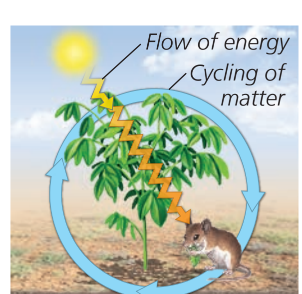
Structure fits function at all levels of a mouse's **organization**.



Genetic **information** encoded in DNA determines a mouse's fur colors.



Energy flows one way from the sun to plants to a mouse; **matter** cycles between a mouse and its environment.



A plant being eaten by a mouse and a mouse being preyed upon by a hawk are **interactions** within a system.

CONCEPT 1.1

The study of life reveals unifying themes

At the most fundamental level, we may ask: What is life? Even a child realizes that a dog or a plant is alive, while a rock or a car is not. Yet the phenomenon we call life defies a simple definition. We recognize life by what living things do. **Figure 1.2** highlights some of the properties and processes we associate with life.

Biology, the scientific study of life, is a subject of enormous scope, and exciting new biological discoveries are being made every day. How can you organize into a comprehensible framework all the information you'll encounter as you study biology? Focusing on a few big ideas will help. Here are five unifying themes—ways of thinking about life that will still be useful decades from now.

- Organization
- Information
- Energy and Matter
- Interactions
- Evolution

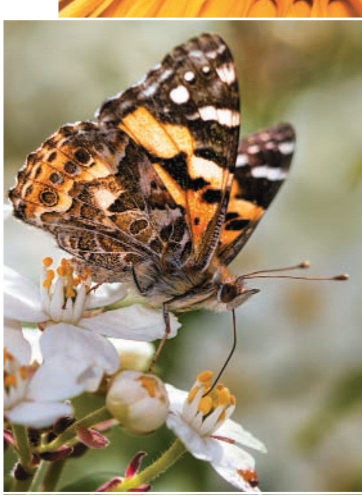
In this section and the next, we'll briefly explore each theme.

▼ **Figure 1.2 Some properties of life.**

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

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

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

Mastering Biology
Animation: Signs of Life
Video: Sea Horse Camouflage

▲ **Growth and development.** Inherited information carried by genes controls the pattern of growth and development of organisms, such as this oak seedling.

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

▼ **Reproduction.** Organisms (living things) reproduce their own kind.

Theme: New Properties Emerge at Successive Levels of Biological Organization

ORGANIZATION The study of life on Earth extends from the microscopic scale of the molecules and cells that make up organisms to the global scale of the entire living planet. As biologists, we can divide this enormous range into different levels of biological organization. In **Figure 1.3**, we zoom in from space to take a closer and closer look at life in a mountain meadow. This journey, depicted as a series of numbered steps, highlights the hierarchy of biological organization.

Zooming in at ever-finer resolution illustrates the principle that underlies *reductionism*, an approach that reduces complex systems to simpler components that are more manageable to study. Reductionism is a powerful strategy in biology. For example, by studying the molecular structure of DNA that had been extracted from cells, James Watson and Francis Crick inferred the chemical basis of biological inheritance. Despite its importance, reductionism provides an incomplete view of life on Earth, as you'll see next.

Emergent Properties

Let's reexamine Figure 1.3, beginning this time at the molecular level and then zooming out. This approach allows us to see novel properties emerge at each level that are absent

▼ Figure 1.3 Exploring Levels of Biological Organization

◄ 1 The Biosphere

Even from space, we can see signs of Earth's life—in the mosaic of greens indicating forests, for example. We can also see the **biosphere**, which consists of all life on Earth and all the places where life exists: most regions of land, most bodies of water, the atmosphere to an altitude of several kilometers, and even sediments far below the ocean floor.

◄ 2 Ecosystems

Our first scale change brings us to a North American mountain meadow, which is an example of an ecosystem, as are a tropical forest, grassland, desert, and coral reef. An **ecosystem** consists of all the living things in a particular area, along with all the nonliving components of the environment with which life interacts, such as soil, water, atmospheric gases, and light.

► 3 Communities

The array of organisms inhabiting a particular ecosystem is called a biological **community**. The community in our meadow ecosystem includes many kinds of plants, various animals, mushrooms and other fungi, and enormous numbers of diverse microorganisms, such as bacteria, that are too small to see without a microscope. Each of these forms of life belongs to a *species*—a group whose members can only reproduce with other members of the group.

► 4 Populations

A **population** consists of all the individuals of a species living within the bounds of a specified area that interbreed with each other. For example, our meadow includes a population of lupines (some of which are shown here) and a population of mule deer. A community is therefore the set of populations that inhabit a particular area.

▲ 5 Organisms

Individual living things are called **organisms**. Each plant in the meadow is an organism, and so is each animal, fungus, and bacterium.

from the preceding one. These **emergent properties** are due to the arrangement and interactions of parts as complexity increases. For example, although photosynthesis occurs in an intact chloroplast, it will not take place if chlorophyll and other chloroplast molecules are simply mixed in a test tube. The coordinated processes of photosynthesis require a specific organization of these molecules in the chloroplast. Isolated components of living systems—the objects of study in a reductionist approach—lack a number of significant properties that emerge at higher levels of organization.

Emergent properties are not unique to life. A box of bicycle parts won't transport you anywhere, but if they are arranged in a certain way, you can pedal to your chosen destination. Compared with such nonliving examples, however, biological systems are far more complex, making the emergent properties of life especially challenging to study.

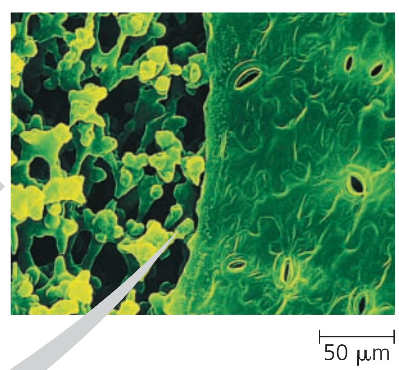
To fully explore emergent properties, biologists today complement reductionism with **systems biology**, the exploration of a biological system by analyzing the interactions among its parts. In this context, a single leaf cell can be considered a system, as can a frog, an ant colony, or a desert ecosystem. By examining and modeling the dynamic behavior of an integrated network of components, systems biology enables us to pose new kinds of questions. For example, how

▼ 6 Organs

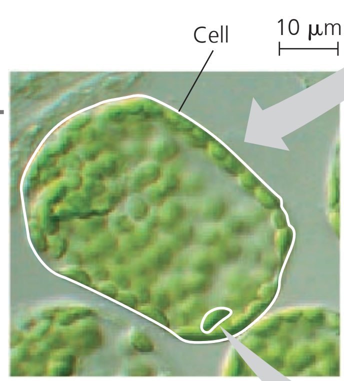
The structural hierarchy of life continues to unfold as we explore the architecture of a complex organism. This lupine leaf (consisting of six leaflets) is an example of an **organ**, a body part that is made up of multiple tissues and has specific functions in the body. Leaves, stems, and roots are the major organs of plants. Within an organ, each tissue has a distinct arrangement and contributes particular properties to organ function.

▼ 7 Tissues

Viewing the tissues of a leaf requires a microscope. Each **tissue** is a group of cells that work together, performing a specialized function. The leaf shown here has been cut on an angle. The honeycombed tissue in the interior of the leaf (left side of photo) is the main location of photosynthesis, the process that converts light energy to the chemical energy of sugar. The jigsaw puzzle–like "skin" on the surface of the leaf (right side of photo) is a tissue called epidermis. The pores through the epidermis allow entry of the gas CO_2, a raw material for sugar production.



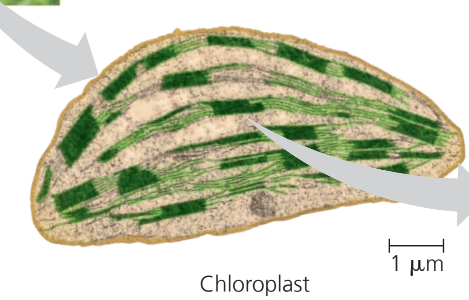
► 8 Cells



The **cell** is life's fundamental unit of structure and function. Some organisms consist of a single cell, which performs all the functions of life. Other organisms are multicellular and feature a division of labor among specialized cells. Here we see a magnified view of a cell in a leaf tissue. This cell is about 40 micrometers (µm) across—about 500 of them would reach across a small coin. Within these tiny cells are even smaller green structures called chloroplasts, which are responsible for photosynthesis.

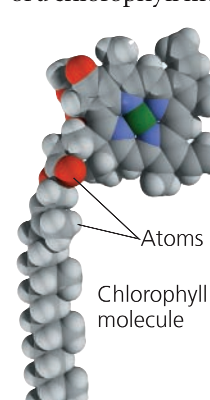
▼ 9 Organelles

Chloroplasts are examples of **organelles**, the various functional components present in cells. The image below, taken by a powerful microscope, shows a single chloroplast.



▼ 10 Molecules

Our last scale change drops us into a chloroplast for a view of life at the molecular level. A **molecule** is a chemical structure consisting of two or more units called atoms, represented as balls in this computer graphic of a chlorophyll molecule. Chlorophyll is the pigment that makes a leaf green, and it absorbs sunlight during photosynthesis. Within each chloroplast, millions of chlorophyll molecules are organized into systems that convert light energy to the chemical energy of food.



do networks of molecular interactions in our bodies generate our 24-hour cycle of wakefulness and sleep? At a larger scale, how does a gradual increase in atmospheric carbon dioxide alter ecosystems and the entire biosphere? Systems biology can be used to study life at all levels.

Structure and Function

At each level of the biological hierarchy, we find a correlation between structure and function. Consider the leaf in Figure 1.3: Its broad, flat shape maximizes the capture of sunlight by chloroplasts. Because such correlations of structure and function are common in all living things, analyzing a biological structure gives us clues about what it does and how it works. For example, the hummingbird's anatomy allows its wings to rotate at the shoulder, so hummingbirds have the ability, unique among birds, to fly backward or hover in place. While hovering, the birds can extend their long, slender beaks into flowers and feed on nectar. The elegant match of form and function in the structures of life is explained by natural selection, which we'll explore shortly.

The Cell: An Organism's Basic Unit of Structure and Function

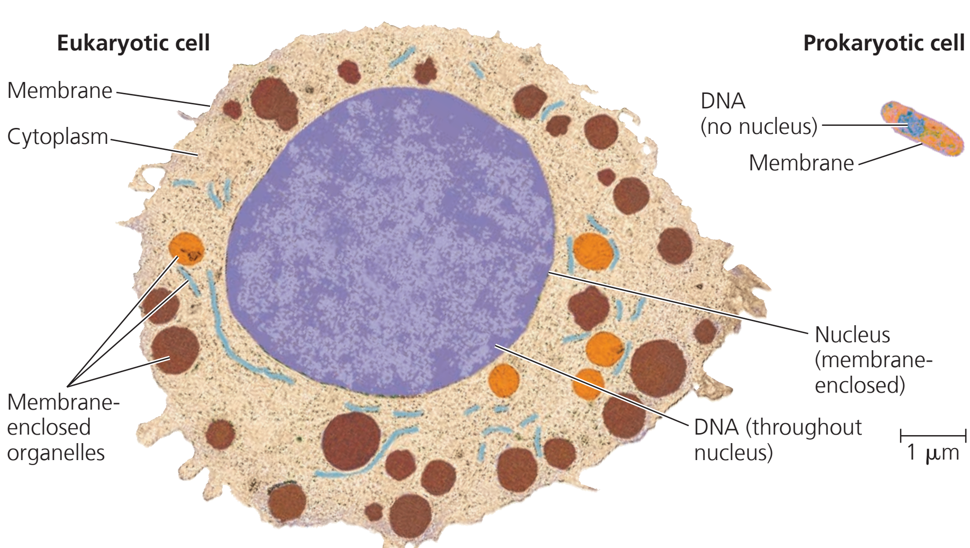
The cell is the smallest unit of organization that can perform all activities required for life. The so-called Cell Theory was first developed in the 1800s, based on the observations of many scientists. The theory states that all living organisms are made of cells, which are the basic unit of life. In fact, the actions of organisms are all based on the activities of cells. For instance, the movement of your eyes as you read this sentence results from the activities of muscle and nerve cells. Even a process that occurs on a global scale, such as the recycling of carbon atoms, is the product of cellular functions, including the photosynthetic activity of chloroplasts in leaf cells.

All cells share certain characteristics. For instance, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. Nevertheless, we distinguish two main forms of cells: prokaryotic and eukaryotic. Prokaryotic cells are found in two groups of single-celled microorganisms, bacteria (singular, *bacterium*) and archaea (singular, *archaean*). All other forms of life, including plants and animals, are composed of eukaryotic cells.

A **eukaryotic cell** contains membrane-enclosed organelles **(Figure 1.4)**. Some organelles, such as the DNA-containing nucleus, are found in the cells of all eukaryotes; other organelles are specific to particular cell types. For example, the chloroplast in Figure 1.3 is an organelle found only in eukaryotic cells that carry out photosynthesis. In contrast to eukaryotic cells, a **prokaryotic cell** lacks a nucleus or other membrane-enclosed organelles. Furthermore, prokaryotic cells are generally smaller than eukaryotic cells, as shown in Figure 1.4.

Theme: Life's Processes Involve the Expression and Transmission of Genetic Information

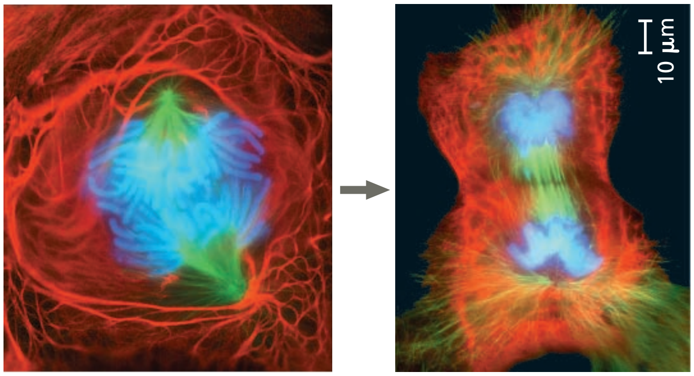
INFORMATION Within cells, structures called chromosomes contain genetic material in the form of **DNA (deoxyribonucleic acid)**. In cells that are preparing to



◀ **Figure 1.4 Contrasting eukaryotic and prokaryotic cells in size and complexity.** The cells are shown to scale here; to see a larger magnification of a prokaryotic cell, see Figure 6.5.

VISUAL SKILLS *Measure the scale bar, the length of the prokaryotic cell, and the diameter of the eukaryotic cell. Knowing that this scale bar represents 1 μm, calculate the length of the prokaryotic cell and the diameter of the eukaryotic cell in μm.*

▼ **Figure 1.5 A lung cell from a newt divides into two smaller cells that will grow and divide again.**



divide, the chromosomes may be made visible using a dye that appears blue when bound to the DNA **(Figure 1.5)**.

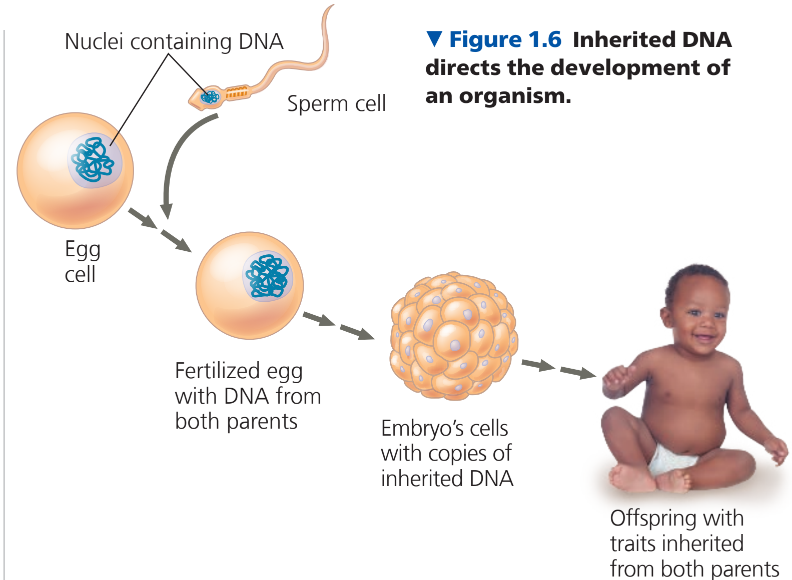
DNA, the Genetic Material

Each chromosome contains one very long DNA molecule with hundreds or thousands of **genes**, each a section of the DNA of the chromosome. Transmitted from parents to offspring, genes are the units of inheritance. They encode the information necessary to build all of the molecules synthesized within a cell, which in turn establish that cell's identity and function. You began as a single cell stocked with DNA inherited from your parents. The replication of that DNA prior to each cell division transmitted copies of the DNA to what eventually became the trillions of cells of your body. As the cells grew and divided, the genetic information encoded by the DNA directed your development **(Figure 1.6)**.

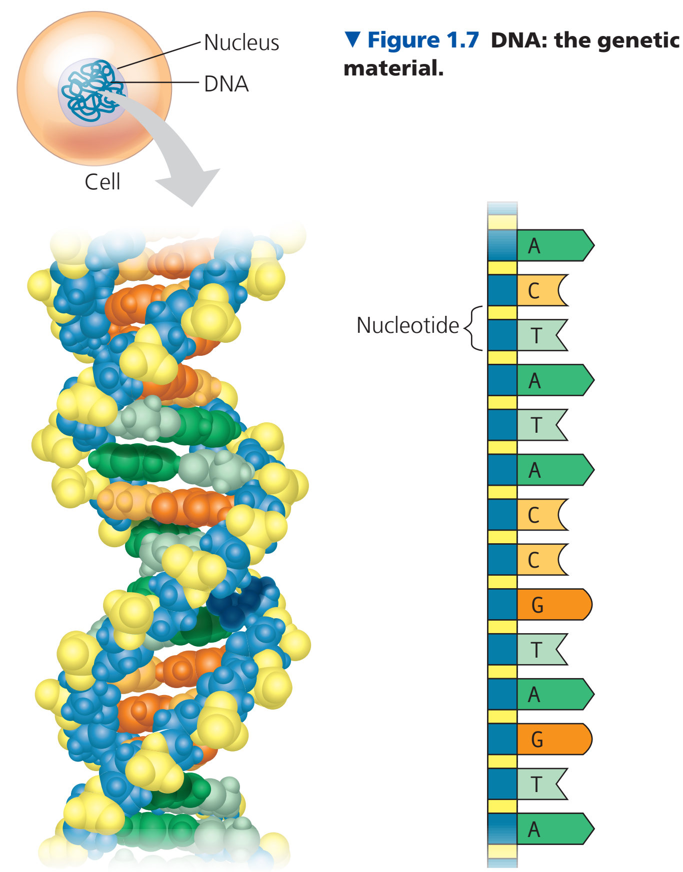
The molecular structure of DNA accounts for its ability to store information. A DNA molecule is made up of two long chains, called strands, arranged in a double helix. Each chain is made up of four kinds of chemical building blocks called nucleotides, abbreviated A, T, C, and G **(Figure 1.7)**. Specific sequences of these four nucleotides encode the information in genes. The way DNA encodes information is analogous to how we arrange the letters of the alphabet into words and phrases with specific meanings. The word *rat*, for example, evokes a rodent; the words *tar* and *art*, which contain the same letters, mean very different things. We can think of nucleotides as a four-letter alphabet.

For many genes, the sequence provides the blueprint for making a protein. For instance, a given bacterial gene may specify a particular protein (such as an enzyme) required to break down a certain sugar molecule, while one particular human gene may denote an enzyme, and another gene a different protein (an antibody, perhaps) that helps fight off infection. Overall, proteins are major players in building and maintaining the cell and carrying out its activities.

▼ **Figure 1.6 Inherited DNA directs the development of an organism.**



▼ **Figure 1.7 DNA: the genetic material.**



(a) DNA double helix. This model shows the atoms in a segment of DNA. Made up of two long chains (strands) of building blocks called nucleotides, a DNA molecule takes the three-dimensional form of a double helix.

(b) Single strand of DNA. These geometric shapes and letters are simple symbols for the nucleotides in a small section of one strand of a DNA molecule. Genetic information is encoded in specific sequences of the four types of nucleotides. Their names are abbreviated A, T, C, and G.

Mastering Biology **Animation: Heritable Information: DNA**

Protein-encoding genes control protein production indirectly, using a related molecule called RNA as an intermediary. The sequence of nucleotides along a gene is transcribed into mRNA, which is then translated into a linked series of protein building blocks called amino acids. Once completed, the amino acid chain forms a specific protein with a unique shape and function. The entire process by which the information in a gene directs the manufacture of a cellular product is called **gene expression** **(Figure 1.8)**.

In carrying out gene expression, all forms of life employ essentially the same genetic code: A particular sequence of nucleotides means the same thing in one organism as it does in another. Differences between organisms reflect differences between their nucleotide sequences rather than between their genetic codes. This universality of the genetic code is a strong piece of evidence that all life is related. Comparing the sequences in several species for a gene that codes for a particular protein can provide valuable information both about the protein and about the relationship of the species to each other.

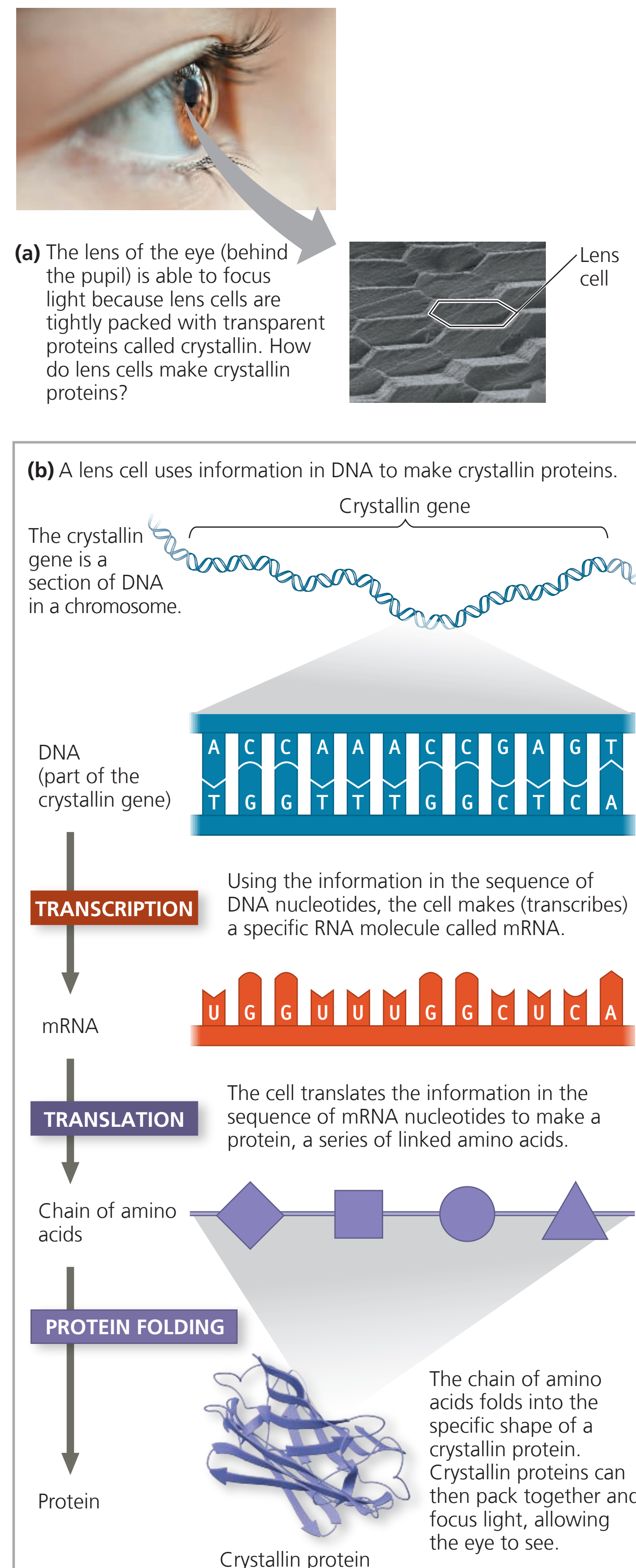
Molecules of mRNA, like the one in Figure 1.8, are translated into proteins, but other cellular RNAs function differently. For example, we have known for decades that some types of RNA are actually components of the cellular machinery that manufactures proteins. In the last few decades, scientists have discovered new classes of RNA that play other roles in the cell, such as regulating the function of protein-coding genes. Genes specify these RNAs as well, and their production is also referred to as gene expression. By carrying the instructions for making proteins and RNAs and by replicating with each cell division, DNA ensures faithful inheritance of genetic information from generation to generation.

Genomics: Large-Scale Analysis of DNA Sequences

The entire "library" of genetic instructions that an organism inherits is called its **genome**. A typical human cell has two similar sets of chromosomes, and each set has approximately 3 billion nucleotide pairs of DNA. If the one-letter abbreviations for the nucleotides of a set were written in letters the size of those you are now reading, the genomic text would fill about 700 biology textbooks.

Since the early 1990s, the pace at which researchers can determine the sequence of a genome has accelerated at an astounding rate, enabled by a revolution in technology. The genome sequence—the entire sequence of nucleotides for a representative member of a species—is now known for humans and many other animals, as well as numerous plants, fungi, bacteria, and archaea. To make sense of the deluge of data from genome-sequencing projects and the growing catalog of known gene functions, scientists are applying a systems biology approach at the cellular and molecular levels. Rather than investigating a single gene at

▼ Figure 1.8 Gene expression: Cells use information encoded in a gene to synthesize a functional protein.



(a) The lens of the eye (behind the pupil) is able to focus light because lens cells are tightly packed with transparent proteins called crystallin. How do lens cells make crystallin proteins?

(b) A lens cell uses information in DNA to make crystallin proteins.

Mastering Biology **Figure Walkthrough**

a time, researchers study whole sets of genes (or other DNA) in one or more species—an approach called **genomics**. Likewise, the term **proteomics** refers to the study of sets of proteins and their properties. (The entire set of proteins expressed by a given cell, tissue, or organism is called a **proteome**.)

Three important research developments have made the genomic and proteomic approaches possible. One is "high-throughput" technology, tools that can analyze many biological samples very rapidly. The second major development is **bioinformatics**, the use of computational tools to store, organize, and analyze the huge volume of data that results from high-throughput methods. The third development is the formation of interdisciplinary research teams—groups of diverse specialists that may include computer scientists, mathematicians, engineers, chemists, physicists, and, of course, biologists from a variety of fields. Researchers in such teams aim to learn how the activities of all the proteins and RNAs encoded by the DNA are coordinated in cells and in whole organisms.

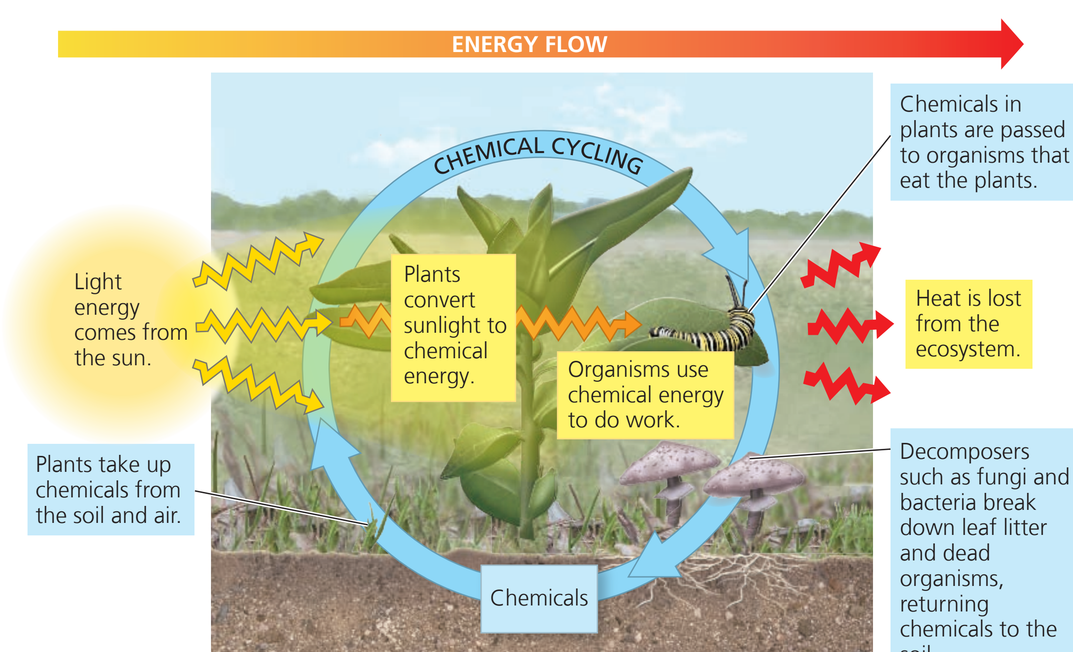
Theme: Life Requires the Transfer and Transformation of Energy and Matter

ENERGY AND MATTER Moving, growing, reproducing, and the various cellular activities of life are work, and work requires energy. The input of energy, primarily from the sun, and the transformation of energy from one form to another make life possible **(Figure 1.9)**. When a plant's leaves absorb sunlight in the process of photosynthesis, molecules within the leaves convert the energy of sunlight to the chemical energy of food, such as sugars. The chemical energy in the food molecules is then passed along from plants and other photosynthetic organisms (**producers**) to consumers. A **consumer** is an organism that feeds on other organisms or their remains.

When an organism uses chemical energy to perform work, such as muscle contraction or cell division, some of that energy is lost to the surroundings as heat. As a result, energy *flows through* an ecosystem in one direction, usually entering as light and exiting as heat. In contrast, chemicals *cycle within* an ecosystem, where they are used and then recycled (see Figure 1.9). Chemicals that a plant absorbs from the air or soil may be incorporated into the plant's body and then passed to an animal that eats the plant. Eventually, these chemicals will be returned to the environment by decomposers such as bacteria and fungi that break down waste products, leaf litter, and the bodies of dead organisms. The chemicals are then available to be taken up by plants again, thereby completing the cycle.

Theme: From Molecules to Ecosystems, Interactions Are Important in Biological Systems

INTERACTIONS At any level of the biological hierarchy, interactions between the components of the system ensure smooth integration of all the parts, such that they function as a whole. This holds true equally well for molecules in a cell and the components of an ecosystem; we'll look at both as examples.



▶ **Figure 1.9 Energy flow and chemical cycling.** There is a one-way flow of energy in an ecosystem: During photosynthesis, plants convert energy from sunlight to chemical energy (stored in food molecules such as sugars), which is used by plants and other organisms to do work and is eventually lost from the ecosystem as heat. In contrast, chemicals cycle between organisms and the physical environment.