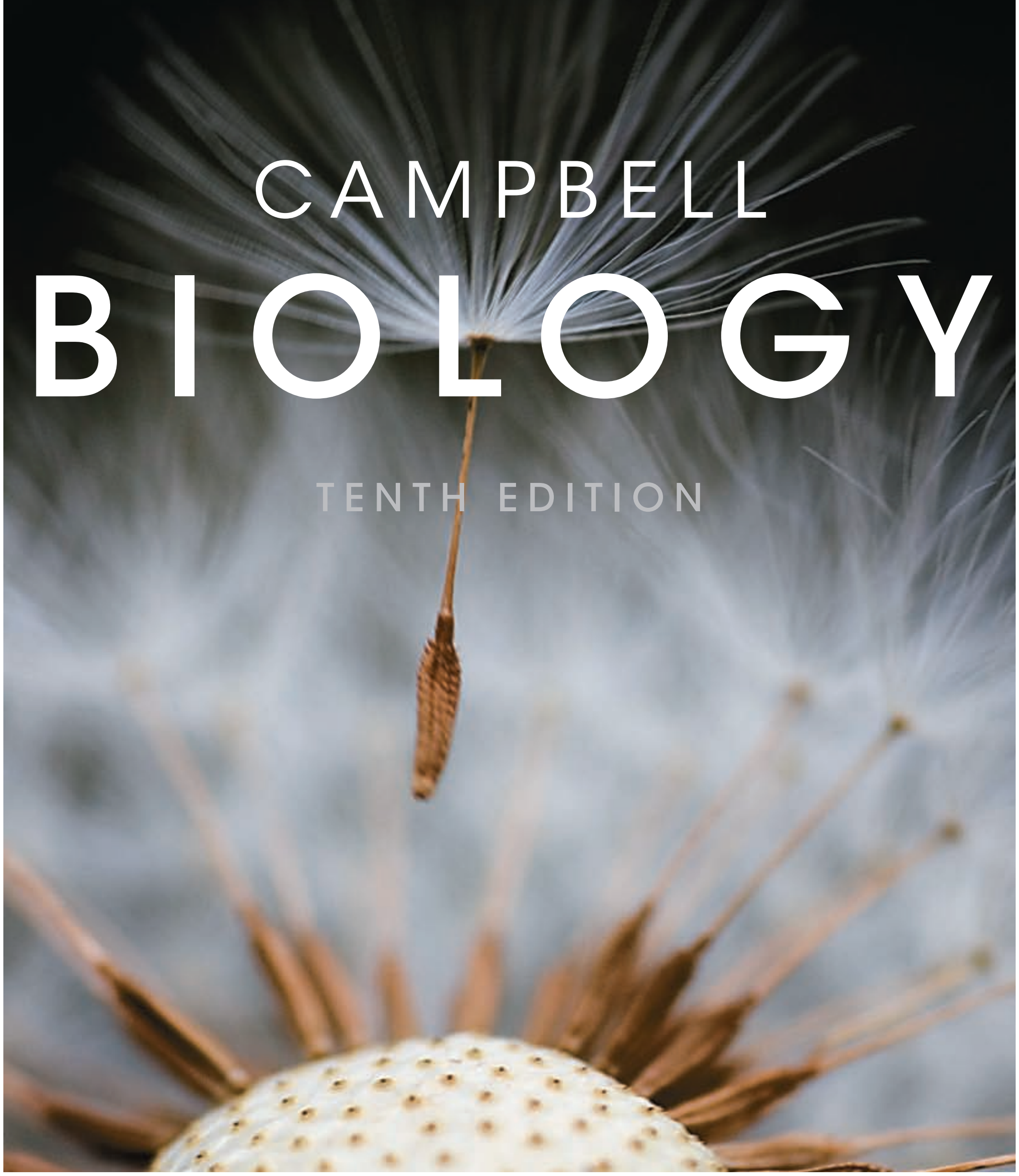
TENTH EDITION

CAMPBELL BIOLOGY

REECE • URRY • CAIN
WASSERMAN • MINORSKY • JACKSON



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Brief Contents

About the Authors

The Tenth Edition author team's contributions reflect their biological expertise as researchers and their 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 Tenth Edition.

Jane B. Reece

Jane Reece was Neil Campbell's longtime collaborator, and she has participated in every edition of *CAMPBELL 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 at UC Berkeley and postdoctoral fellow at Stanford University focused on genetic recombination in bacteria. Besides her work on *CAMPBELL BIOLOGY*, she has been a coauthor on *Campbell Biology in Focus*, *Campbell Biology: Concepts & Connections*, *Campbell Essential Biology*, and *The World of the Cell*.

Lisa A. Urry

Lisa Urry is Professor of Biology and Chair of the Biology Department at Mills College in Oakland, California, and a Visiting Scholar at the University of California, Berkeley. After graduating from Tufts University with a double major in biology and French, Lisa completed her Ph.D. in molecular and developmental biology at the Massachusetts Institute of Technology (MIT) in the MIT/Woods Hole Oceanographic Institution Joint Program. She has published a number of research papers, most of them focused on gene expression during embryonic and larval development in sea urchins. Lisa has taught a variety of courses, from introductory biology to developmental biology and senior seminar. As a part of her mission to increase understanding of evolution, Lisa also teaches a nonmajors course called Evolution for Future Presidents and is on the Teacher Advisory Board for the Understanding Evolution website developed by the University of California Museum of Paleontology. Lisa is also deeply committed to promoting opportunities in science for women and underrepresented minorities. Lisa is also a coauthor of *Campbell Biology in Focus*.

Michael L. Cain

Michael Cain 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* and *Campbell Biology in Focus*, Michael is the lead author of an ecology textbook.

Steven A. Wasserman

Steve Wasserman is Professor of Biology 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 currently focuses on teaching introductory biology. 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 Lucile Packard Foundation. In 2007, he received UCSD's Distinguished Teaching Award for undergraduate teaching. Steve is also a coauthor of *Campbell Biology in Focus*.

Peter V. Minorsky

Peter Minorsky is Professor of Biology at Mercy College in New York, where he teaches introductory biology, evolution, ecology, and botany. He received his A.B. 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. His research interests concern how plants sense environmental change. Peter received the 2008 Award for Teaching Excellence at Mercy College. Peter is also a coauthor of *Campbell Biology in Focus*.

Robert B. Jackson

Rob Jackson is the Douglas Professor of Environment and Energy in the Department of Environmental Earth System Science at Stanford 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. While a biology professor at Duke University, Rob directed the university's Program in Ecology and was Vice President of Science for the Ecological Society of America. He has received numerous awards, including a Presidential Early Career Award in Science and Engineering from the National Science Foundation. Rob is a Fellow of both the Ecological Society of America and the American Geophysical Union. 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*. Rob is also a coauthor of *Campbell Biology in Focus*.

Neil A. Campbell

Neil Campbell (1946–2004) 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 the University of California, Los Angeles, 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 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. Neil was a visiting scholar in the Department of Botany and Plant Sciences at the University of California, Riverside.

Preface

We are honored to present the Tenth Edition of *Campbell Biology*. For the last quarter century, *Campbell Biology* has been the leading college text in the biological sciences. It has been translated into more than a dozen 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 thousands of reviewers, who, together with editors, artists, and contributors, have shaped and inspired this work. Although this Tenth Edition represents a milestone, science and pedagogy are not static—as they evolve, so does *Campbell Biology*.

Our goals for the Tenth Edition include:

- helping students **make connections visually** across the diverse topics of biology
- giving students a strong foundation in **scientific thinking and quantitative reasoning skills**
- inspiring students with the excitement and relevance of modern biology, particularly in the realm of **genomics**

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

New to This Edition

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

- **Make Connections Figures** draw together topics from different chapters to show how they are all related in the "big picture." By reinforcing fundamental conceptual connections throughout biology, these figures help overcome students' tendencies to compartmentalize information.
- **Scientific Skills Exercises** in every chapter use real data and guide students in learning and practicing data interpretation, graphing, experimental design, and math skills. All 56 Scientific Skills Exercises have assignable, automatically graded versions in **MasteringBiology**®.
- **Interpret the Data Questions** throughout the text engage students in scientific inquiry by asking them to interpret data presented in a graph, figure, or table. The Interpret the Data Questions can be assigned and automatically graded in **MasteringBiology**.
- The impact of **genomics** across biology is explored throughout the Tenth Edition with examples that reveal how our ability to rapidly sequence DNA and proteins is transforming all areas of biology, from molecular and cell biology to phylogenetics, physiology, and ecology. Chapter 5 provides a launching point for this feature in a new Key Concept, "Genomics and proteomics have transformed biological inquiry and applications." Illustrative examples are distributed throughout later chapters.
- **Synthesize Your Knowledge Questions** at the end of each chapter ask students to synthesize the material in the chapter and demonstrate their big-picture understanding. A striking photograph with a thought-provoking question helps students see how material they learned in the chapter connects to their world and provides insight into natural phenomena.
- The Tenth Edition provides a range of new practice and assessment opportunities in **MasteringBiology.** Besides the Scientific Skills Exercises and Interpret the Data Questions, **Solve It Tutorials** in MasteringBiology engage students in a multistep investigation of a "mystery" or open question. Acting as scientists, students must analyze real data and work through a simulated investigation. In addition, **Adaptive Follow-Up Assignments** provide coaching and practice that continually adapt to each student's needs, making efficient use of study time. Students can use the **Dynamic Study Modules** to study anytime and anywhere with their smartphones, tablets, or computers.
- **Learning Catalytics**™ allows students to use their smartphones, tablets, or laptops to respond to questions in class.
- As in each new edition of *Campbell Biology*, the Tenth Edition incorporates **new content** and **organizational improvements**. These are summarized on pp. viii–ix, following this Preface.

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.

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 MasteringBiology all reinforce these main ideas and essential facts.

CAMPBELL BIOLOGY also helps students organize and make sense of what they learn by emphasizing **evolution and other unifying themes** that pervade biology. These themes are introduced in Chapter 1 and are integrated throughout the book. Each chapter 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.

Because text and illustrations are equally important for learning biology, **integration of text and figures** has been a hallmark of this text since the First Edition. In addition to the new Make Connections Figures, 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 as an instructor would. Visual Organizer Figures highlight the main parts of a figure, helping students see key categories at a glance. And Summary Figures visually recap information from the chapter.

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. Active learning questions include Make Connections Questions, What If? Questions, Figure Legend Questions, Draw It Questions, Summary Questions, and the new Synthesize Your Knowledge and Interpret the Data Questions.

Finally, *CAMPBELL BIOLOGY* has always featured **scientific inquiry**, an essential component of any biology course. Complementing stories of scientific discovery in the text narrative and the unit-opening interviews, our standard-setting Inquiry Figures deepen the ability of students to understand how we know what we know. Scientific Inquiry Questions give students opportunities to practice scientific thinking, along with the new Scientific Skills Exercises and Interpret the Data Questions.

MasteringBiology®

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 the new Scientific Skills Exercises, Interpret the Data Questions, Solve It Tutorials, Adaptive Follow-Up Assignments, and Dynamic Study Modules, MasteringBiology offers BioFlix® Tutorials with 3-D Animations, Experimental Inquiry Tutorials, Interpreting Data Tutorials, BLAST Tutorials, Make Connections Tutorials, Video Tutor Sessions, Get Ready for Biology, Activities, Reading Quiz Questions, Student Misconception Questions, 4,500 Test Bank Questions, and MasteringBiology Virtual Labs. MasteringBiology also includes the *CAMPBELL BIOLOGY* eText, Study Area, and Instructor Resources. See pages xviii–xxi and www.masteringbiology.com for more details.

Our Partnership with Instructors and Students

A core value underlying our work is our belief in the importance of a partnership with instructors and students. One primary way of serving instructors and students, of course, is providing a text that teaches biology well. In addition, Pearson Education offers a rich variety of instructor and student resources, in both print and electronic form (see pp. xviii–xxiii). In our continuing efforts to improve the book and its supplements, we benefit tremendously from instructor and student feedback, not only in formal reviews from hundreds of scientists, but also via e-mail and other avenues of informal communication.

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 any of us:

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New Content

This section highlights selected new content and organizational changes in *CAMPBELL BIOLOGY*, Tenth Edition.

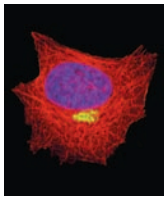
CHAPTER 1 Evolution, the Themes of Biology, and Scientific Inquiry

To help students focus on the big ideas of biology, we now emphasize five themes: Organization, Information, Energy and Matter, Interactions, and the core theme of Evolution. The new Figure 1.8 on gene expression equips students from the outset with an understanding of how gene sequences determine an organism's characteristics. Concept 1.3 has been reframed to more realistically reflect the scientific process, including a new figure on the complexity of the practice of science (Figure 1.23). A new case study in scientific inquiry (Figures 1.24 and 1.25) deals with evolution of coloration in mice.

UNIT 1 The Chemistry of Life

New chapter-opening photos and introductory stories engage students in learning this foundational material. Chapter 2 has a new Evolution section on radiometric dating. In Chapter 5, there is a new Key Concept section, "Genomics and proteomics have transformed biological inquiry and applications" (Concept 5.6), and a new Make Connections Figure, "Contributions of Genomics and Proteomics to Biology" (Figure 5.26).

UNIT 2 The Cell



Our main goal for this unit was to make the material more accessible to students. We have streamlined coverage of the cytoskeleton in Chapter 6 and historical aspects of the membrane model in Chapter 7. We have revised the photosynthesis summary figure (Figure 10.22) to incorporate a big-picture view of photosynthesis. The new Make Connections Figure 10.23 integrates the cellular activities covered in Chapters 5–10 in the context of a single plant cell. Concept 12.3 has been streamlined, with a new Figure 12.17 that covers the M checkpoint as well as the G_1 checkpoint.

UNIT 3 Genetics

In Chapters 13–17, we have incorporated changes that help students make connections between the more abstract concepts of genetics and their molecular underpinnings. For example, Chapter 13 includes a new figure (Figure 13.9) detailing the events of crossing over during prophase. Figure 14.4, showing alleles on chromosomes, has been enhanced to show the DNA sequences of both alleles, along with their biochemical and phenotypic consequences. A new figure on sickle-cell disease also connects these levels (Figure 14.17). In Chapter 17, material on coupled transcription and translation in bacteria has been united with coverage of polyribosomes.

Chapters 18–21 are extensively updated, driven by exciting new discoveries based on high-throughput sequencing. Chapter 18 includes a new figure (Figure 18.15) on the role of siRNAs in chromatin remodeling. A new Make Connections Figure (Figure 18.27) describes four subtypes of breast cancer that have recently been proposed, based on gene expression in tumor cells. In Chapter 20, techniques that are less commonly used have been pruned, and the chapter has been reorganized to emphasize the important role of sequencing. A new figure (Figure 20.4) illustrates next-generation sequencing. Chapter 21 has been updated to reflect new research, including the ENCODE project, the Cancer Genome Atlas, and the genome sequences of the gorilla and bonobo. A new figure (Figure 21.15) compares the 3-D structures of lysozyme and α-lactalbumin and their amino acid sequences, providing support for their common evolutionary origin.

UNIT 4 Mechanisms of Evolution

One goal of this revision was to highlight connections among fundamental evolutionary concepts. Helping meet this goal, new material connects Darwin's ideas to what can be learned from phylogenetic trees, and a new figure (Figure 25.13) and text illustrate how the combined effects of speciation and extinction determine the number of species in different groups of organisms. The unit also features new material on nucleotide variability within genetic loci, including a new figure (Figure 23.4) that shows variability within coding and noncoding regions of a gene. Other changes enhance the storyline of the unit. For instance, Chapter 25 includes new text on how the rise of large eukaryotes in the Ediacaran period represented a monumental transition in the history of life—the end of a microbe-only world. Updates include revised discussions of the events and underlying causes of the Cambrian explosion and the Permian mass extinction, as well as new figures providing fossil evidence of key evolutionary events, such as the formation of plant-fungi symbioses (Figure 25.12). A new Make Connections Figure (Figure 23.17) explores the sickle-cell allele and its impact from the molecular and cellular levels to organisms to the evolutionary explanation for the allele's global distribution in the human population.

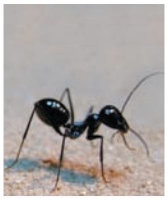
UNIT 5 The Evolutionary History of Biological Diversity

In keeping with our Tenth Edition goals, we have expanded the coverage of genomic and other molecular studies and how they inform our understanding of phylogeny. Examples include a new Inquiry Figure (Figure 34.49) on the Neanderthal genome and presentation of new evidence that mutualistic interactions between plants and fungi are ancient. In addition, many phylogenies have been revised to reflect recent miRNA and genomic data. The unit also contains new material on tree-thinking, such as a new figure (Figure 26.11) that distinguishes between paraphyletic and polyphyletic taxa. We continue to emphasize evolutionary events that underlie the diversity of life on Earth. For example, a new section in Chapter 32 discusses the origin of multicellularity in animal ancestors. A new Make Connections Figure (Figure 33.9) explores the diverse structural solutions for maximizing surface area that have evolved across different kingdoms.

UNIT 6 Plant Form and Function

In developing the Tenth Edition, we have continued 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. To underscore the relevance of plant biology to society, there is now expanded coverage of plant biotechnology and the development of biofuels in Chapter 38. Other updates include expanded coverage of bacterial components of the rhizosphere (Figure 37.9), plant mineral deficiency symptoms (Table 37.1), evolutionary trends in floral morphology (Chapter 38), and chemical communication between plants (Chapter 39). The discussion of plant defenses against pathogens and herbivores has been extensively revised and now includes a Make Connections Figure that examines how plants deter herbivores at numerous levels of biological organization, ranging from the molecular level to the community level (Figure 39.27).

UNIT 7 Animal Form and Function



In revising this unit, we strove to enhance student appreciation of the core concepts and ideas that apply across diverse organisms and varied organ systems. For example, a new Make Connections Figure (Figure 40.22) highlights challenges common to plant and animal physiology and presents both shared and divergent solutions to those challenges; this figure provides both a useful summary of plant physiology and an introduction to animal physiology. To help students recognize the central concept of homeostasis, figures have been revised across six chapters to provide a consistent organization that facilitates interpretation of individual hormone pathways as well as the comparison of pathways for different hormones. Homeostasis and endocrine regulation are highlighted by new and engaging chapter-opening photos and stories on the desert ant (Chapter 40) and on sexual dimorphism (Chapter 45), a revised presentation of the variation in target cell responses to a hormone (Figure 45.8), and a new figure integrating art and text on human endocrine glands and hormones (Figure 45.9). Many figures have been reconceived to emphasize key information, including new figures introducing the classes of essential nutrients (Figure 41.2) and showing oxygen and carbon dioxide partial pressures throughout the circulatory system (Figure 42.29). A new Make Connections Figure (Figure 44.17) demonstrates the importance of concentration gradients in animals as well as all other organisms. Throughout the unit, new state-of-the-art images and material on current and compelling topics—such as the human stomach microbiome (Figure 41.18) and the identification of the complete set of human taste receptors (Chapter 50)—will help engage students and encourage them to make connections beyond the text.

UNIT 8 Ecology

For the Tenth Edition, the ecology unit engages students with new ideas and examples. Chapter 52 highlights the discovery of the world's smallest vertebrate species. New text and a figure use the saguaro cactus to illustrate how abiotic and biotic factors limit the distribution of species (Figure 52.15). Greater emphasis is placed on the importance of disturbances, such as the effects of Hurricane Katrina on forest mortality. Chapter 53 features the loggerhead turtle in the chapter opener, Concept 53.1 (reproduction), and Concept 53.4 (evolution and life history traits). The chapter also includes new molecular coverage: how ecologists use genetic profiles to estimate the number of breeding loggerhead turtles (Figure 53.7) and how a single gene influences dispersal in the Glanville fritillary. In Chapter 54, new text and a figure highlight the mimic octopus, a recently discovered species that illustrates how predators use mimicry (Figure 54.6). A new Make Connections Figure ties together population, community, and ecosystem processes in the arctic tundra (Figure 55.13). Chapter 55 also has a new opening story on habitat transformation in the tundra. Chapter 56 highlights the emerging fields of urban ecology and conservation biology, including the technical and ethical challenges of resurrecting extinct species. It also examines the threat posed by pharmaceuticals in the environment. The book ends on a hopeful note, charging students to use biological knowledge to help solve problems and improve life on Earth.

See the Big Picture

KEY CONCEPTS

Each chapter is organized around a framework of 3 to 7 **Key Concepts** that focus on the big picture and provide a context for the supporting details.

41 Animal Nutrition

KEY CONCEPTS

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

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

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

41.4 Evolutionary adaptations of vertebrate digestive systems correlate with diet

41.5 Feedback circuits regulate digestion, energy storage, and appetite

▲ **Figure 41.1** How does a crab help an otter make fur?

The Need to Feed

Dinnertime has arrived for the sea otter in **Figure 41.1** (and for the crab, though in quite a different sense). The muscles and other organs of the crab will be chewed into pieces, broken down by acid and enzymes in the otter's digestive system, and finally absorbed as small molecules into the body of the otter. Such a process is what is meant by animal **nutrition**: food being taken in, taken apart, and taken up.

Although dining on fish, crabs, urchins, and abalone is the sea otter's specialty, all animals eat other organisms—dead or alive, piecemeal or whole. Unlike plants, animals must consume food for both energy and the organic molecules used to assemble new molecules, cells, and tissues. Despite this shared need, animals have diverse diets. **Herbivores**, such as cattle, sea slugs, and caterpillars, dine mainly on plants or algae. **Carnivores**, such as sea otters, hawks, and spiders, mostly eat other animals. Rats and other **omnivores** (from the Latin *omnis*, all) don't in fact eat everything, but they do regularly consume animals as well as plants or algae. We humans are typically omnivores, as are cockroaches and crows.

The terms *herbivore*, *carnivore*, and *omnivore* represent the kinds of food an animal usually eats. Keep in mind, however, that most animals are opportunistic feeders, eating foods outside their standard diet when their usual foods aren't available.

◀ Every chapter opens with a visually dynamic **photo** accompanied by an **intriguing question** that invites students into the chapter.

▲ The **List of Key Concepts** introduces the big ideas covered in the chapter.

After reading a Key Concept section, students can check their understanding using the **Concept Check Questions**.

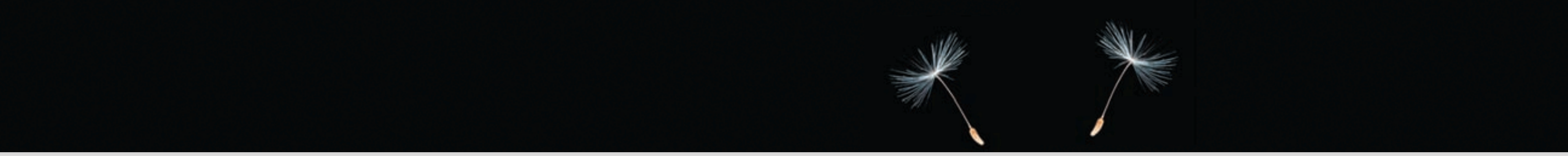
CONCEPT CHECK 41.1

1. All 20 amino acids are needed to make animal proteins. Why aren't they all essential to animal diets?
2. **MAKE CONNECTIONS** Considering the role of enzymes in metabolic reactions (see Concept 8.4), explain why vitamins are required in very small amounts in the diet.
3. **WHAT IF?** If a zoo animal eating ample food shows signs of malnutrition, how might a researcher determine which nutrient is lacking in its diet?

◀ Questions throughout the chapter encourage students to **read the text actively**.

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

What if? Questions ask students to apply what they've learned. ▶



The **Summary of Key Concepts** refocuses students on the main points of the chapter.

41 Chapter Review

SUMMARY OF KEY CONCEPTS

- Animals have diverse diets. **Herbivores** mainly eat plants; **carnivores** mainly eat other animals; and **omnivores** eat both. In meeting their nutritional needs, animals must balance consumption, storage, and use of food.

CONCEPT 41.1

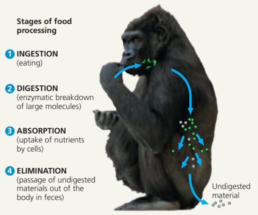
An animal's diet must supply chemical energy, organic molecules, and essential nutrients (pp. 893–897)

- Food provides animals with energy for ATP production, carbon skeletons for biosynthesis, and **essential nutrients**—nutrients that must be supplied in preassembled form. Essential nutrients include certain amino acids and fatty acids that animals cannot synthesize; **vitamins**, which are organic molecules; and **minerals**, which are inorganic substances.
- Animals can suffer from two types of malnutrition: an inadequate intake of essential nutrients and a deficiency in sources of chemical energy. Studies of disease at the population level help researchers determine human dietary requirements.

? *How can an enzyme cofactor needed for a process that is vital to all animals be an essential nutrient (vitamin) for only some?*

CONCEPT 41.2

The main stages of food processing are ingestion, digestion, absorption, and elimination (pp. 897–900)

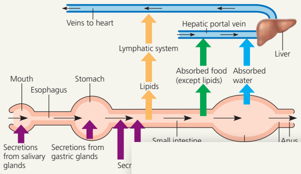


- Animals differ in the ways they obtain and ingest food. Many animals are **bulk feeders**, eating large pieces of food. Other strategies include filter feeding, suspension feeding, and fluid feeding.
- Compartmentalization is necessary to avoid self-digestion. In intracellular digestion, food particles are engulfed by endocytosis and digested within food vacuoles that have fused with lysosomes. In extracellular digestion, which is used by most animals, enzymatic hydrolysis occurs outside cells in a **gastrovascular cavity** or **alimentary canal**.

? *Propose an artificial diet that would eliminate the need for one of the first three steps in food processing.*

CONCEPT 41.3

Organs specialized for sequential stages of food processing form the mammalian digestive system (pp. 900–906)



? *What structural feature of th*
for absorption of nutrients than t

CONCEPT 41.4

Evolutionary adaptations of
correlate with diet (pp. 906

- Vertebrate digestive system
tions associated with diet. F
assortment of teeth, general
mutualism, many herbivore
chambers where microorga
also usually have longer alin
flecting the longer time nee

? *How does human anatomy i*
were not strict vegetarians?

CONCEPT 41.5

Feedback circuits regulate
appetite (pp. 908–912)

- **Nutrition** is regulated at m
canal triggers nervous and
secretion of digestive juices
ingested material through t
for energy production is reg
and **glucagon**, which contr
glycogen.
- Vertebrates store excess cal
cells) and in fat (in adipose
tapped when an animal exp
If, however, an animal cons
normal metabolism, the res
the serious health problem
- Several hormones, includin
by affecting the brain's satie

? *Explain why your stomach m*
skip a meal.

▲ **Summary Figures** recap key information in a visual way. **Summary of Key Concepts Questions** check students' understanding of a key idea from each concept.

▼ **Test Your Understanding Questions** at the end of each chapter are organized into three levels based on **Bloom's Taxonomy**:

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

Test Bank questions and multiple-choice questions in MasteringBiology® are also categorized by Bloom's Taxonomy.

TEST YOUR UNDERSTANDING

LEVEL 1: KNOWLEDGE/COMPREHENSION

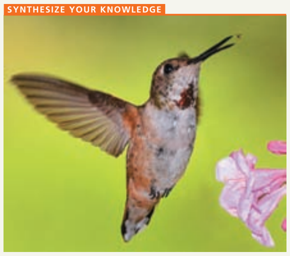
1. Fat digestion yields fatty acids and glycerol, whereas protein digestion yields amino acids. Both digestive processes
   a. occur inside cells in most animals.
   b. add a water molecule to break bonds.
   c. require a low pH resulting from HCl production.
   d. consume ATP.
2. The mammalian trachea and esophagus both connect to the
   a. pharynx.
   b. stomach.
   c. large intestine.
   d. rectum.
3. Which of the following organs is *incorrectly* paired with its function?
   a. stomach—protein digestion
   b. large intestine—bile production
   c. small intestine—nutrient absorption
   d. pancreas—enzyme production
4. Which of the following is *not* a major activity of the stomach?
   a. mechanical digestion
   b. HCl production
   c. nutrient absorption
   d. enzyme secretion

LEVEL 2: APPLICATION/ANALYSIS

5. After surgical removal of an infected gallbladder, a person must be especially careful to restrict dietary intake of
   a. starch.
   b. protein.
   c. sugar.
   d. fat.
6. If you were to jog 1 km a few hours after lunch, which stored fuel would you probably tap?
   a. muscle proteins
   b. muscle and liver glycogen
   c. fat in the liver
   d. fat in adipose tissue

LEVEL 3: SYNTHESIS/EVALUATION

7. DRAW IT Make a flowchart of the events that occur after partially digested food leaves the stomach. Use the following terms: bicarbonate secretion, circulation, decrease in acidity, increase in acidity, secretin secretion, signal detection. Next to each term, indicate the compartment(s) involved. You may use terms more than once.
8. EVOLUTION CONNECTION
   The human esophagus and trachea share a passage leading from the mouth and nasal passages, which can cause problems. After reviewing vertebrate evolution (see Chapter 34), explain how the evolutionary concept of descent with modification explains this "imperfect" anatomy.
9. SCIENTIFIC INQUIRY
   In human populations of northern European origin, the disorder called hemochromatosis causes excess iron uptake from food and affects one in 200 adults. Among adults, men are ten times as likely as women to suffer from iron overload. Taking into account the existence of a menstrual cycle in humans, devise a hypothesis that explains this difference.
10. WRITE ABOUT A THEME: ORGANIZATION
   Hair is largely made up of the protein keratin. In a short essay (100–150 words), explain why a shampoo containing protein is not effective in replacing the protein in damaged hair.
11. SYNTHESIZE YOUR KNOWLEDGE



Hummingbirds are well adapted to obtain sugary nectar from flowers, but they use some of the energy obtained from nectar when they forage for insects and spiders. Explain why this foraging is necessary.

For selected answers, see Appendix A.

MasteringBiology®

Students Go to **MasteringBiology** for assignments, the eText, and the Study Area with practice tests, animations, and activities.

Instructors Go to **MasteringBiology** for automatically graded tutorials and questions that you can assign to your students, plus Instructor Resources.

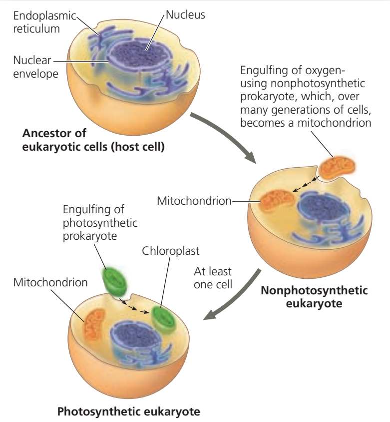
◀ **NEW! Synthesize Your Knowledge Questions** ask students to apply their understanding of the chapter content to explain an intriguing photo.

THEMES

To help students focus on the big ideas of biology, five **themes** are introduced in Chapter 1 and woven throughout the text:

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

▲ To reinforce the themes, every chapter ends with an **Evolution Connection Question** and a **Write About a Theme Question**.



Every chapter has a section explicitly relating the chapter content to **evolution**, the fundamental theme of biology. ▶

The Evolutionary Origins of Mitochondria and Chloroplasts

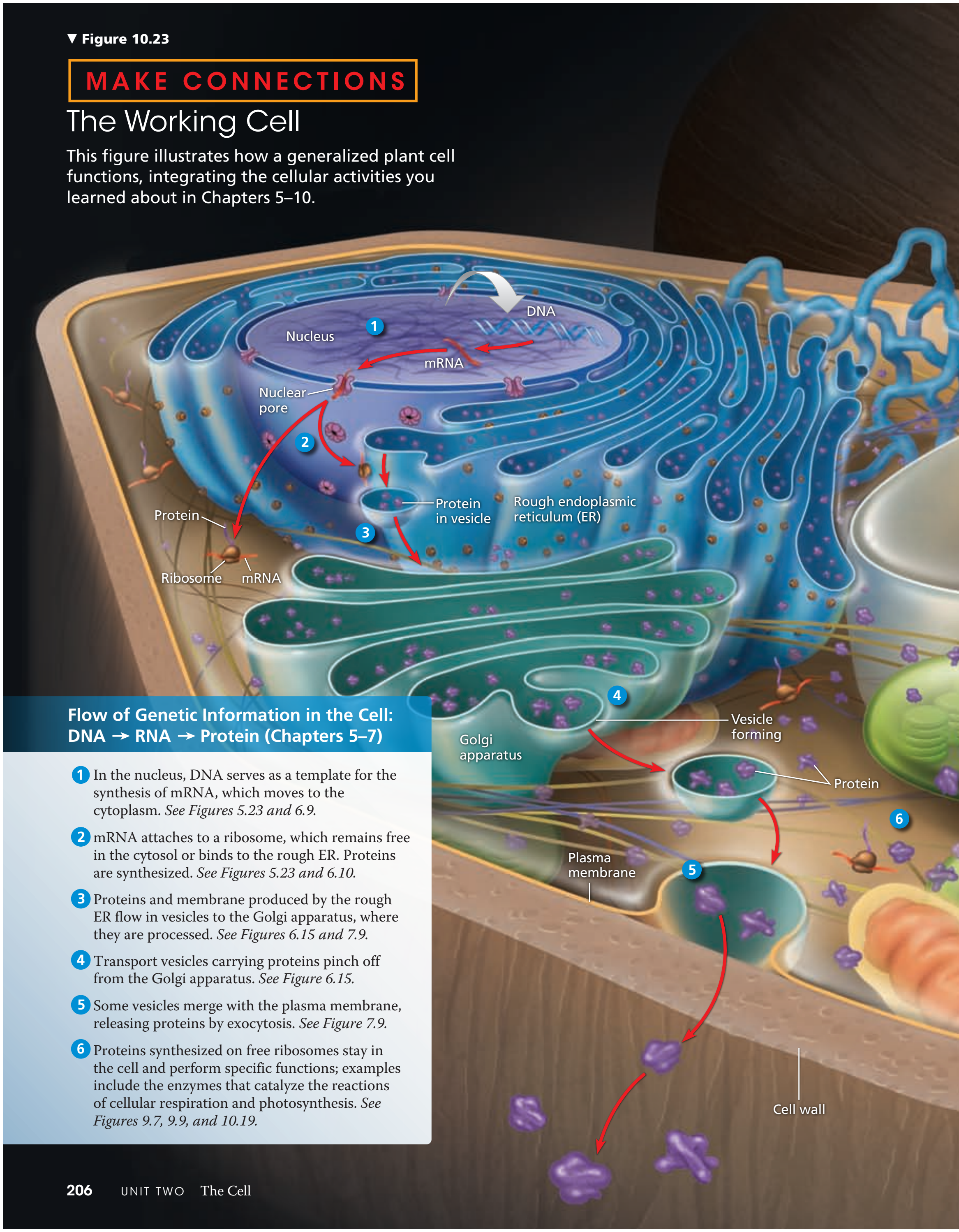
EVOLUTION Mitochondria and chloroplasts display similarities with bacteria that led to the **endosymbiont theory**, illustrated in **Figure 6.16**. This theory states that an early ancestor of eukaryotic cells engulfed an oxygen-using nonphotosynthetic prokaryotic cell. Eventually, the engulfed

Make Connections Visually

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

Make Connections Figures include:

- Figure 5.26 Contributions of Genomics and Proteomics to Biology, p. 88
- Figure 10.23 The Working Cell, shown at right and on pp. 206–207
- Figure 18.27 Genomics, Cell-Signaling, and Cancer, p. 387
- Figure 23.17 The Sickle-Cell Allele, pp. 496–497
- Figure 33.9 Maximizing Surface Area, p. 689
- Figure 39.27 Levels of Plant Defenses Against Herbivores, pp. 862–863
- Figure 40.22 Life Challenges and Solutions in Plants and Animals, pp. 888–889
- Figure 44.17 Ion Movement and Gradients, p. 987
- Figure 55.13 The Working Ecosystem, pp. 1242–1243



▼ **Figure 10.23**

MAKE CONNECTIONS

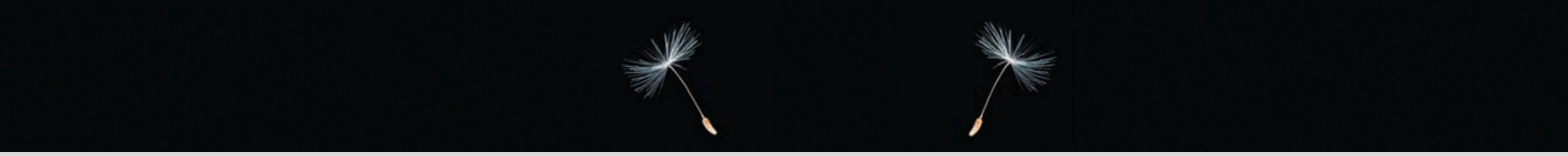
The Working Cell

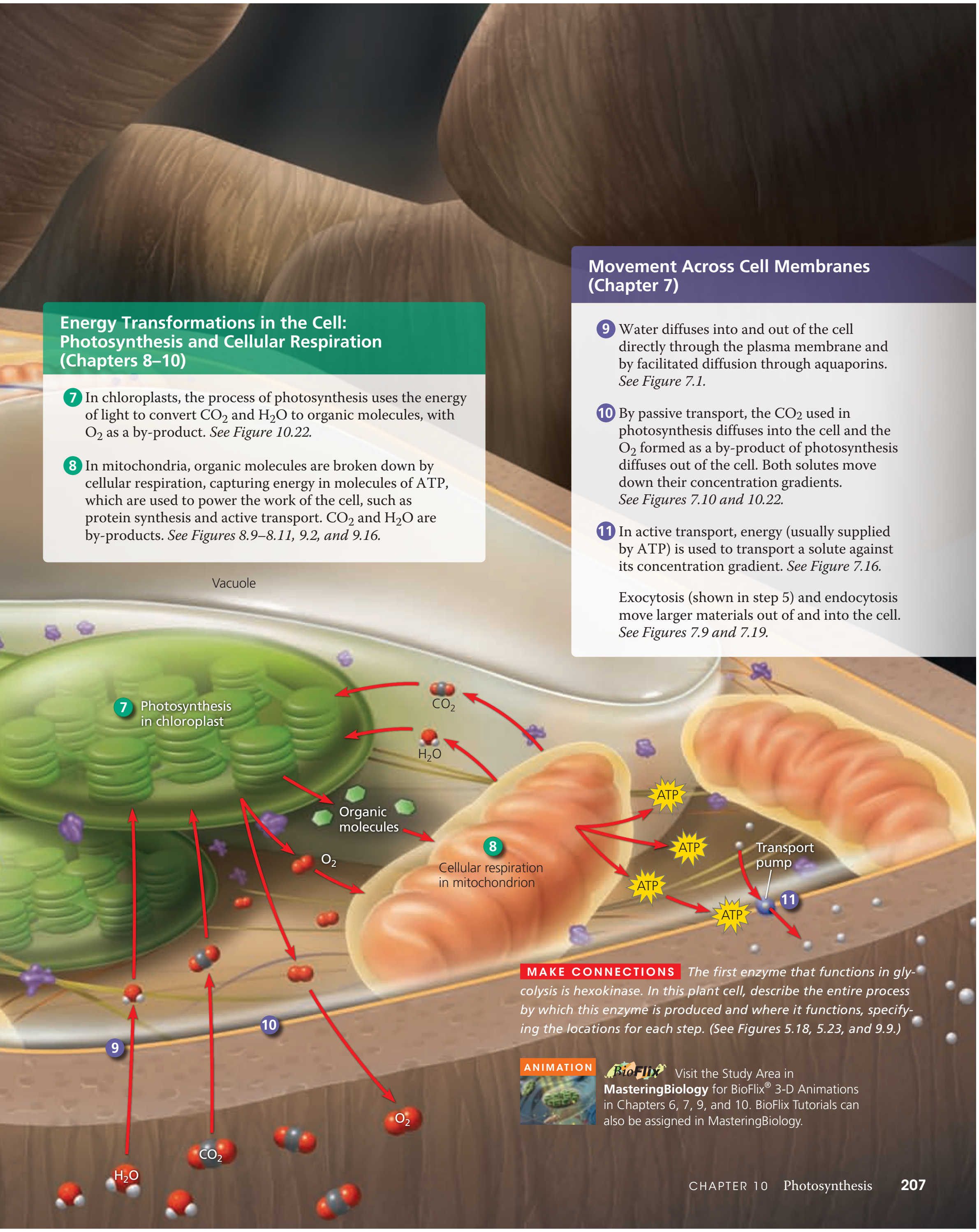
This figure illustrates how a generalized plant cell functions, integrating the cellular activities you learned about in Chapters 5–10.

Flow of Genetic Information in the Cell: DNA → RNA → Protein (Chapters 5–7)

1. In the nucleus, DNA serves as a template for the synthesis of mRNA, which moves to the cytoplasm. *See Figures 5.23 and 6.9.*
2. mRNA attaches to a ribosome, which remains free in the cytosol or binds to the rough ER. Proteins are synthesized. *See Figures 5.23 and 6.10.*
3. Proteins and membrane produced by the rough ER flow in vesicles to the Golgi apparatus, where they are processed. *See Figures 6.15 and 7.9.*
4. Transport vesicles carrying proteins pinch off from the Golgi apparatus. *See Figure 6.15.*
5. Some vesicles merge with the plasma membrane, releasing proteins by exocytosis. *See Figure 7.9.*
6. Proteins synthesized on free ribosomes stay in the cell and perform specific functions; examples include the enzymes that catalyze the reactions of cellular respiration and photosynthesis. *See Figures 9.7, 9.9, and 10.19.*

206 UNIT TWO The Cell





Energy Transformations in the Cell: Photosynthesis and Cellular Respiration (Chapters 8–10)

7 In chloroplasts, the process of photosynthesis uses the energy of light to convert CO_2 and H_2O to organic molecules, with O_2 as a by-product. *See Figure 10.22.*

8 In mitochondria, organic molecules are broken down by cellular respiration, capturing energy in molecules of ATP, which are used to power the work of the cell, such as protein synthesis and active transport. CO_2 and H_2O are by-products. *See Figures 8.9–8.11, 9.2, and 9.16.*

Movement Across Cell Membranes (Chapter 7)

9 Water diffuses into and out of the cell directly through the plasma membrane and by facilitated diffusion through aquaporins. *See Figure 7.1.*

10 By passive transport, the CO_2 used in photosynthesis diffuses into the cell and the O_2 formed as a by-product of photosynthesis diffuses out of the cell. Both solutes move down their concentration gradients. *See Figures 7.10 and 10.22.*

11 In active transport, energy (usually supplied by ATP) is used to transport a solute against its concentration gradient. *See Figure 7.16.*

Exocytosis (shown in step 5) and endocytosis move larger materials out of and into the cell. *See Figures 7.9 and 7.19.*

MAKE CONNECTIONS *The first enzyme that functions in glycolysis is hexokinase. In this plant cell, describe the entire process by which this enzyme is produced and where it functions, specifying the locations for each step. (See Figures 5.18, 5.23, and 9.9.)*

ANIMATION BioFlix® Visit the Study Area in **MasteringBiology** for BioFlix® 3-D Animations in Chapters 6, 7, 9, and 10. BioFlix Tutorials can also be assigned in MasteringBiology.

◀ Make Connections Questions

Ask students to relate content in the chapter to material presented earlier in the course. Every chapter has at least three Make Connections Questions.

Practice Scientific Skills

NEW! **Scientific Skills Exercises** in every chapter use real data to build key skills needed for biology, including data interpretation, graphing, experimental design, and math skills.

▼ **Photos** provide visual interest and context.

Each Scientific Skills Exercise ▶ is based on an **experiment related to the chapter content**.

Most Scientific Skills Exercises ▶ use **data from published research**.

Questions build in difficulty, ▶ walking students through new skills step by step and providing opportunities for higher-level critical thinking.

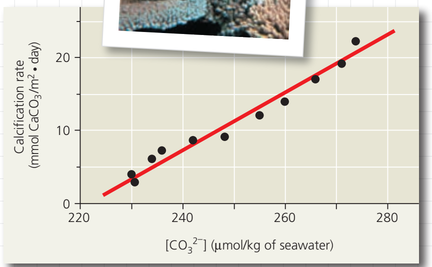
SCIENTIFIC SKILLS EXERCISE

Interpreting a Scatter Plot with a Regression Line

How Does the Carbonate Ion Concentration of Seawater Affect the Calcification Rate of a Coral Reef? Scientists predict that acidification of the ocean due to higher levels of atmospheric CO_2 will lower the concentration of dissolved carbonate ions, which living corals use to build calcium carbonate reef structures. In this exercise, you will analyze data from a controlled experiment that examined the effect of carbonate ion concentration ($[CO_3^{2-}]$) on calcium carbonate deposition, a process called calcification.

How the Experiment Was Done The Biosphere 2 aquarium in Arizona contains a large coral reef system that behaves like a natural reef. For several years, a group of researchers measured the rate of calcification by the reef organisms and examined how the calcification rate changed with differing amounts of dissolved carbonate ions in the seawater.

Data from the Experiment The black data points in the graph form a scatter plot. The red line, known as a linear regression line, is the best-fitting straight line for these points.



Interpret the Data

1. When presented with a graph of experimental data, the first step in analysis is to determine what each axis represents. (a) In words, explain what is being shown on the *x*-axis. Be sure to include the units. (b) What is being shown on the *y*-axis (including units)? (c) Which variable is the independent variable—the variable that was *manipulated* by the researchers? (d) Which variable is the dependent variable—the variable that responded to or depended on the treatment, which was *measured* by the researchers? (For additional information about graphs, see the Scientific Skills Review in Appendix F and in the Study Area in MasteringBiology.)
2. Based on the data shown in the graph, describe in words the relationship between carbonate ion concentration and calcification rate.
3. (a) If the seawater carbonate ion concentration is 270 μmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square meter of reef to accumulate 30 mmol of calcium carbonate ($CaCO_3$)? (b) If the seawater carbonate ion concentration is 250 μmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square meter of reef to accumulate 30 mmol of calcium carbonate? (c) If carbonate ion concentration decreases, how does the calcification rate change, and how does that affect the time it takes coral to grow?
4. (a) Referring to the equations in Figure 3.11, determine which step of the process is measured in this experiment. (b) Are the results of this experiment consistent with the hypothesis that increased atmospheric $[CO_2]$ will slow the growth of coral reefs? Why or why not?

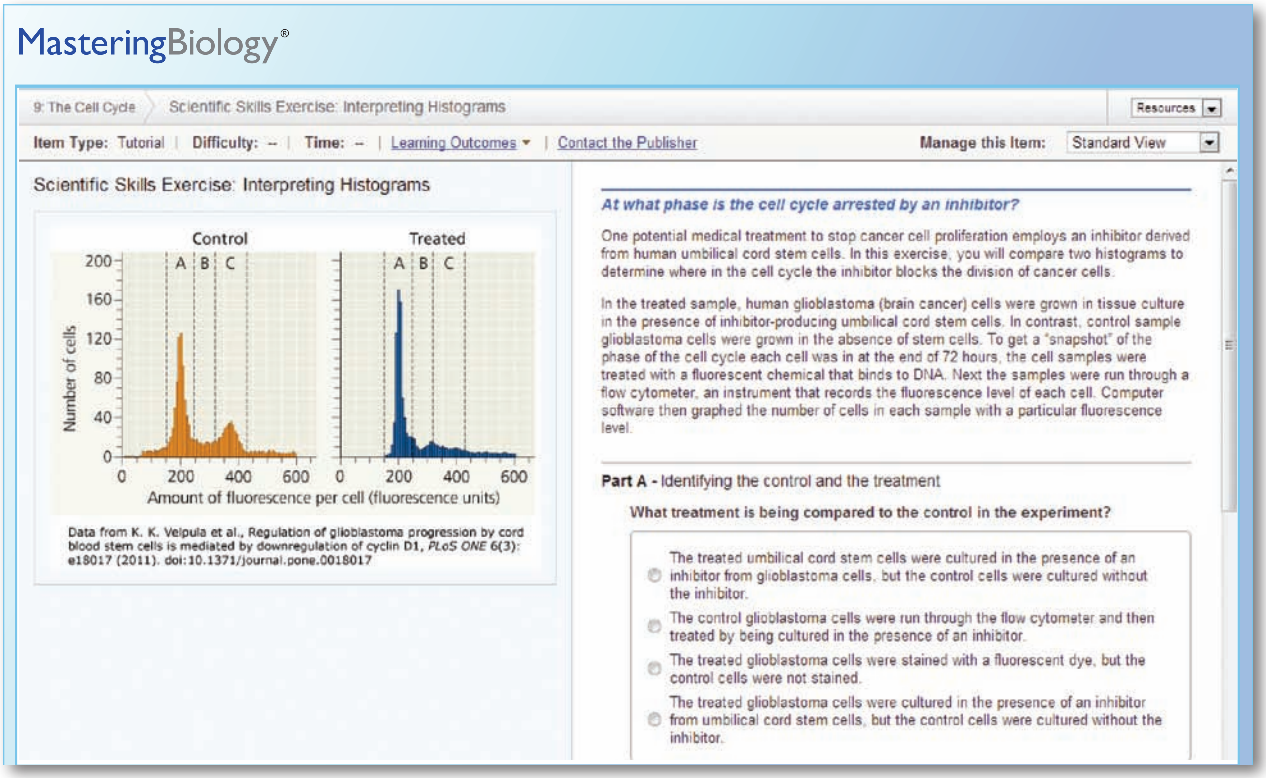
MB A version of this Scientific Skills Exercise can be assigned in MasteringBiology.

Data from C. Langdon et al., Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef, *Global Biogeochemical Cycles* 14:639–654 (2000).

▲ Each Scientific Skills Exercise **cites the published research**.

Every chapter has a Scientific Skills Exercise

NEW! All **56 Scientific Skills Exercises** from the text have assignable, interactive versions in **MasteringBiology®** that are automatically graded.



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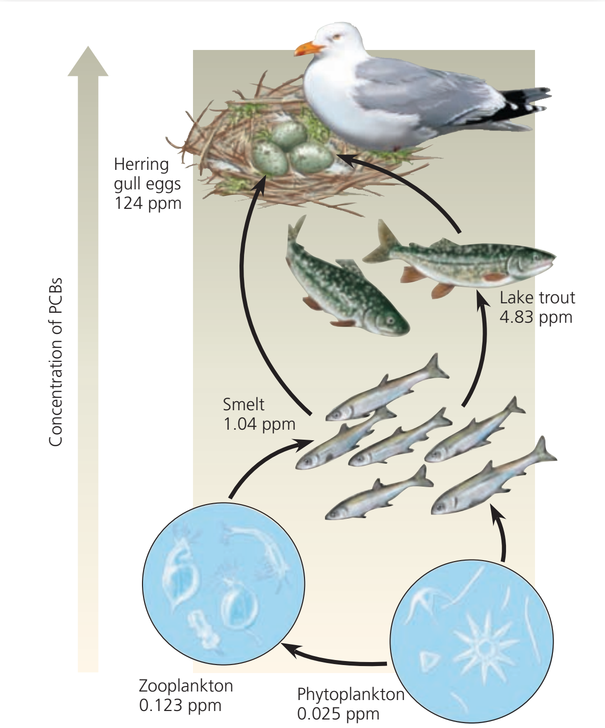
Interpret Data

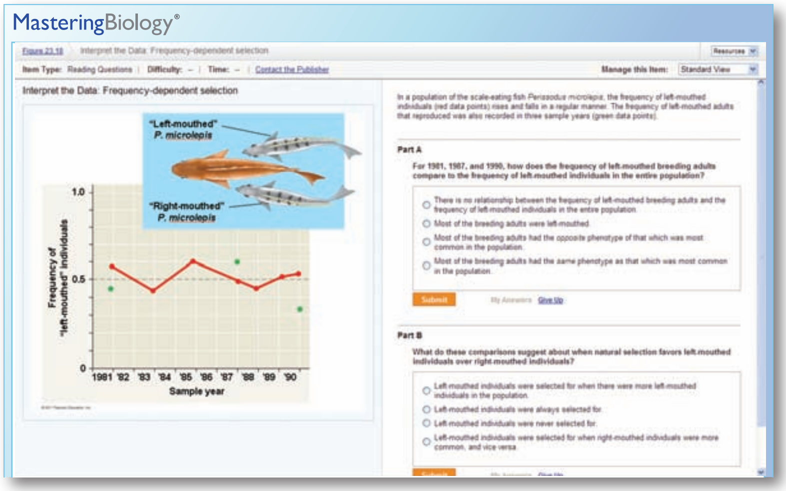
Campbell Biology, Tenth Edition, and MasteringBiology® offer a wide variety of ways for students to move beyond memorization and **think like a scientist**.



▲ **Figure 56.25 Biological magnification of PCBs in a Great Lakes food web.** (ppm = parts per million)

INTERPRET THE DATA *If a typical smelt weighs 225 g, what is the total mass of PCBs in a smelt in the Great Lakes? If an average lake trout weighs 4,500 g, what is the total mass of PCBs in a trout in the Great Lakes? Assume that a lake trout from an unpolluted source is introduced into the Great Lakes and smelt are the only source of PCBs in the trout's diet. The new trout would have the same level of PCBs as the existing trout after eating how many smelt? (Assume that the trout retains 100% of the PCBs it consumes.)*

◀ **NEW!** **Interpret the Data Questions** throughout the text ask students to analyze a graph, figure, or table.



▲ **NEW!** Every **Interpret the Data Question** from the text is assignable in **MasteringBiology**.

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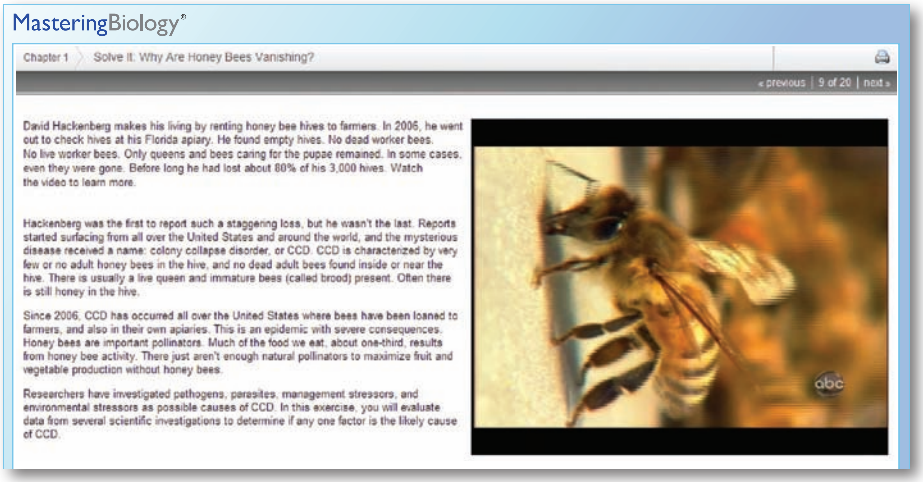


◀ **NEW!** **Solve It Tutorials** engage students in a multi-step investigation of a "mystery" or open question in which they must analyze real data. These are assignable in **MasteringBiology**.

Topics include:

- Is It Possible to Treat Bacterial Infections Without Traditional Antibiotics?
- Are You Getting the Fish You Paid For?
- Why Are Honey Bees Vanishing?
- Which Biofuel Has the Most Potential to Reduce our Dependence on Fossil Fuels?
- Which Insulin Mutations May Result in Disease?
- What is Causing Episodes of Muscle Weakness in a Patient?

Explore the Impact of Genomics

NEW! Throughout the Tenth Edition, new examples show students how our ability to **sequence DNA and proteins rapidly and inexpensively** is transforming every subfield of biology, from cell biology to physiology to ecology.

▼ Figure 5.26

MAKE CONNECTIONS

Contributions of Genomics and Proteomics to Biology

Nucleotide sequencing and the analysis of large sets of genes and proteins can be done rapidly and inexpensively due to advances in technology and information processing. Taken together, genomics and proteomics have advanced our understanding of biology across many different fields.

Paleontology

New DNA sequencing techniques have allowed decoding of minute quantities of DNA found in ancient tissues from our extinct relatives, the Neanderthals (*Homo neanderthalensis*). Sequencing the Neanderthal genome has informed our understanding of their physical appearance as well as their relationship with modern humans. *See Figure 34.49.*

Medical Science

Identifying the genetic basis for human diseases like cancer helps researchers focus their search for potential future treatments. Currently, sequencing the sets of genes expressed in an individual's tumor can allow a more targeted approach to treating the cancer, a type of "personalized medicine." *See Figures 12.20 and 18.27.*

Evolution

A major aim of evolutionary biology is to understand the relationships among species, both living and extinct. For example, genome sequence comparisons have identified the hippopotamus as the land mammal sharing the most recent common ancestor with whales. *See Figure 22.20.*

Hippopotamus

Short-finned pilot whale

Conservation Biology

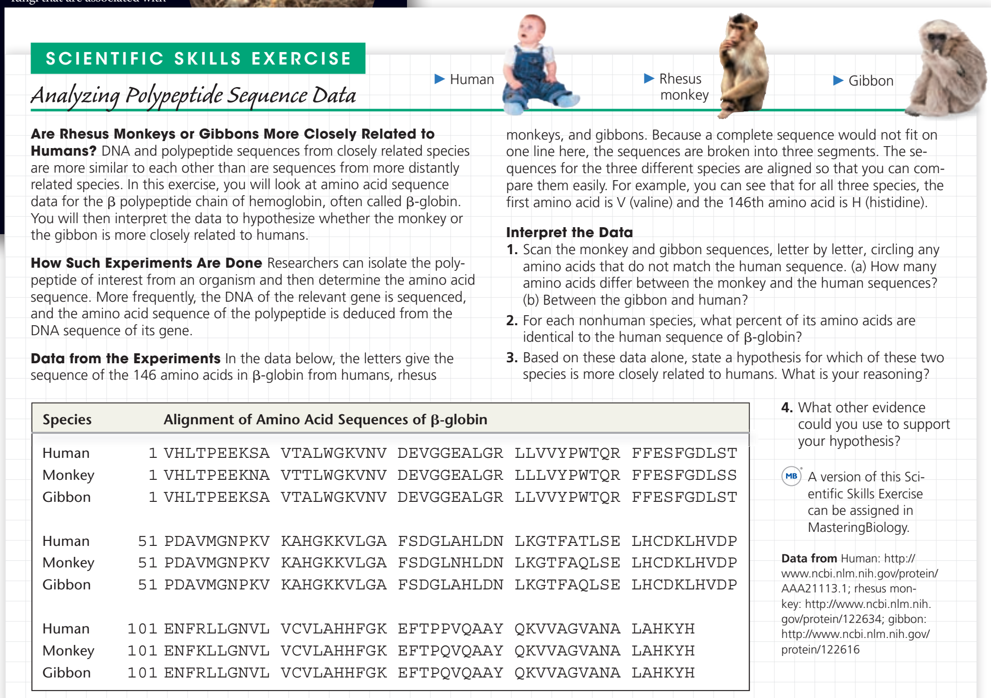
The tools of molecular genetics and genomics are increasingly used by ecologists to identify which species of animals and plants are killed illegally. In one case, genomic sequences of DNA from illegal shipments of elephant tusks were used to track down poachers and pinpoint the territory where they were operating. *See Figure 56.9.*

Species Interactions

Over 90% of all plant species exist in a mutually beneficial partnership with fungi that are associated with

88 UNIT ONE The Chemistry of Life

◀ This new **Make Connections Figure** in Chapter 5 previews some examples of how genomics and proteomics have helped shed light on diverse biological questions. These examples are explored in greater depth later in the text.



SCIENTIFIC SKILLS EXERCISE

Analyzing Polypeptide Sequence Data

▶ Human ▶ Rhesus monkey ▶ Gibbon

Are Rhesus Monkeys or Gibbons More Closely Related to Humans? DNA and polypeptide sequences from closely related species are more similar to each other than are sequences from more distantly related species. 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 broken into three segments. The sequences for the three different species are aligned so that you can compare them easily. For example, you can see that for all three species, the first amino acid is V (valine) and the 146th amino acid is H (histidine).

Interpret the Data

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?

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 ENFKLLGNVL VCVLAHHFGK EFTPQVQAAY QKVVAGVANA LAHKYH
Gibbon	101 ENFRLLGNVL VCVLAHHFGK EFTPQVQAAY QKVVAGVANA LAHKYH

4. What other evidence could you use to support your hypothesis?

MB A version of this Scientific Skills Exercise can be assigned in MasteringBiology.

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

Selected Scientific Skills Exercises involve **working with DNA or protein sequences**. ▶

Study Anytime, Anywhere

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eTEXT

Access the complete **textbook online**!

▲ The **Pearson eText** gives students access to the text whenever and wherever they can access the Internet. The eText can be viewed on PCs, Macs, and tablets, including iPad® and Android.® The eText includes powerful interactive and customization functions:

- Write notes
- Highlight text
- Bookmark pages
- Zoom
- Click hyperlinked words to view definitions
- Search
- Link to media activities and quizzes

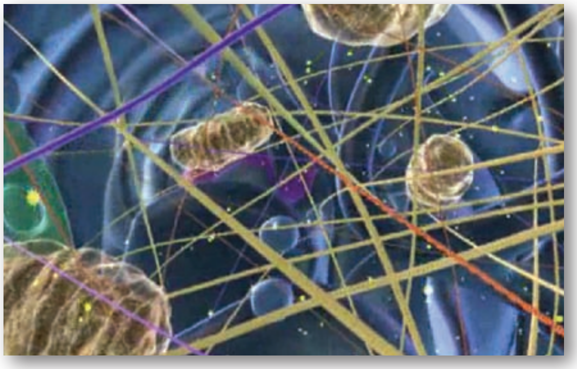
Instructors can even write notes for the class and highlight important materials using a tool that works like an electronic pen on a whiteboard.

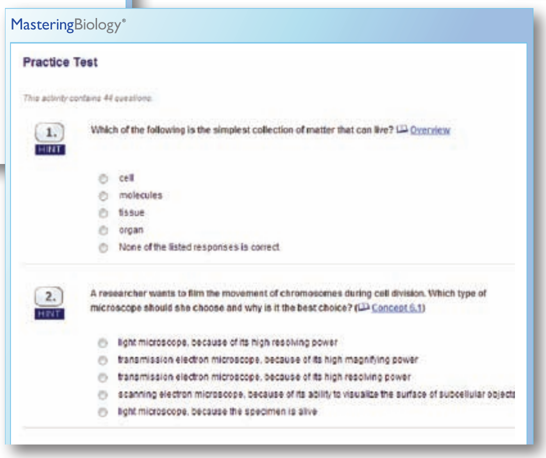
STUDY AREA

Students can access the **Study Area** for use on their own or in a study group.

▲ **Get Ready for Biology** helps students get up to speed for their course by covering study skills, basic math, terminology, chemistry, and biology basics.

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



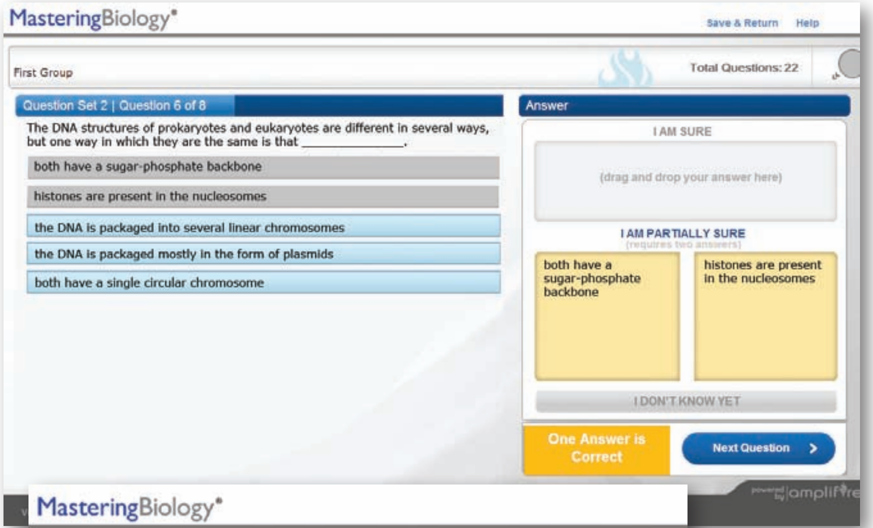


◀ **Practice Tests** help students assess their understanding of each chapter, providing feedback for right and wrong answers.

The **Study Area** also includes: Cumulative Test, MP3 Tutor Sessions, Videos, Activities, Investigations, Lab Media, Audio Glossary, Word Roots, Key Terms, Flashcards, and Art.

DYNAMIC STUDY MODULES

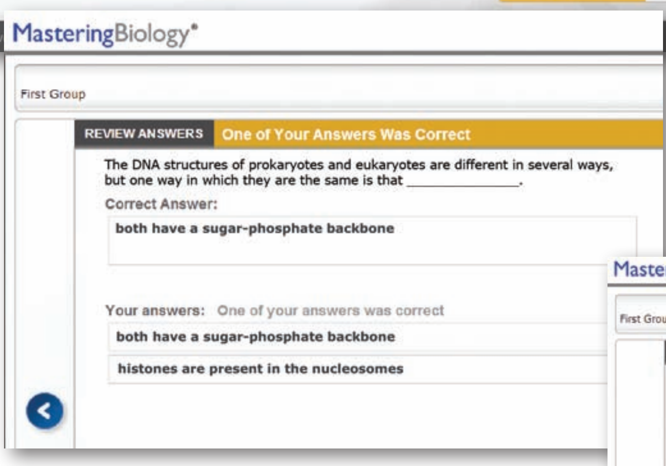
NEW! **Dynamic Study Modules**, designed to enable students to study effectively on their own, help students quickly access and learn the information they need to be more successful on quizzes and exams.



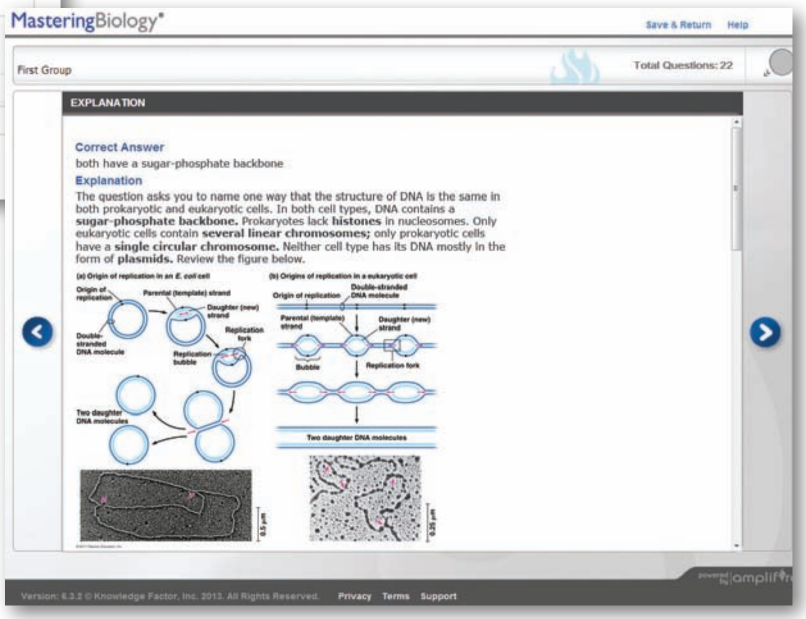
How it works:

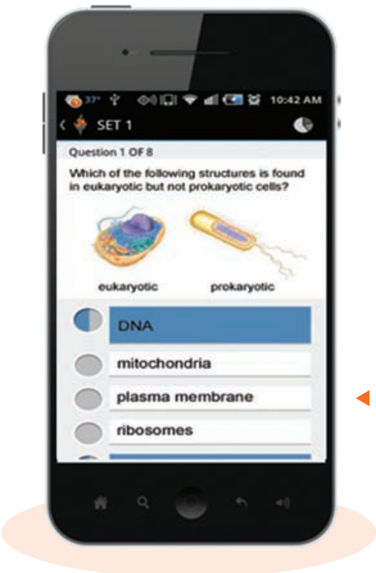
1. Students receive an initial **set of questions**.

A unique answer format asks students to indicate how **confident** they are about their answer.



2. After answering each set of questions, students **review their answers**.
3. Each answer has an **explanation** using material that is taken directly **from the textbook**.





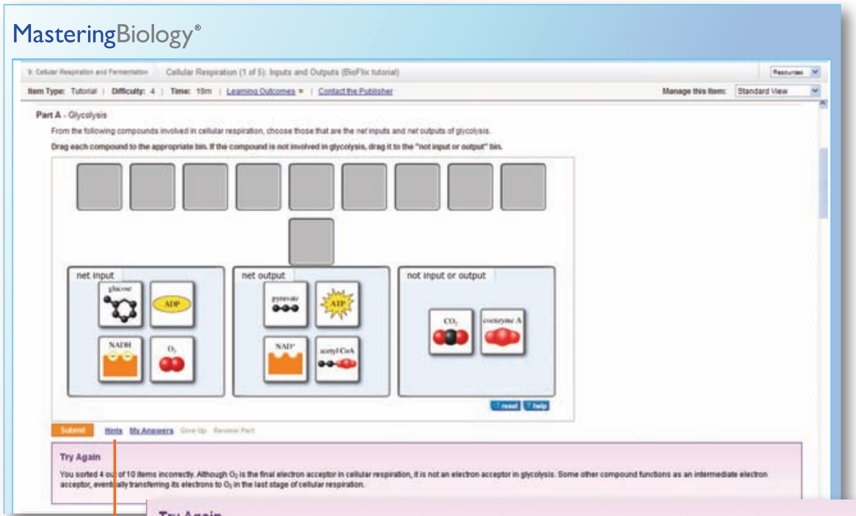
These modules can be accessed on smartphones, tablets, and computers. Results can be tracked in the MasteringBiology Gradebook.

4. Once students review the explanations from the textbook, they are presented with a new set of questions. Students cycle through this **dynamic process of test-learn-retest** until they achieve mastery of the textbook material.

Learn more at www.masteringbiology.com

Learn Through Assessment

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



Try Again

You sorted 4 out of 10 items incorrectly. Although O_2 is the final electron acceptor in cellular respiration, it is not an electron acceptor in glycolysis. Some other compound functions as an intermediate electron acceptor, eventually transferring its electrons to O_2 in the last stage of cellular respiration.

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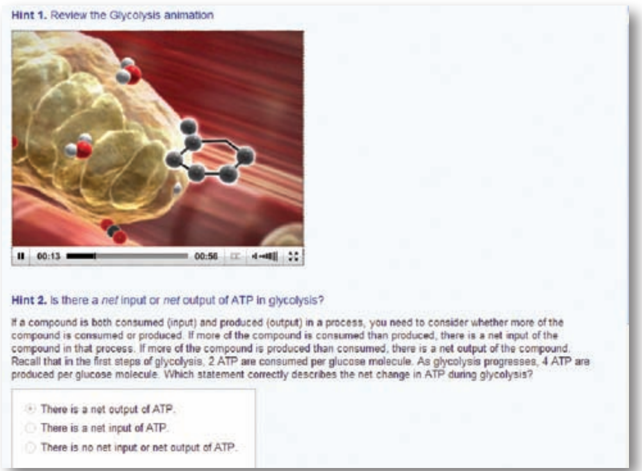
1. If a student gets stuck ...

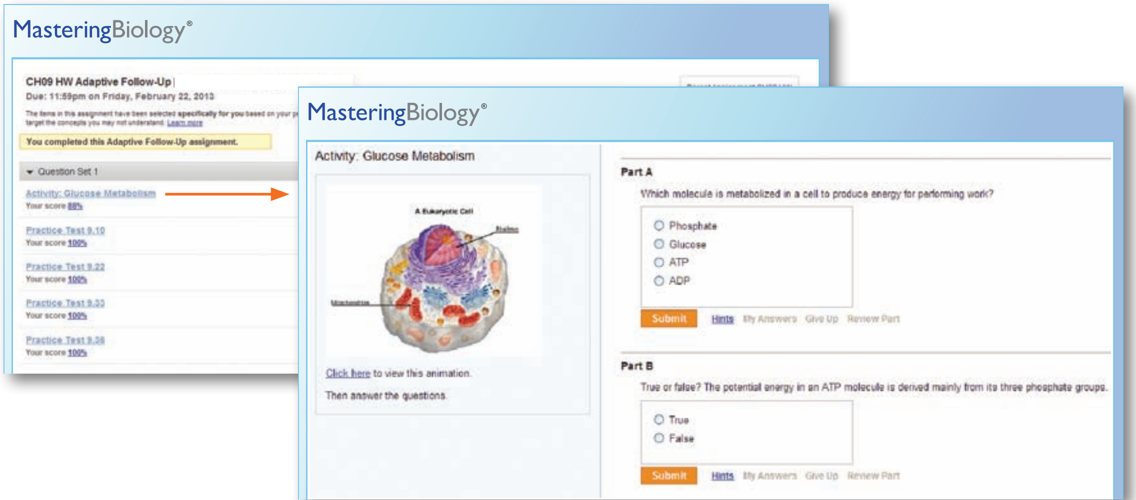


2. specific wrong-answer **feedback** appears in the purple feedback box.

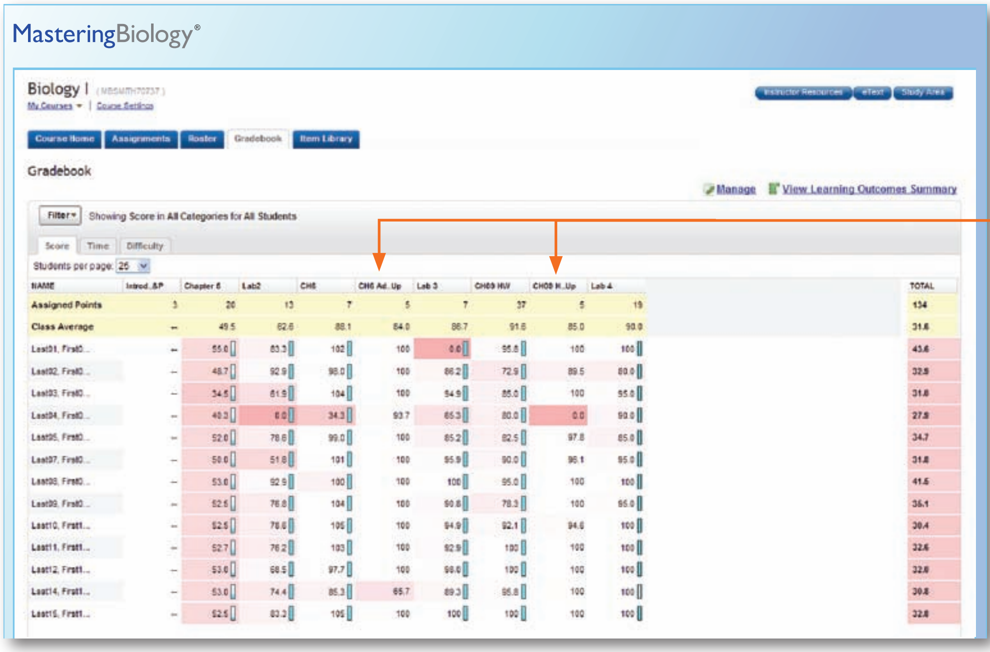
3. **Hints** coach the student to the correct response.

4. **NEW!** Optional **Adaptive Follow-Up Assignments** are based on each student's performance on the original homework assignment and provide additional coaching and practice as needed.

Question sets in the Adaptive Follow-Up Assignments **continuously adapt** to each student's needs, making efficient use of study time.



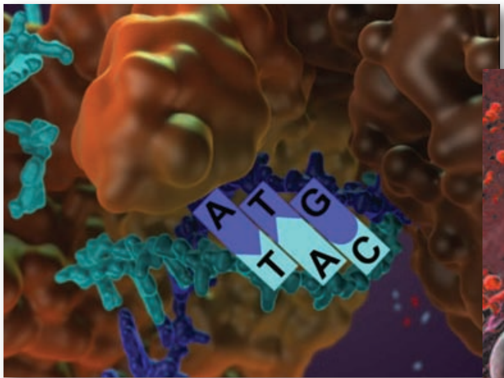
The MasteringBiology® Gradebook provides instructors with quick results and easy-to-interpret insights into student performance. Every assignment is automatically graded. Shades of red highlight vulnerable students and challenging assignments.

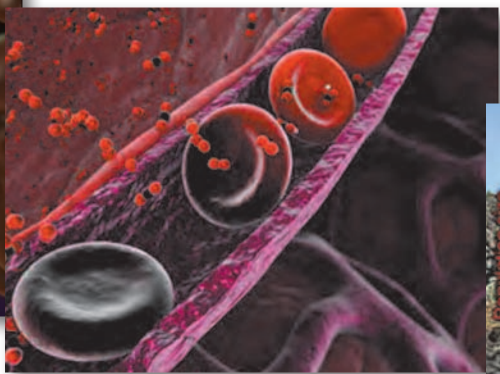


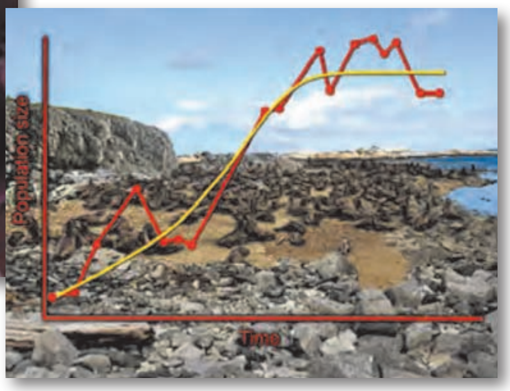
NEW! Student scores on the optional **Adaptive Follow-Up Assignments** are recorded in the gradebook and offer additional diagnostic information for instructors to monitor learning outcomes and more.

BioFlix®

MasteringBiology offers a wide variety of tutorials that can be assigned as homework. For example, **BioFlix Tutorials** use 3-D, movie-quality **Animations** and coaching exercises to help students master tough topics outside of class. Animations can also be shown in class.







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- A Tour of the Animal Cell
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- Cellular Respiration
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- Mitosis
- Meiosis
- DNA Replication
- Protein Synthesis
- Mechanisms of Evolution
- Water Transport in Plants
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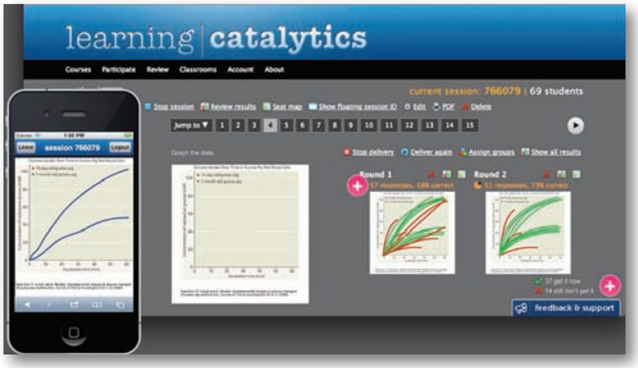
- Gas Exchange
- How Neurons Work
- How Synapses Work
- Muscle Contraction
- Population Ecology
- The Carbon Cycle

FOR INSTRUCTORS

NEW! **Learning Catalytics™** allows students to use their smartphone, tablet, or laptop to respond to questions in class. Visit www.learningcatalytics.com.



Instructor's Resource DVD (IRDVD) Package

978-0-321-83494-2 / 0-321-83494-1

The instructor resources for ***Campbell Biology*, Tenth Edition,** are combined into one chapter-by-chapter resource that includes DVDs of all chapter visual resources. Assets include:

- Editable figures (art and photos) and tables from the text in PowerPoint®
- Prepared PowerPoint Lecture Presentations for each chapter, with lecture notes, editable figures, tables, and links to animations and videos
- 250+ Instructor Animations and Videos, including BioFlix® 3-D Animations and *ABC News* Videos
- JPEG Images, including labeled and unlabeled art, photos from the text, and extra photos
- Digital Transparencies
- Clicker Questions in PowerPoint
- Quick Reference Guide
- Test Bank questions in TestGen® software and Microsoft® Word

Instructor Resources Area in MasteringBiology®

This area includes:

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- Clicker Questions
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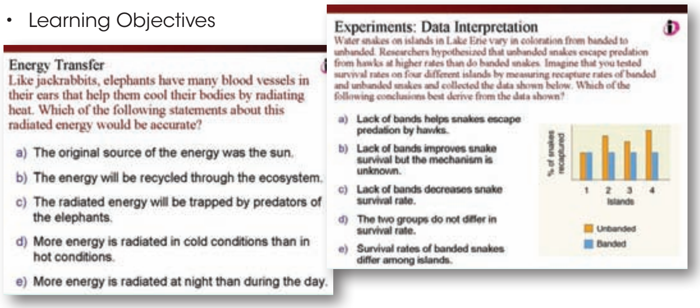
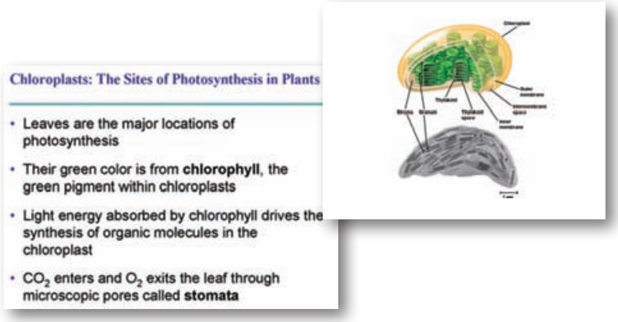
- Learning Objectives
- Pre-Tests, Post-Tests, and Strategies for Overcoming Common Student Misconceptions
- Instructor Guides for Supplements
- Rubric and Tips for Grading Short-Answer Essays
- Suggested Answers for Scientific Skills Exercises and Short-Answer Essay Questions
- Lab Media



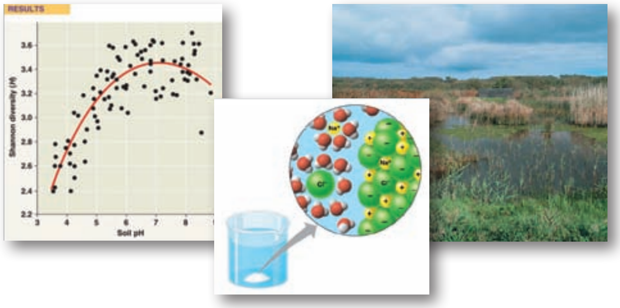
▲ **Clicker Questions** can be used to stimulate effective classroom discussions (for use with or without clickers).

Instructor Resources for Flipped Classrooms

- Lecture videos can be posted on MasteringBiology for students to view before class.
- Homework can be assigned in MasteringBiology so students come to class prepared.
- In-class resources: Learning Catalytics, Clicker Questions, Student Misconception Questions, end-of-chapter essay questions, and activities and case studies from the student supplements.



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



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

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978-0-321-82371-7 / 0-321-82371-0

This invaluable resource contains more than 4,500 questions, including scenario-based questions and art, graph, and data interpretation questions. In addition to a print version, the Test Bank is available electronically in MasteringBiology, on the Instructor's Resource DVD Package, within the Blackboard course management system, and at www.pearsonhighered.com.

Course Management Systems

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by Ruth Buskirk, *University of Texas at Austin,*
and Christopher M. Gillen, *Kenyon College*
978-0-321-83417-1 / 0-321-83417-8
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,* Fifth Edition
by Jean Heitz and Cynthia Giffen, *University of Wisconsin, Madison*
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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,* Fourth Edition
by Margaret Waterman, *Southeast Missouri State University,* and Ethel Stanley, *BioQUEST Curriculum Consortium and Beloit College*
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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 MasteringBiology.

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978-0-321-55671-4 / 0-321-55671-2
These nine short tales vividly depict key discoveries in evolutionary biology and the excitement of the scientific process. Online resources available at www.aw-bc.com/carroll.

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978-0-321-50057-1 / 0-321-50057-1
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978-0-8053-9571-6 / 0-8053-9571-7
This text/workbook helps students review and master all the basic facts, concepts, and terminology of chemistry that they need for their life science course.

FOR LAB

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***An Instructor Guide is available for download in the Instructor Resources Area in MasteringBiology.**

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Make Connections Figures

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Inquiry 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*, Third Edition.
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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 Venki Ramakrishnan, Haifan Lin, Charles Rotimi, Hopi Hoekstra, Nicole King, Jeffery Dangl, Ulrike Heberlein, and Monica Turner.

The value of *CAMPBELL BIOLOGY* as a learning tool is greatly enhanced by the supplementary materials that have been created for instructors and students. We recognize that the dedicated authors of these materials are essentially writing mini (and not so mini) books. We appreciate the hard work and creativity of all the authors listed, with their creations, on page xxiii. We are also grateful to Kathleen Fitzpatrick and Nicole Tunbridge (PowerPoint® Lecture Presentations); Scott Meissner, Roberta Batorsky, Tara Turley Stoulig, Lisa Flick, and Bryan Jennings (Clicker Questions); Ed Zalisko, Melissa Fierke, Rebecca Orr, and Diane Jokinen (Test Bank); Natalie Bronstein, Linda Logdberg, Matt McArdle, Ria Murphy, Chris Romero, and Andy Stull (Dynamic Study Modules); and Eileen Gregory, Rebecca Orr, and Elena Pravosudova (Adaptive Follow-up Assignments).

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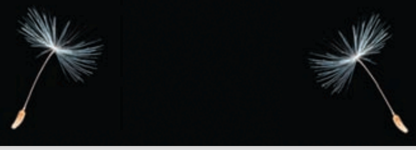

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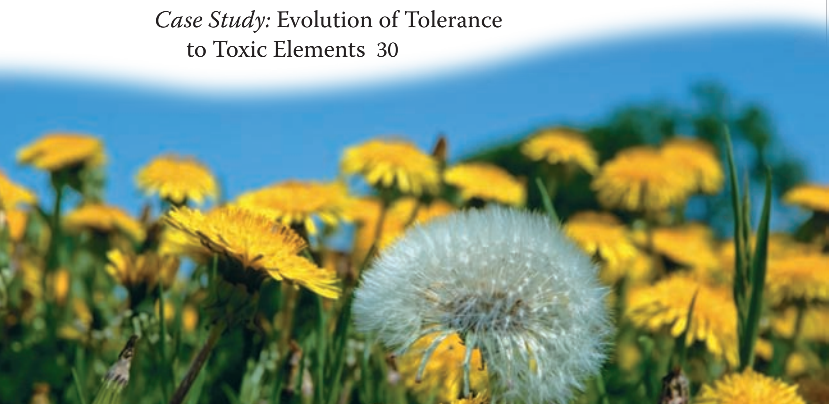

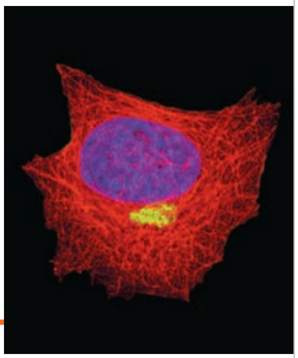

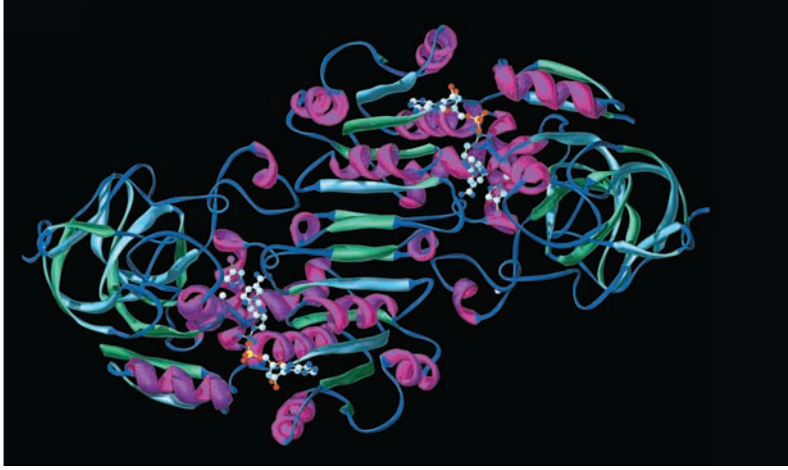

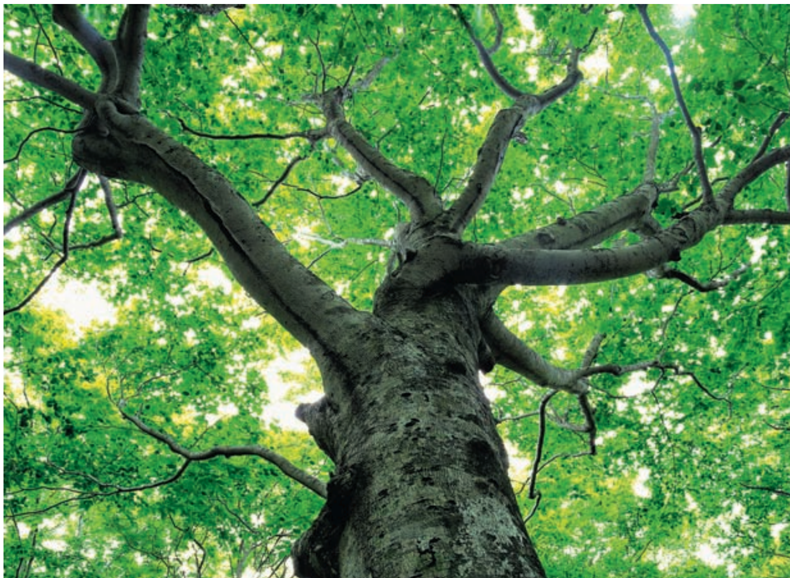

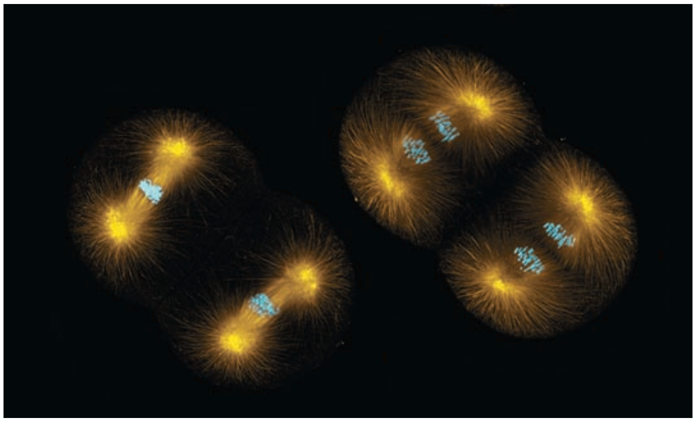

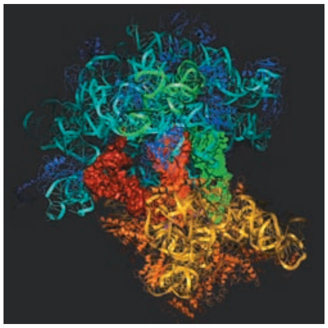

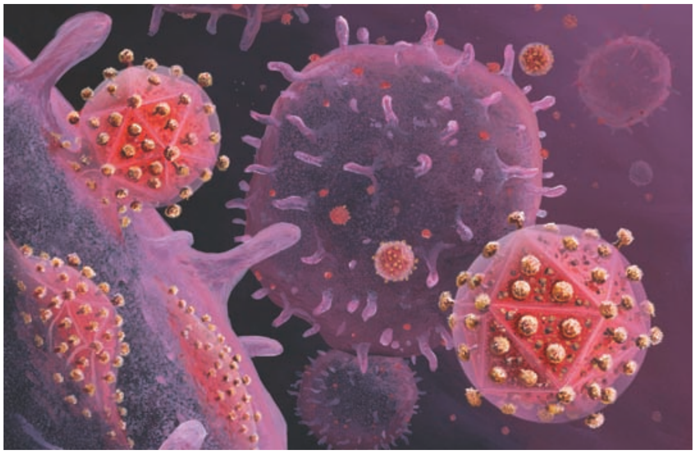

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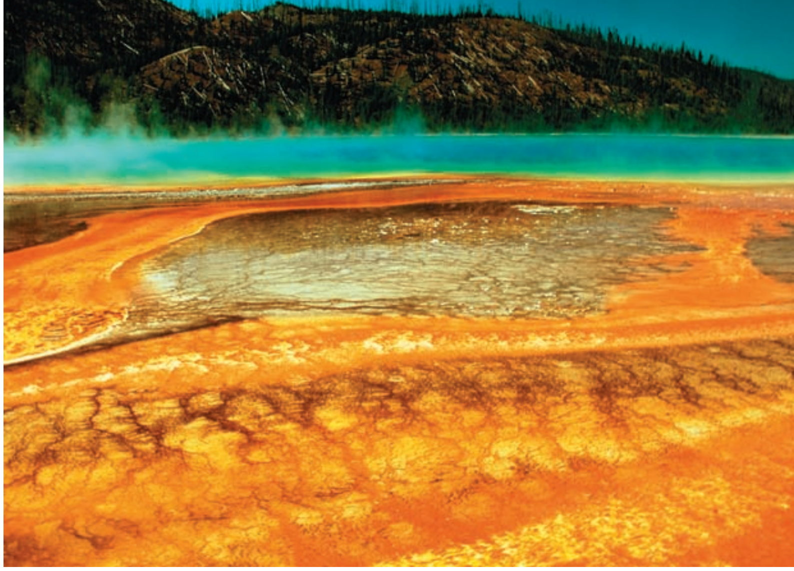

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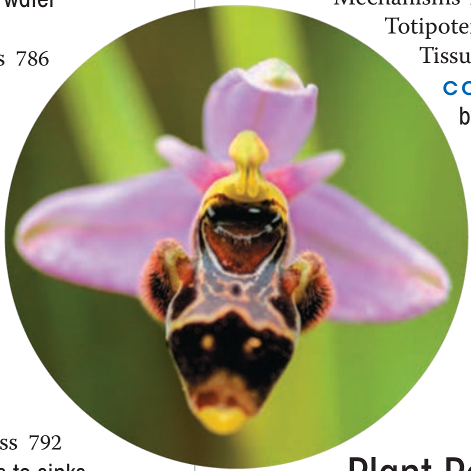

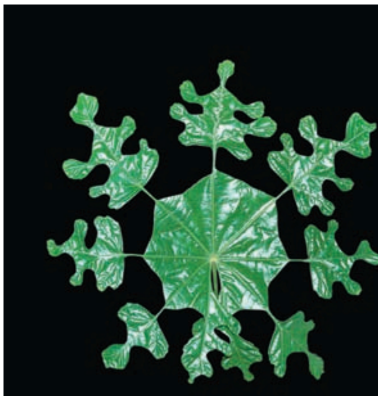

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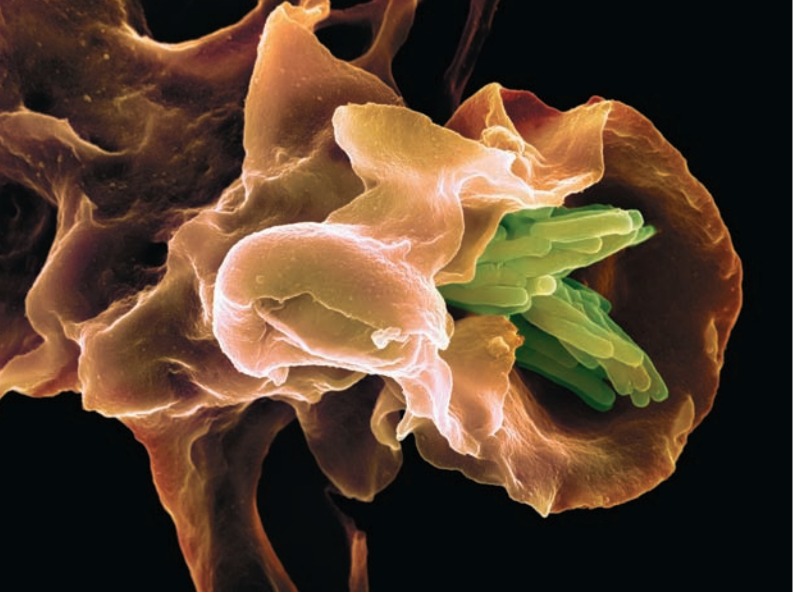
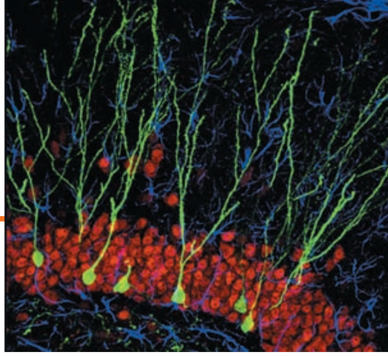
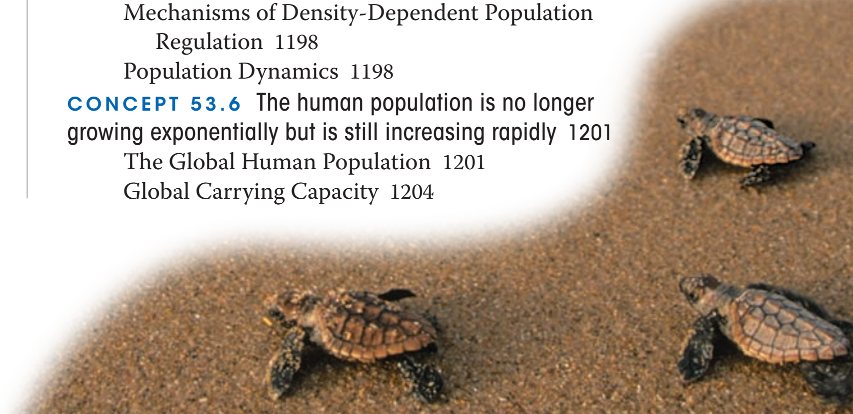






1

Evolution, the Themes of Biology, and Scientific Inquiry

KEY CONCEPTS

1.1 The study of life reveals common themes

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

1.3 In studying nature, scientists make observations and form and test hypotheses

1.4 Science benefits from a cooperative approach and diverse viewpoints

▲ **Figure 1.1** **How is the dandelion adapted to its environment?**

Inquiring About Life

The dandelions shown in **Figure 1.1** send their seeds aloft for dispersal. A seed is an embryo surrounded by a store of food and a protective coat. The dandelion's seeds, shown at the lower left, are borne on the wind by parachute-like structures made from modified flower parts. The parachutes harness the wind, which carries such seeds to new locations where conditions may favor sprouting and growth. Dandelions are very successful plants, found in temperate regions worldwide.

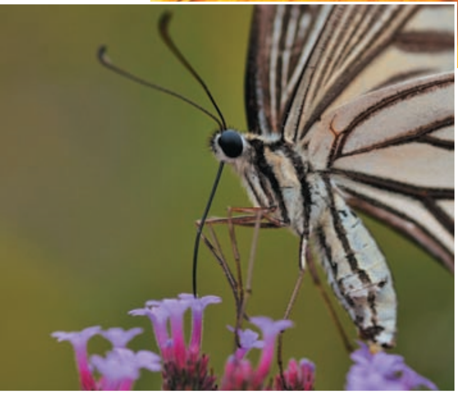
An organism's adaptations to its environment, such as the dandelion seed's parachute, are the result of evolution. **Evolution** is the process of change that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. Because evolution is the fundamental organizing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

Although biologists know a great deal about life on Earth, many mysteries remain. For instance, what processes led to the origin of flowering among plants such as the ones pictured above? Posing questions about the living world and seeking answers through 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

▼ **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.

▲ **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.

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

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

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

forms of life in a forest interact. 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.

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, one-sentence definition. We recognize life by what living things do. **Figure 1.2** highlights some of the properties and processes we associate with life.

While limited to a handful of images, Figure 1.2 reminds us that the living world is wondrously varied. How do biologists 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, which accounts for life's unity and diversity. Next, we look at scientific inquiry—how scientists ask and attempt to answer questions about the natural world. Finally, we address the culture of science and its effects on society.

CONCEPT 1.1

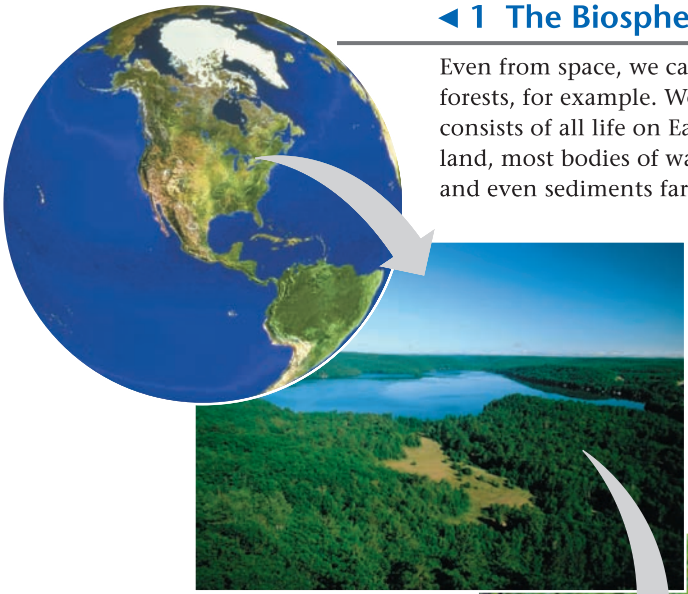
The study of life reveals common themes

Biology 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 the broad range of topics included in biology? Focusing on a few big ideas will help. Here, we'll list five unifying themes—ways of thinking about life that will still hold true decades from now. These unifying themes are described in greater detail in the next few pages. We hope they will serve as touchstones as you proceed through this text:

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

▼ **Figure 1.3**

Exploring Levels of Biological Organization



◀ 1 The Biosphere

Even from space, we can see signs of Earth's life—in the green mosaic of the forests, for example. We can also see the scale of the entire 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 forest with many deciduous trees (trees that lose their leaves and grow new ones each year). A deciduous forest is an example of an ecosystem, as are grasslands, deserts, and coral reefs. 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 forest ecosystem includes many kinds of trees and other plants, various animals, mushrooms and other fungi, and enormous numbers of diverse microorganisms, which are living forms, such as bacteria, that are too small to see without a microscope. Each of these forms of life is called a *species*.

▶ 4 Populations

A population consists of all the individuals of a species living within the bounds of a specified area. For example, our forest includes a population of sugar maple trees and a population of white-tailed deer. A community is therefore the set of populations that inhabit a particular area.

▲ 5 Organisms

Individual living things are called organisms. Each of the maple trees and other plants in the forest is an organism, and so is each deer, frog, beetle, and other forest animals. The soil teems with microorganisms such as bacteria.

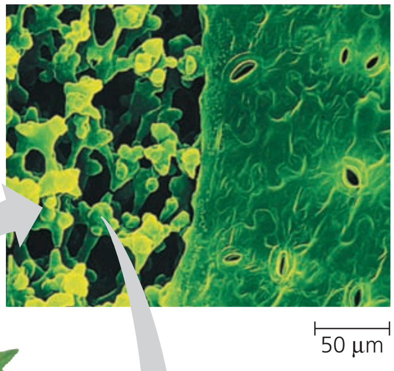
Theme: New Properties Emerge at Successive Levels of Biological Organization

ORGANIZATION In **Figure 1.3**, we zoom in from space to take a closer and closer look at life in a deciduous forest in Ontario, Canada. This journey shows the different levels of organization recognized by biologists: The study of life extends from the global scale of the entire living planet to the microscopic scale of cells and molecules. The numbers in the figure guide you through the hierarchy of biological organization.

Zooming in at ever-finer resolution illustrates an approach called *reductionism*, which 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. However, although it has propelled many major discoveries, reductionism provides a necessarily incomplete view of life on Earth, as we'll discuss next.

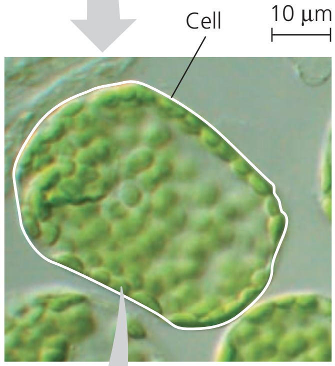
▼ 6 Organs and Organ Systems

The structural hierarchy of life continues to unfold as we explore the architecture of more complex organisms. A maple leaf is an example of an organ, a body part that carries out a particular function in the body. Stems and roots are the other major organs of plants. The organs of complex animals and plants are organized into organ systems, each a team of organs that cooperate in a larger function. Organs consist of multiple tissues.



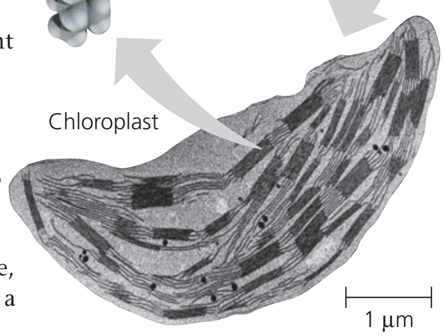
◀ 7 Tissues

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 is a tissue called epidermis (right side of photo). The pores through the epidermis allow entry of the gas CO_2, a raw material for sugar production.



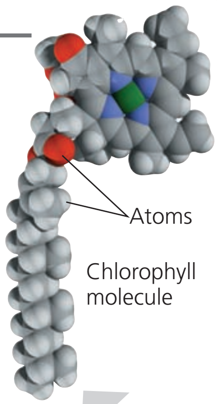
▲ 8 Cells

The cell is life's fundamental unit of structure and function. Some organisms are single cells, while others are multicellular. A single cell performs all the functions of life, while a multicellular organism has a division of labor among specialized cells. Here we see a magnified view of cells in a leaf tissue. One cell is about 40 micrometers (µm) across—about 500 of them would reach across a small coin. As tiny as these cells are, you can see that each contains numerous green structures called chloroplasts, which are responsible for photosynthesis.



▶ 9 Organelles

Chloroplasts are examples of organelles, the various functional components present in cells. This image, 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 molecule that makes a maple 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.

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 from the preceding level. 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 in a disorganized test-tube mixture of chlorophyll and other chloroplast molecules. The coordinated processes of photosynthesis require a specific organization of these molecules in the chloroplast. Isolated components of living systems, serving as the objects of study in a reductionist approach to biology, 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 explore emergent properties more fully, 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, we can ask how a drug that lowers blood pressure affects the functioning of organs throughout the human body. 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

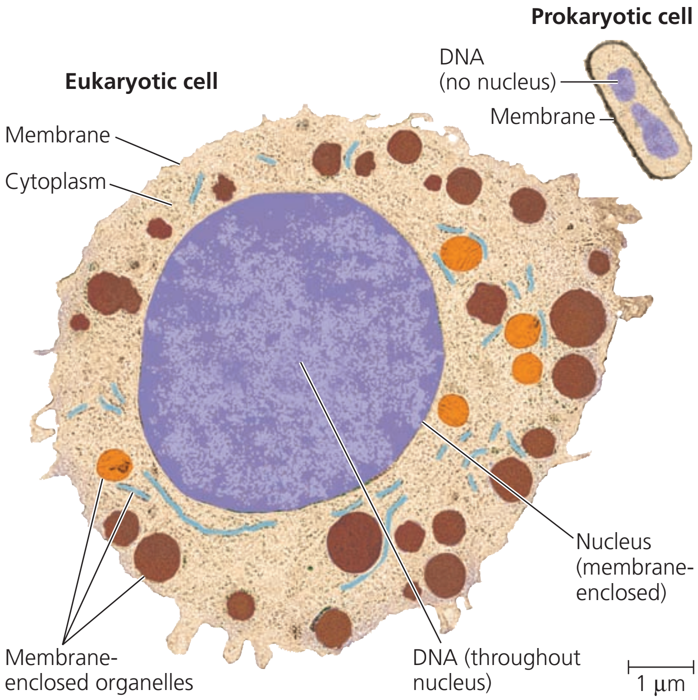
At each level of the biological hierarchy, we find a correlation of structure and function. Consider the leaf shown in Figure 1.3: Its thin, flat shape maximizes the capture of sunlight by chloroplasts. More generally, analyzing a biological structure gives us clues about what it does and how it works. Conversely, knowing the function of something provides insight into its structure and organization. Many examples from the animal kingdom show a correlation between structure and function. For example, the hummingbird's anatomy allows the 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

In life's structural hierarchy, the cell is the smallest unit of organization that can perform all activities required for life. In fact, the actions of organisms are all based on the functioning 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 recognize two main forms of cells: prokaryotic and eukaryotic. The cells of two groups of single-celled microorganisms—bacteria (singular, *bacterium*) and archaea (singular, *archaean*)—are prokaryotic. 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

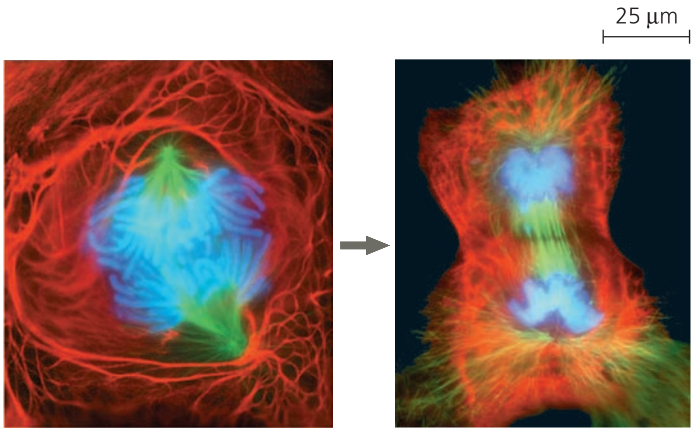


▲ **Figure 1.4 Contrasting eukaryotic and prokaryotic cells in size and complexity.**

only in eukaryotic cells that carry out photosynthesis. In contrast to eukaryotic cells, a **prokaryotic cell** lacks a nucleus or other membrane-enclosed organelles. Another distinction is that 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 divide, the chromosomes may be made visible using a dye that appears blue when bound to the DNA **(Figure 1.5)**.

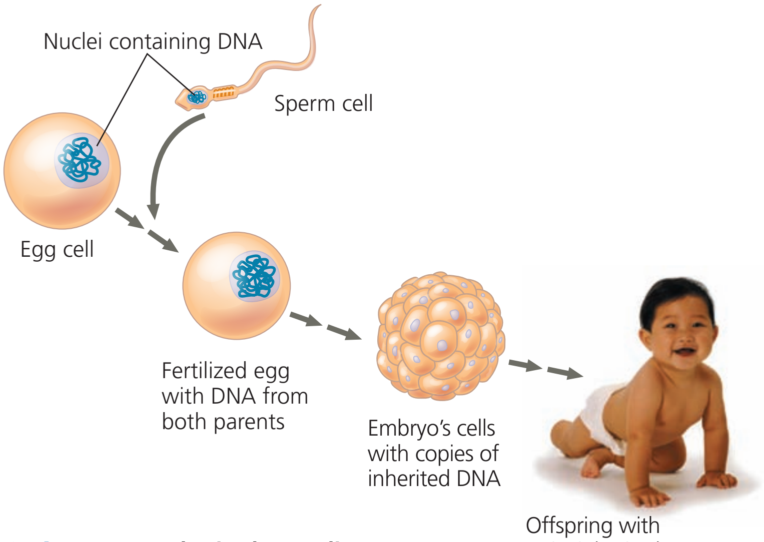


▲ **Figure 1.5 A lung cell from a newt divides into two smaller cells that will grow and divide again.**

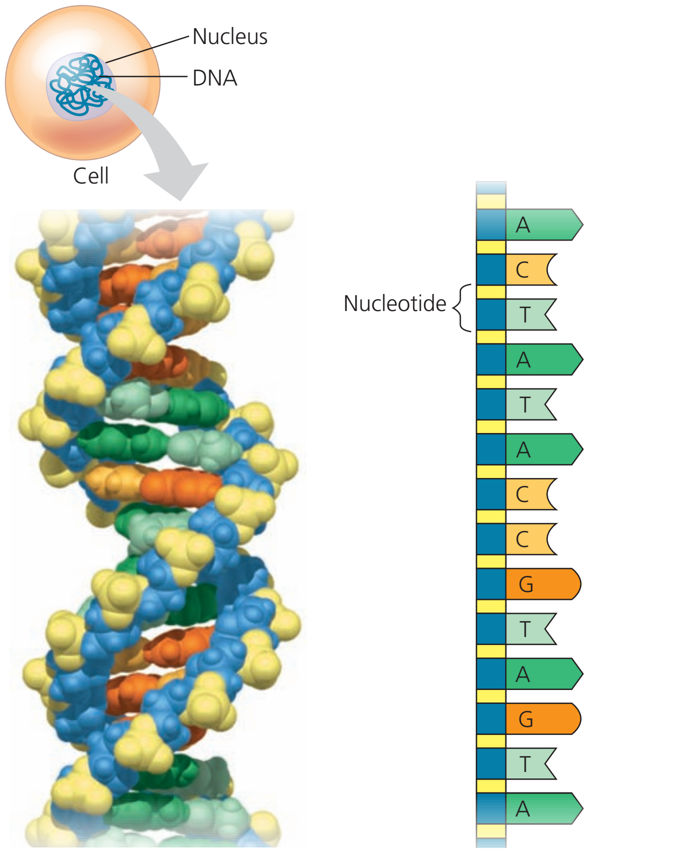
DNA, the Genetic Material

Each time a cell divides, the DNA is first replicated, or copied, and each of the two cellular offspring inherits a complete set of chromosomes, identical to that of the parent cell. 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. Each of us began as a single cell stocked with DNA inherited from our parents. The replication of that DNA during each round of cell division transmitted copies of the DNA to what eventually became the trillions of cells of our body. As the cells grew and divided, the genetic information encoded by the DNA directed our 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)**.



▲ **Figure 1.6 Inherited DNA directs development of an organism.**



(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.

▲ **Figure 1.7 DNA: The genetic material.**

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. Specific sequences of these four nucleotides encode the information in genes.

Many genes provide the blueprints for making proteins, which are the major players in building and maintaining the cell and carrying out its activities. For instance, a given bacterial gene may specify a particular protein (an enzyme) required to break down a certain sugar molecule, while a human gene may denote a different protein (an antibody) that helps fight off infection.

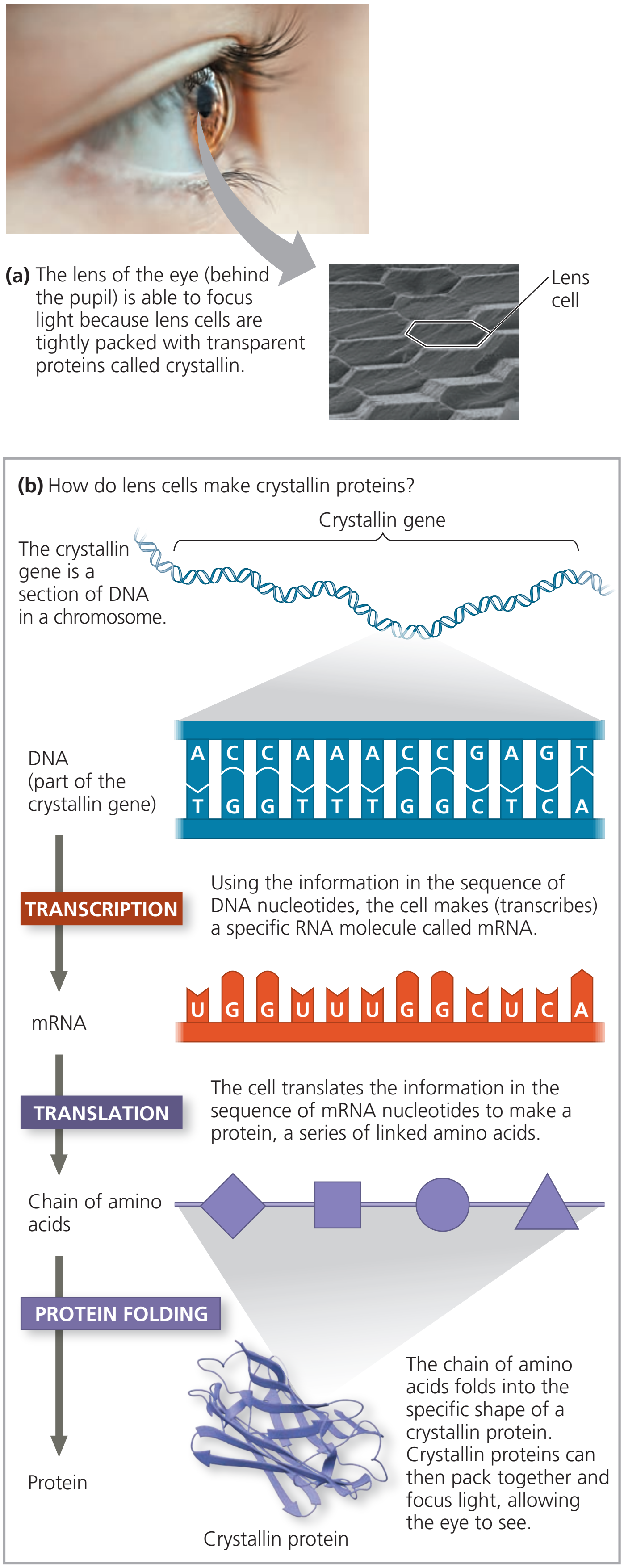
Genes control protein production indirectly, using a related molecule called RNA as an intermediary **(Figure 1.8)**. The sequence of nucleotides along a gene is transcribed into RNA, which is then translated into a linked series of protein building blocks called amino acids. These two stages result in 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**.

In translating genes into proteins, all forms of life employ essentially the same genetic code: A particular sequence of nucleotides says 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. 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, as you will see.

In addition to RNA molecules (called mRNAs) that are translated into proteins, some RNAs in the cell carry out other important tasks. For example, we have known for decades that some types of RNA are actually components of the cellular machinery that manufactures proteins. Recently, scientists have discovered whole new classes of RNA that play other roles in the cell, such as regulating the functioning of protein-coding genes. All of these RNAs are specified by genes, and the production of these RNAs 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 genetic text would fill about 700 biology textbooks.



▲ **Figure 1.8 Gene expression: The transfer of information from a gene results in a functional protein.**

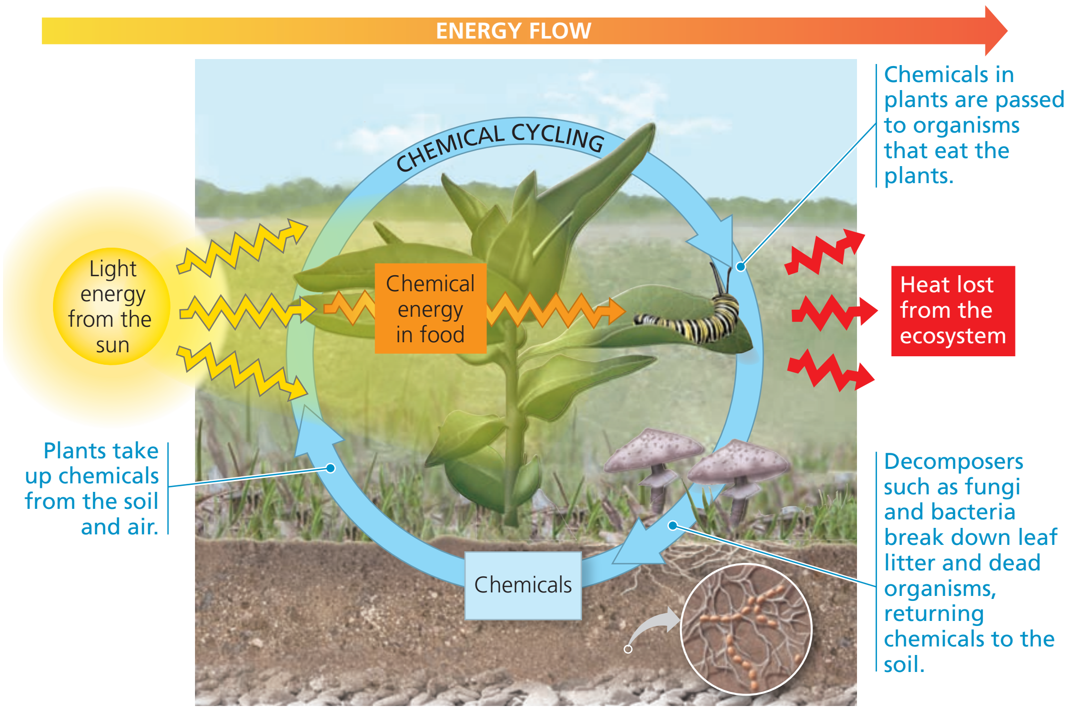
Since the early 1990s, the pace at which researchers can determine the sequence of a genome has accelerated at an astounding rate, enabled by a revolution in technology. The entire sequence of nucleotides in the human genome is now known, along with the genome sequences of many other organisms, including other animals and 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 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 or group of cells 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 non-translated 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 A fundamental characteristic of living organisms is their use of energy to carry out life's activities. 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. A plant's leaves absorb sunlight, and molecules within the leaves convert the energy of sunlight to the chemical energy of food, such as sugars, produced during photosynthesis. The chemical energy in the food molecules is then passed along by plants and other photosynthetic organisms (**producers**) to consumers. **Consumers** are organisms, such as animals, that feed on producers and other consumers.

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 one way *through* an ecosystem, usually entering as light and exiting as heat. In contrast, chemicals are recycled *within* an ecosystem **(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.



◀ **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.

Theme: From Ecosystems to Molecules, 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 the components of an ecosystem and the molecules in a cell; we'll discuss both as examples.

Ecosystems: An Organism's Interactions with Other Organisms and the Physical Environment

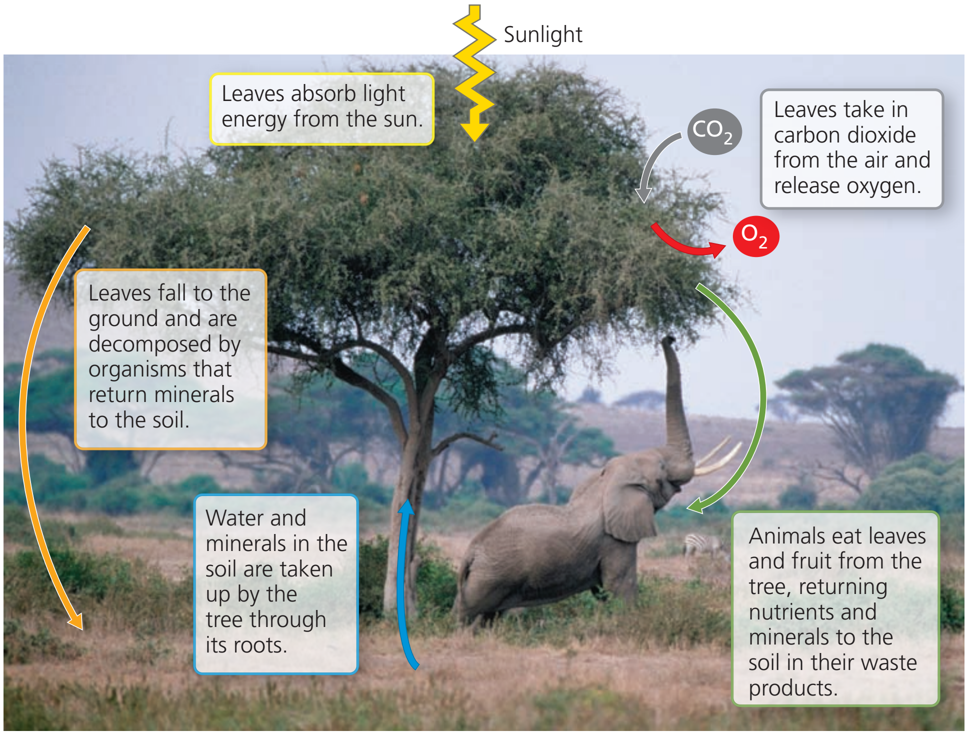
At the ecosystem level, each organism interacts with other organisms. For instance, an acacia tree interacts with soil microorganisms associated with its roots, insects that live on it, and animals that eat its leaves and fruit **(Figure 1.10)**. In some cases, interactions between organisms are mutually beneficial. An example is the association between a sea turtle and the so-called "cleaner fish" that hover around it. The fish feed on parasites that would otherwise harm the turtle, while gaining a meal and protection from predators. Sometimes, one species benefits and the other is harmed, as when a lion kills and eats a zebra. In yet other cases, both species are harmed—for example, when two plants compete for a soil resource that is in short supply. Interactions among organisms help regulate the functioning of the ecosystem as a whole.

Organisms also interact continuously with physical factors in their environment. The leaves of a tree, for example, absorb light from the sun, take in carbon dioxide from the air, and release oxygen to the air (see Figure 1.10). The environment is also affected by the organisms living there. For instance, in addition to taking up water and minerals from the soil, the roots of a plant break up rocks as they grow, thereby contributing to the formation of soil. On a global scale, plants and other photosynthetic organisms have generated all the oxygen in the atmosphere.

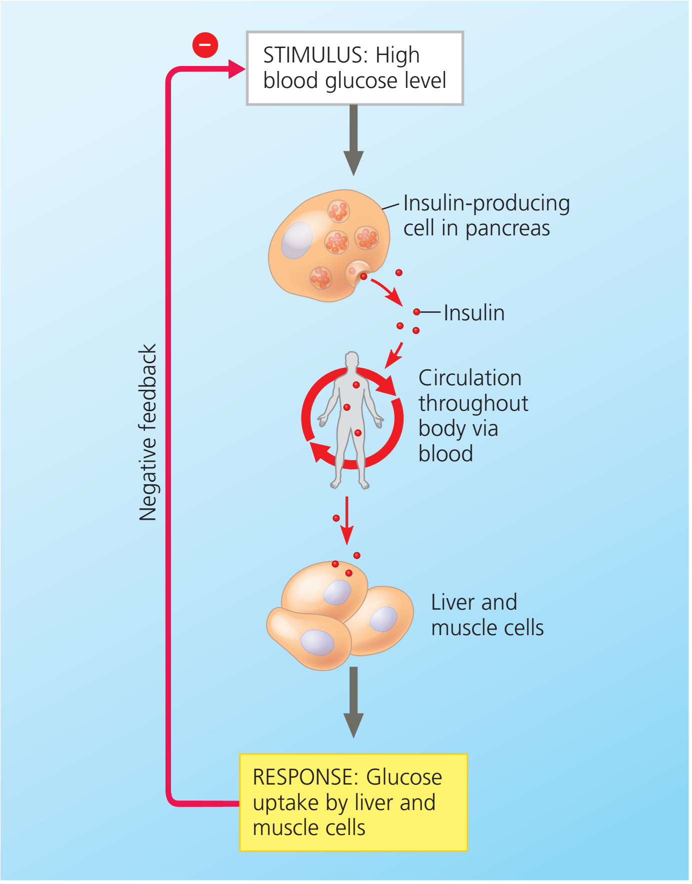
Molecules: Interactions Within Organisms

At lower levels of organization, the interactions between components that make up living organisms—organs, tissues, cells, and molecules—are crucial to their smooth operation. Consider the sugar in your blood, for instance. After a meal, the level of the sugar glucose in your blood rises **(Figure 1.11)**. The increase in blood glucose stimulates the pancreas to release insulin into the blood. Once it reaches liver or muscle cells, insulin causes excess glucose to be stored in the form of a very large carbohydrate called glycogen, reducing blood glucose level to a range that is optimal for bodily functioning. The lower blood glucose level that results no longer stimulates insulin secretion by pancreas cells. Some sugar is also used by cells for energy: When you exercise, your muscle cells increase their consumption of sugar molecules.

Interactions among the body's molecules are responsible for most of the steps in this process. For instance, like most chemical activities in the cell, those that either decompose or store sugar are accelerated at the molecular level (catalyzed) by proteins called enzymes. Each type of enzyme



▶ **Figure 1.10 Interactions of an African acacia tree with other organisms and the physical environment.**



▲ **Figure 1.11 Feedback regulation.** The human body regulates the use and storage of glucose, a major cellular fuel derived from food. This figure shows negative feedback: The response (glucose uptake by cells) decreases the high glucose levels that provide the stimulus for insulin secretion, thus negatively regulating the process.

catalyzes a specific chemical reaction. In many cases, these reactions are linked into chemical pathways, each step with its own enzyme. How does the cell coordinate its various chemical pathways? In our example of sugar management, how does the cell match fuel supply to demand, regulating its opposing pathways of sugar consumption and storage? The key is the ability of many biological processes to self-regulate by a mechanism called feedback.

In **feedback regulation**, the output, or product, of a process regulates that very process. The most common form of regulation in living systems is *negative feedback*, a loop in which the response reduces the initial stimulus. As seen in the example of insulin signaling (see Figure 1.11), the uptake of glucose by cells (the response) decreases blood glucose levels, eliminating the stimulus for insulin secretion and thereby shutting off the pathway. Thus, the output of the process negatively regulates that process.

Though less common than processes regulated by negative feedback, there are also many biological processes regulated by *positive feedback*, in which an end product *speeds up* its own production. The clotting of your blood in response to injury is an example. When a blood vessel is damaged, structures in the blood called platelets begin to aggregate at the site. Positive feedback occurs as chemicals released by the platelets attract *more* platelets. The platelet pileup then initiates a complex process that seals the wound with a clot.

Feedback is a regulatory motif common to life at all levels, from the molecular level through ecosystems and the biosphere. Interactions between organisms can affect system-wide processes like the growth of a population. And as we'll see, interactions between individuals not only affect the participants, but also affect how populations evolve over time.

Evolution, the Core Theme of Biology

Having considered four of the unifying themes that run through this text (organization, information, energy and matter, and interactions), let's now turn to biology's core theme—evolution. Evolution is the one idea that makes logical sense of everything we know about living organisms. As we will see in Units 4 and 5 of this text, the fossil record documents the fact that life has been evolving on Earth for billions of years, resulting in a vast diversity of past and present organisms. But along with the diversity are many shared features. For example, while sea horses, jackrabbits, hummingbirds, and giraffes all look very different, their skeletons are organized in the same basic way. The scientific explanation for this unity and diversity—as well as for the adaptation of organisms to their environments—is evolution: the concept that the organisms living on Earth today are the modified descendants of common ancestors. In other words, we can explain the sharing of traits by two organisms with the premise that the organisms have descended from a common ancestor, and we can account for differences with the idea that heritable changes have occurred along the way. Many kinds of evidence support the occurrence of evolution and the theory that describes how it takes place. In the next section, we'll consider the fundamental concept of evolution in greater detail.

CONCEPT CHECK 1.1

1. Starting with the molecular level in Figure 1.3, write a sentence that includes components from the previous (lower) level of biological organization, for example: "A molecule consists of *atoms* bonded together." Continue with organelles, moving up the biological hierarchy.
2. Identify the theme or themes exemplified by (a) the sharp quills of a porcupine, (b) the development of a multicellular organism from a single fertilized egg, and (c) a hummingbird using sugar to power its flight.
3. **WHAT IF?** For each theme discussed in this section, give an example not mentioned in the text.

For suggested answers, see Appendix A.