

TENTH EDITION

CAMPBELL
BIOLOGY

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CAMPBELL BIOLOGY

TENTH EDITION

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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 post-doctoral 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*.

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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

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Steven A. Wasserman



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tion, 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*.

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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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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.

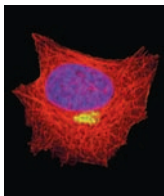
UNIT 1 The Chemistry of Life

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 G₁ 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



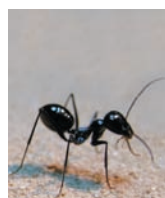
In keeping with our Tenth Edition goals, we have expanded the coverage of genomic and other molecular studies and how they inform our understanding of phylogeny. Examples include a new Inquiry Figure (Figure 34.49) on the Neanderthal genome and presentation of new evidence that mutualistic interactions 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.



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**.

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.

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**.



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)

Stages of food processing

1. INGESTION

(eating)

2. DIGESTION

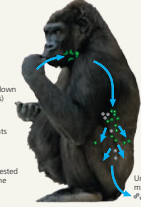
(enzymatic breakdown of large molecules)

3. ABSORPTION

(uptake of nutrients by cells)

4. ELIMINATION

(passage of undigested materials out of the body in feces)

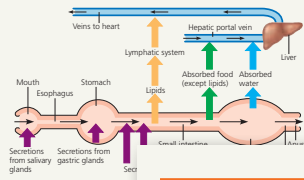


Animals differ in the ways they obtain and ingest food. Many animals are **bulk feeders**, eating large pieces of food. Other strategies include filter feeding, suspension feeding, and fluid feeding. Compartmentalization is necessary to avoid self-digestion. In intracellular digestion, food particles 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 it for absorption of nutrients than?

CONCEPT 41.4

Evolutionary adaptations of correlate with diet (pp. 906

Vertebrate digestive system types associated with diet. F assortment of teeth, genera mutualism, many herbivore chambers where microorga also usually have longer lif flexing the longer time ne

How does human anatomy? were not strict vegetarians?

CONCEPT 41.5

Feedback circuits regulate appetite (pp. 908–912)

Nutrition is regulated at m canal triggers nervous and l secretion of digestive juices ingested material through t for energy production is reg and **glucagon**, which cotts glycogen.

Explain why your stomach n skip a meal.

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.

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.

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.

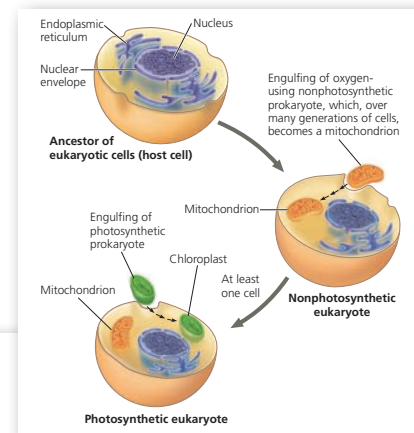
Summary Figures recap key information in a visual way. Summary of Key Concepts Questions check students' understanding of a key idea from each concept.

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.



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

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

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

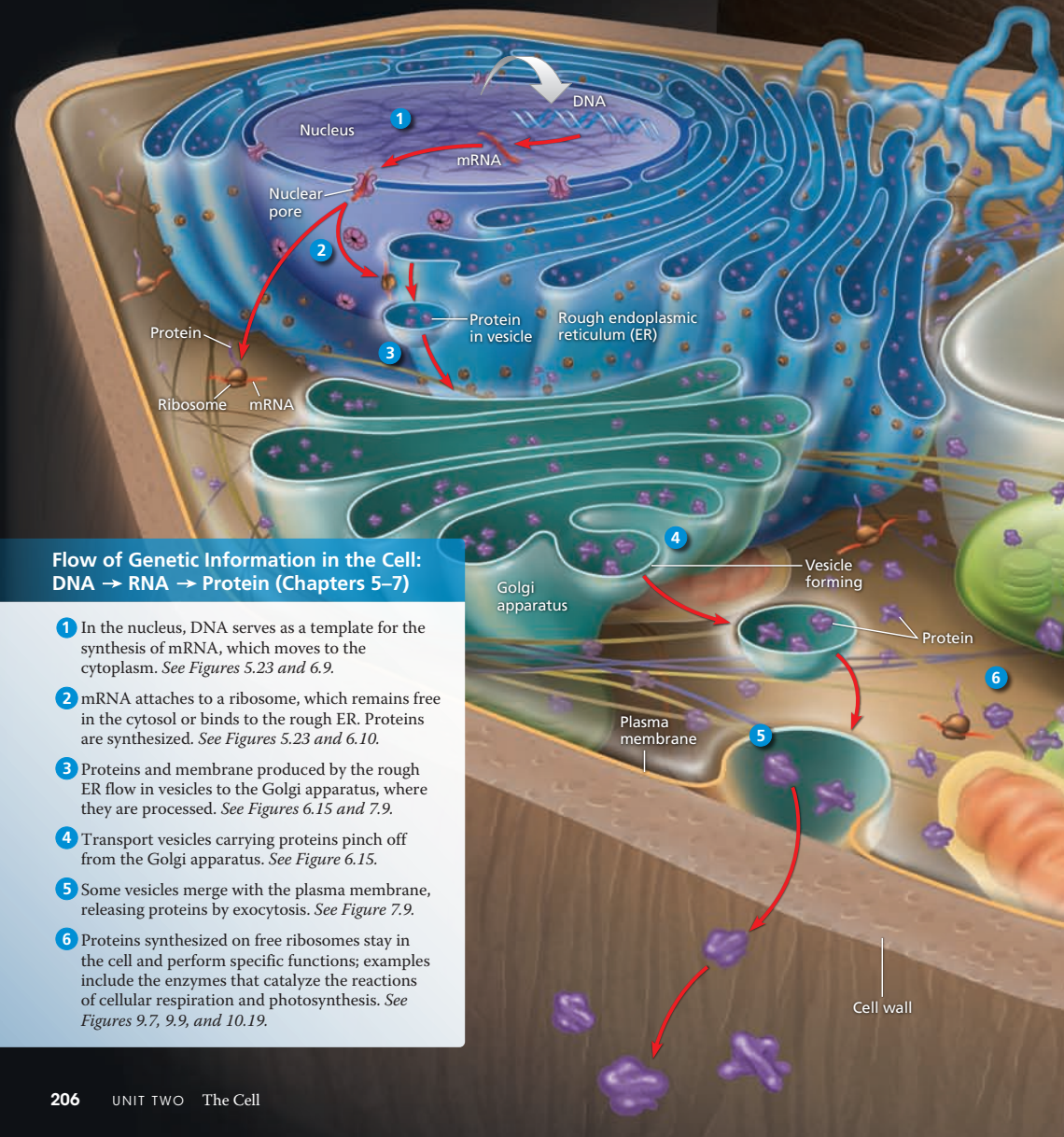
Figure 55.13 The Working Ecosystem, pp. 1242–1243

▼ 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.





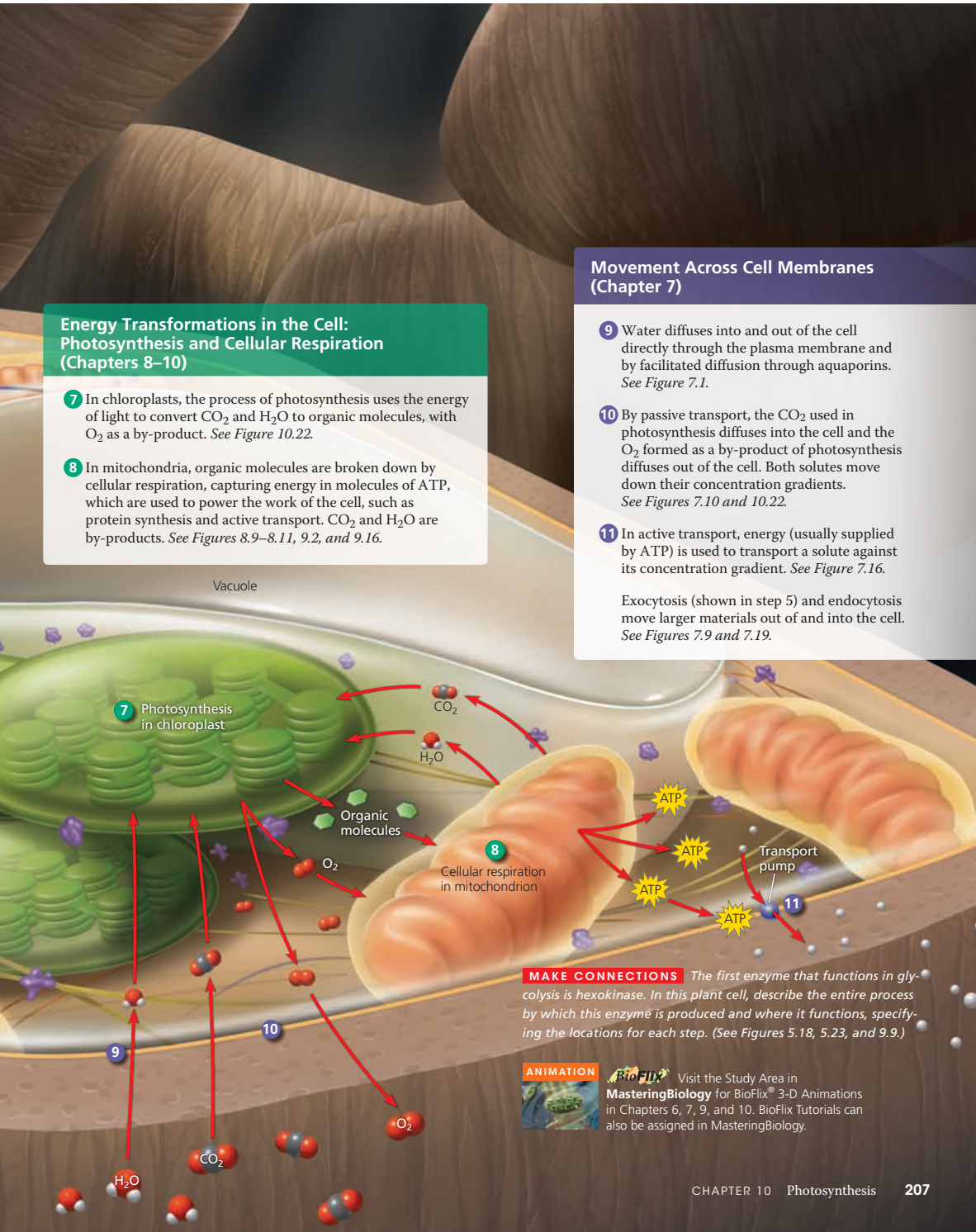
Movement Across Cell Membranes (Chapter 7)

- 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 CO₂ used in photosynthesis diffuses into the cell and the O₂ 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.

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 CO₂ and H₂O to organic molecules, with O₂ 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. CO₂ and H₂O are by-products. See Figures 8.9–8.11, 9.2, and 9.16.



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  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

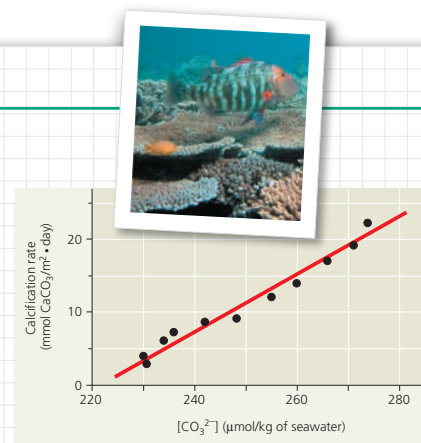
How Does the Carbonate Ion Concentration of Seawater Affect the Calcification Rate of a Coral Reef? Scientists predict that acidification of the ocean due to higher levels of atmospheric CO_2 will lower the concentration of dissolved carbonate ions, which living corals use to build calcium carbonate reef structures. In this exercise, you will analyze data from a controlled experiment that examined the effect of carbonate ion concentration ($[\text{CO}_3^{2-}]$) 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

- 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.)
- Based on the data shown in the graph, describe in words the relationship between carbonate ion concentration and calcification rate.
- (a) If the seawater carbonate ion concentration is $270 \mu\text{mol/kg}$, 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 $250 \mu\text{mol/kg}$, 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?

- (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 $[\text{CO}_2]$ will slow the growth of coral reefs? Why or why not?

► 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

- Interpreting a Pair of Bar Graphs, p. 22
- Calibrating a Standard Radioactive Isotope Decay Curve and Interpreting Data, p. 33
- Interpreting a Scatter Plot with a Regression Line, p. 54
- Working with Moles and Molar Ratios, p. 58
- Analyzing Polypeptide Sequence Data, p. 89
- Using a Scale Bar to Calculate Volume and Surface Area of a Cell, p. 99
- Interpreting a Scatter Plot with Two Sets of Data, p. 134
- Making a Line Graph and Calculating a Slope, p. 155
- Making a Bar Graph and Evaluating a Hypothesis, p. 177
- Making Scatter Plots with Regression Lines, p. 203
- Using Experiments to Test a Model, p. 226
- Interpreting Histograms, p. 248
- Making a Line Graph and Converting Between Units of Data, p. 262
- Making a Histogram and Analyzing a Distribution Pattern, p. 281
- Using the Chi-Square (χ^2) Test, p. 302
- Working with Data in a Table, p. 316
- Interpreting a Sequence Logo, p. 349
- Analyzing DNA Deletion Experiments, p. 370
- Analyzing a Sequence-Based Phylogenetic Tree to Understand Viral Evolution, p. 404
- Analyzing Quantitative and Spatial Gene Expression Data, p. 420
- Reading an Amino Acid Sequence Identity Table, p. 452
- Making and Testing Predictions, p. 477
- Using the Hardy-Weinberg Equation to Interpret Data and Make Predictions, p. 487
- Identifying Independent and Dependent Variables, Making a Scatter Plot, and Interpreting Data, p. 507
- Estimating Quantitative Data from a Graph and Developing Hypotheses, p. 532
- Using Protein Sequence Data to Test an Evolutionary Hypothesis, p. 564



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

MasteringBiology®

9: The Cell Cycle > Scientific Skills Exercise: Interpreting Histograms

Item Type: Tutorial | Difficulty: -- | Time: -- | Learning Outcomes ▾ | Contact the Publisher | Manage this Item: Standard View ▾

Scientific Skills Exercise: Interpreting Histograms

At what phase is the cell cycle arrested by an inhibitor?

One potential medical treatment to stop cancer cell proliferation employs an inhibitor derived from human umbilical cord stem cells. In this exercise, you will compare two histograms to determine where in the cell cycle the inhibitor blocks the division of cancer cells.

In the treated sample, human glioblastoma (brain cancer) cells were grown in tissue culture in the presence of inhibitor-producing umbilical cord stem cells. In contrast, control sample glioblastoma cells were grown in the absence of stem cells. To get a "snapshot" of the phase of the cell cycle each cell was in at the end of 72 hours, the cell samples were treated with a fluorescent chemical that binds to DNA. Next the samples were run through a flow cytometer, an instrument that records the fluorescence level of each cell. Computer software then graphed the number of cells in each sample with a particular fluorescence level.

Part A - Identifying the control and the treatment

What treatment is being compared to the control in the experiment?

- The treated umbilical cord stem cells were cultured in the presence of an inhibitor from glioblastoma cells, but the control cells were cultured without the inhibitor.
- The control glioblastoma cells were run through the flow cytometer and then treated by being cultured in the presence of an inhibitor.
- The treated glioblastoma cells were stained with a fluorescent dye, but the control cells were not stained.
- The treated glioblastoma cells were cultured in the presence of an inhibitor from umbilical cord stem cells, but the control cells were cultured without the inhibitor.

Data from K. K. Veipula et al., Regulation of glioblastoma progression by cord blood stem cells is mediated by downregulation of cyclin D1, *PLoS ONE* 6(3): e18017 (2011). doi:10.1371/journal.pone.0018017

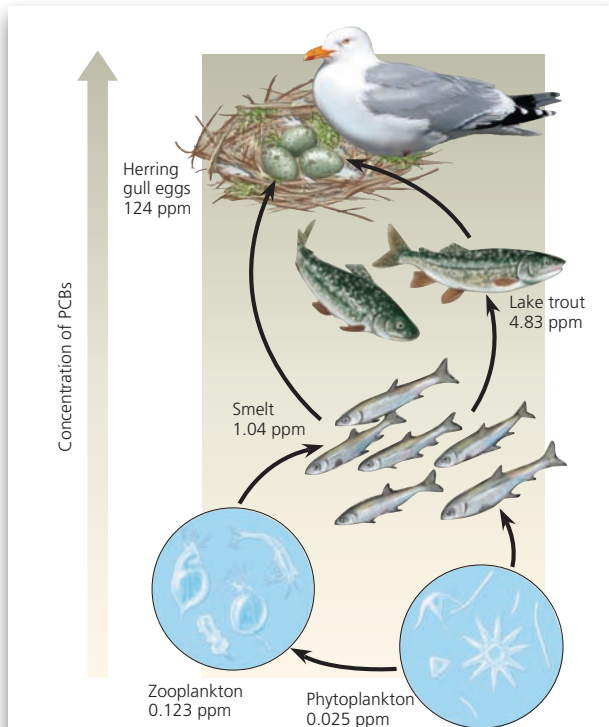
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27. Making a Bar Graph and Interpreting Data, p. 584
28. Interpreting Comparisons of Genetic Sequences, p. 589
29. Making Bar Graphs and Interpreting Data, p. 623
30. Using Natural Logarithms to Interpret Data, p. 633
31. Interpreting Genomic Data and Generating Hypotheses, p. 651
32. Calculating and Interpreting Correlation Coefficients, p. 672
33. Understanding Experimental Design and Interpreting Data, p. 694
34. Determining the Equation of a Regression Line, p. 745
35. Using Bar Graphs to Interpret Data, p. 756
36. Calculating and Interpreting Temperature Coefficients, p. 784
37. Making Observations, p. 806
38. Using Positive and Negative Correlations to Interpret Data, p. 828
39. Interpreting Experimental Results from a Bar Graph, p. 858
40. Interpreting Pie Charts, p. 886
41. Interpreting Data from Experiments with Genetic Mutants, p. 912
42. Making and Interpreting Histograms, p. 932
43. Comparing Two Variables on a Common *x*-Axis, p. 967
44. Describing and Interpreting Quantitative Data, p. 975
45. Designing a Controlled Experiment, p. 1008
46. Making Inferences and Designing an Experiment, p. 1025
47. Interpreting a Change in Slope, p. 1043
48. Interpreting Data Values Expressed in Scientific Notation, p. 1076
49. Designing an Experiment Using Genetic Mutants, p. 1089
50. Interpreting a Graph with Log Scales, p. 1130
51. Testing a Hypothesis with a Quantitative Model, p. 1144
52. Making a Bar Graph and a Line Graph to Interpret Data, p. 1181
53. Using the Logistic Equation to Model Population Growth, p. 1194
54. Making a Bar Graph and a Scatter Plot, p. 1211
55. Interpreting Quantitative Data in a Table, p. 1240
56. Graphing Cyclic Data, p. 1273

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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www.masteringbiology.com

◀ **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?

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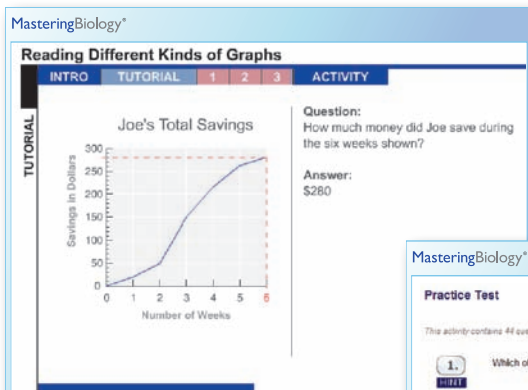
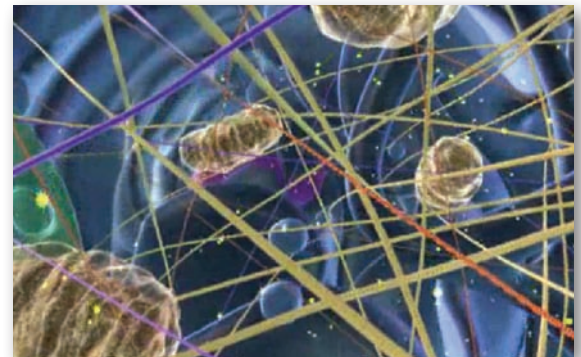
▲ The **Pearson eText** gives students access to the text whenever and wherever they can access the Internet. The eText can be viewed on PCs, Macs, and tablets, including iPad® and Android®. The eText includes powerful interactive and customization functions:

- Write notes
- Click hyperlinked words to view definitions
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- Zoom

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

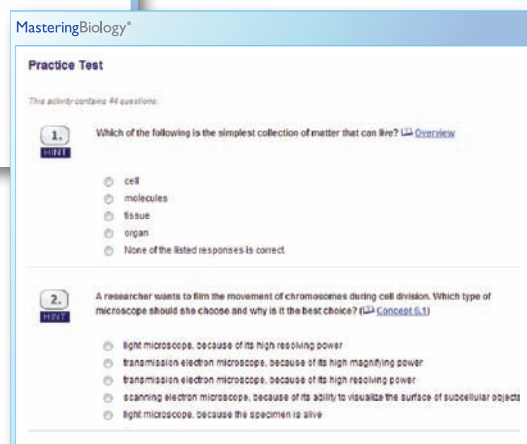
STUDY AREA

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



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

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



◀ **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.

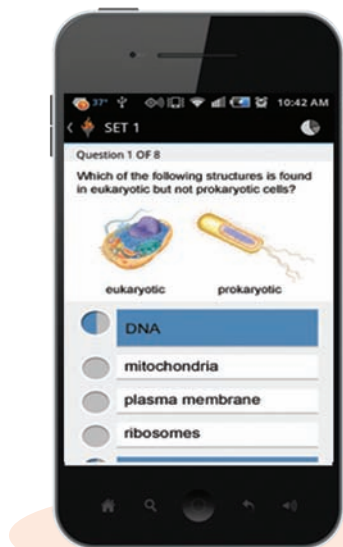
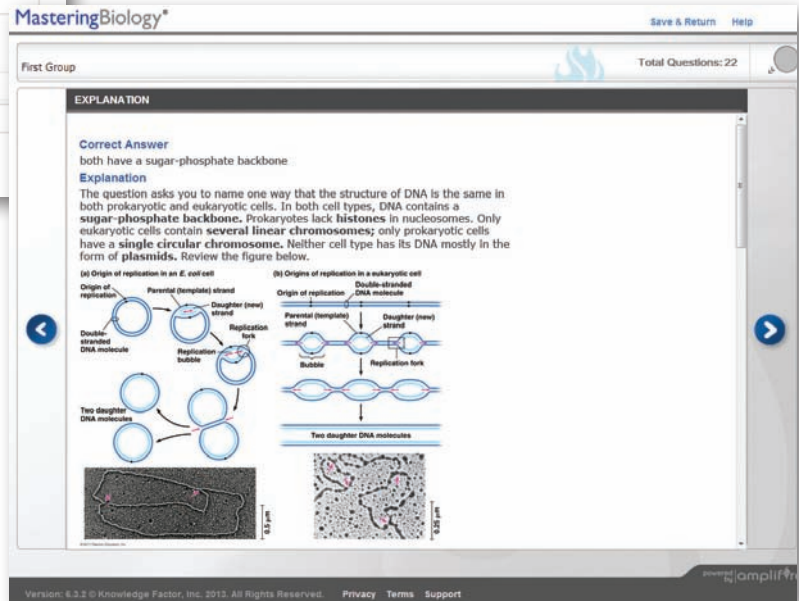
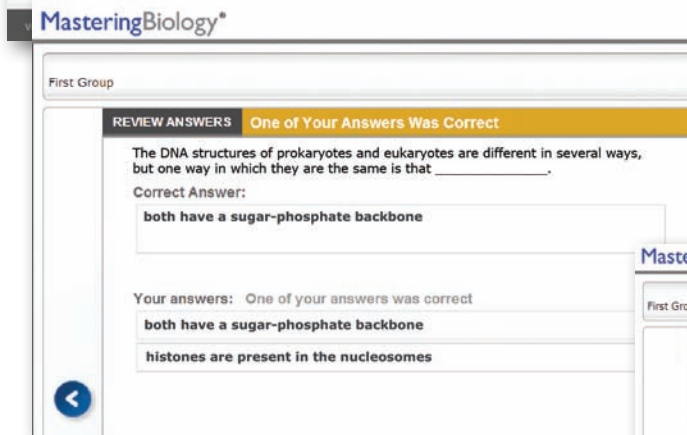
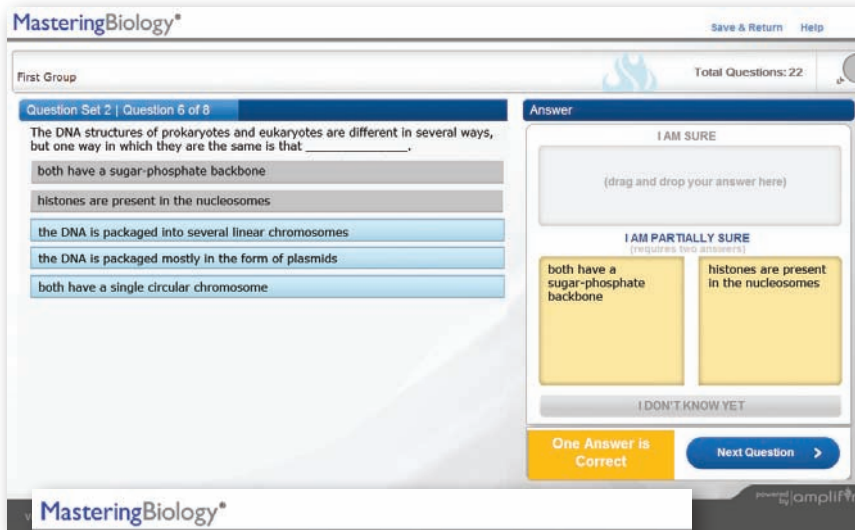
How it works:

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.

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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.

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Cellular Respiration and Fermentation Cellular Respiration (1 of 5): Inputs and Outputs (Self-paced tutorial)

Item Type: Tutorial | Difficulty: 4 | Time: 19m | Learning Outcomes | Contact the Publisher

Part A - Glycolysis

From the following compounds involved in cellular respiration, choose those that are the net inputs and net outputs of glycolysis. Drag each compound to the appropriate bin. If the compound is not involved in glycolysis, drag it to the "not input or output" bin.

net input: glucose, ATP, NADH, O₂

net output: pyruvate, H₂O, NADP⁺, acetyl CoA

not input or output: CO₂, succinate A

Submit Hints My Answers Give Up Review Part

Try Again

You sorted 4 out of 10 items incorrectly. Although O₂ 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 O₂ in the last stage of cellular respiration.

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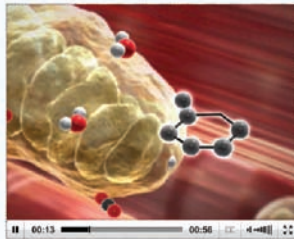
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1. If a student gets stuck ...

Try Again

You sorted 4 out of 10 items incorrectly. Although O₂ 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 O₂ in the last stage of cellular respiration.

Hint 1. Review the Glycolysis animation



Hint 2. Is there a net input or net output of ATP in glycolysis?

If a compound is both consumed (input) and produced (output) in a process, you need to consider whether more of the compound is consumed or produced. If more of the compound is consumed than produced, there is a net input of the compound in that process. If more of the compound is produced than consumed, there is a net output of the compound. Recall that in the first steps of glycolysis, 2 ATP are consumed per glucose molecule. As glycolysis progresses, 4 ATP are produced per glucose molecule. Which statement correctly describes the net change in ATP during glycolysis?

- There is a net output of ATP.
- There is a net input of ATP.
- There is no net input or net output of ATP.

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.

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CH09 HW Adaptive Follow-Up

Due: 11:59pm on Friday, February 22, 2013

The items on this assignment have been selected specifically for you based on your progress. Target the concepts you may not understand. [Learn More](#)

You completed this Adaptive Follow-Up assignment.

Question Set 1

Activity: Glucose Metabolism Your score 100%

Practice Test 3.10 Your score 100%

Practice Test 3.22 Your score 100%

Practice Test 3.33 Your score 100%

Practice Test 3.38 Your score 100%

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Activity: Glucose Metabolism

A Eukaryotic Cell

Phosphate

Glucose

ATP

ADP

Submit Hints My Answers Give Up Review Part

Part B

True or false? The potential energy in an ATP molecule is derived mainly from its three phosphate groups.

True

False

Submit Hints My Answers Give Up Review Part



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.

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Score Time Difficulty

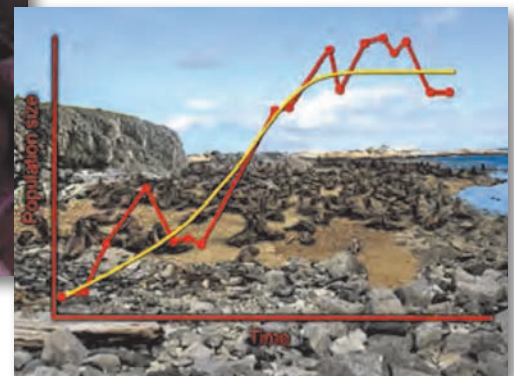
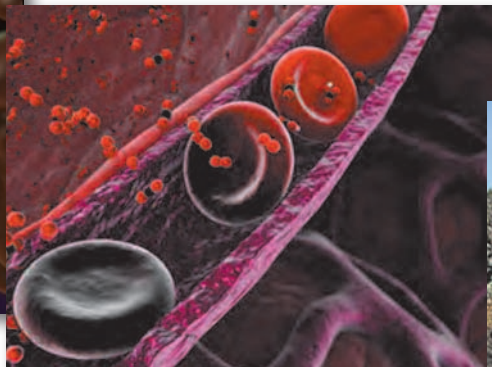
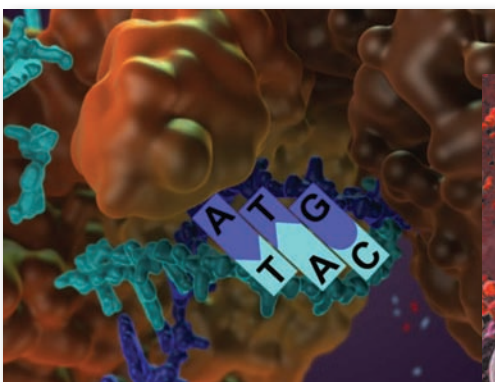
Students per page: 25

NAME	Assigned Points	Chap 6	Lab 2	CH6	CH6 Ad. Up	Lab 3	CH6 HW	CH6 H. Up	Lab 4	TOTAL
Class Average	3	20	13	7	5	7	37	5	19	434
Leat01, First...	49.5	82.0	88.1	84.0	88.7	91.0	85.0	93.0		31.6
Leat02, First...	55.0	83.3	100	100	0.0	95.0	100	100		43.6
Leat03, First...	48.7	92.9	98.0	100	90.2	72.9	89.5	89.0		32.9
Leat04, First...	34.9	81.9	104	100	94.9	85.0	100	95.0		31.8
Leat05, First...	49.3	8.0	34.3	93.7	85.3	80.0	0.0	99.0		27.8
Leat06, First...	52.0	78.9	99.0	100	85.2	82.5	97.8	85.0		34.7
Leat07, First...	58.0	51.0	101	100	95.9	90.0	96.1	85.0		31.8
Leat08, First...	53.6	92.9	100	100	100	95.0	100	100		41.6
Leat09, First...	82.6	78.0	104	100	90.8	79.3	100	85.0		36.1
Leat10, First...	82.5	78.6	106	100	94.9	92.1	94.6	100		39.4
Leat11, First...	52.7	78.2	103	100	92.9	100	100	100		32.6
Leat12, First...	53.0	98.5	97.7	100	98.6	100	100	100		32.8
Leat14, First...	53.0	74.4	86.3	85.7	89.3	95.8	100	100		29.8
Leat15, First...	52.6	80.3	100	100	100	100	100	100		32.8

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.



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.



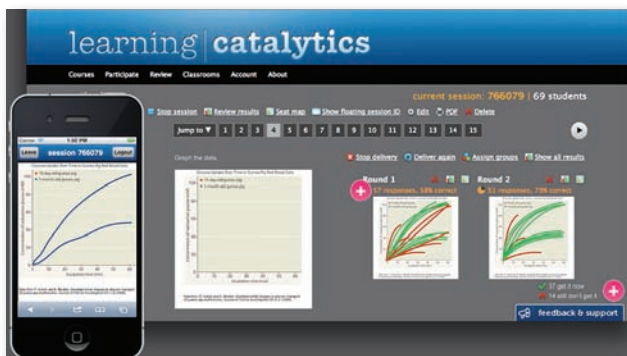
BioFlix Tutorials and 3-D Animations include:

- A Tour of the Animal Cell
- A Tour of the Plant 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
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- 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

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

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

Experiments: Data Interpretation
Water snakes on islands in Lake Erie vary in coloration from banded to unbanded. Researchers hypothesized that unbanded snakes escape predation from hawks at higher rates than do banded snakes. Imagine that you tested survival rates on four different islands by measuring recapture rates of banded and unbanded snakes and collected the data shown below. Which of the following conclusions best derive from the data shown?

Islands	Unbanded	Banded
1	10	10
2	10	10
3	10	10
4	10	10

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

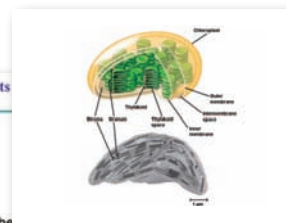
▲ **Clicker Questions** can be used to stimulate effective classroom discussions (for use with or without clickers).

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.

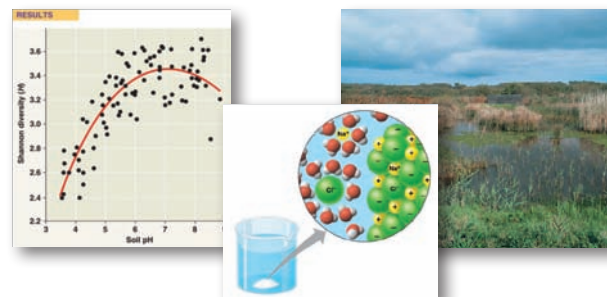
Chloroplasts: The Sites of Photosynthesis in Plants

- Leaves are the major locations of photosynthesis
- Their green color is from chlorophyll, the green pigment within chloroplasts
- Light energy absorbed by chlorophyll drives the synthesis of organic molecules in the chloroplast
- CO₂ enters and O₂ exits the leaf through microscopic pores called stomata



▲ Customizable PowerPoints

provide a jumpstart for each lecture.



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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.

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- Chat and class live (synchronous whiteboard presentation)
- Discussion boards
- Submissions (Dropbox)



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by Martha R. Taylor, *Ithaca, New York*
978-0-321-83392-1 / 0-321-83392-9

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Inquiry in Action: Interpreting Scientific Papers, Third Edition*

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.

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by Jean Heitz and Cynthia Giffen, *University of Wisconsin, Madison*
978-0-321-87705-5 / 0-321-87705-5

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*
978-0-321-83391-4 / 0-321-83391-0

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.

Study Card, Tenth Edition

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

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978-0-321-83498-0 / 0-321-83498-4

This resource provides definitions in Spanish for glossary terms.

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

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

Get Ready for Biology

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A Short Guide to Writing About Biology, Eighth Edition

by Jan A. Pechenik, *Tufts University*
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This best-selling writing guide teaches students to think as biologists and to express ideas clearly and concisely through their writing.

An Introduction to Chemistry for Biology Students, Ninth Edition

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

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

FOR LAB

Investigating Biology Laboratory Manual, Eighth Edition

by Judith Giles Morgan, *Emory University*, and M. Eloise Brown
Carter, *Oxford College of Emory University*
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Now in full color! With its distinctive investigative approach to learning, this best-selling laboratory manual is now more engaging than ever, with full-color art and photos throughout. As always, the lab manual encourages students to participate in the process of science and develop creative and critical-reasoning skills.

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Annotated Instructor Edition for Investigating Biology Laboratory Manual, Eighth Edition

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



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*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.
†A related Experimental Inquiry Tutorial can be assigned in MasteringBiology.®



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MRC Laboratory of Molecular Biology
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UNIT 8

ECOLOGY 1157



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

Interviews with prominent scientists have been a hallmark of *CAMPBELL BIOLOGY* since its inception, and conducting these interviews was again one of the great pleasures of revising the book. To open the eight units of this edition, we are proud to include interviews with 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).

MasteringBiology® and the other electronic accompaniments for this text are invaluable teaching and learning aids. We thank the hardworking, industrious instructors who worked on the revised and new media: Beverly Brown, Erica Cline, Willy Cushwa, Tom Kennedy, Tom Owens, Michael Pollock, Frieda Reichsman, Rick Spinney, Dennis Venema, Carolyn Wetzel, Heather Wilson-Ashworth, and Jennifer Yeh. We are also grateful to the many other people—biology instructors, editors, and production experts—who are listed in the credits for these and other elements of the electronic media that accompany the text.

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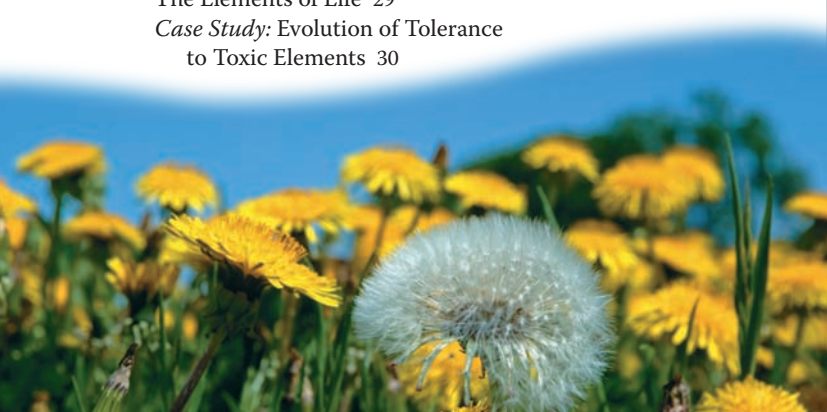
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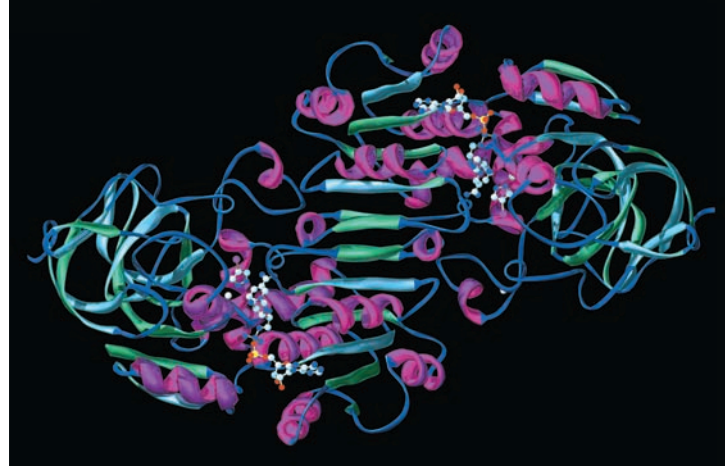
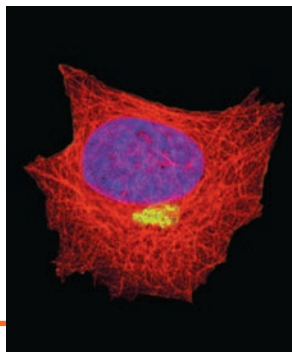
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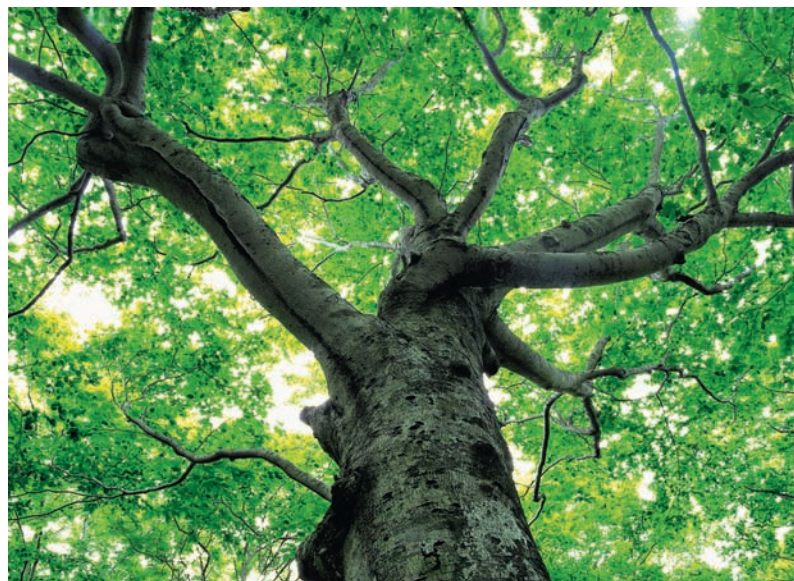
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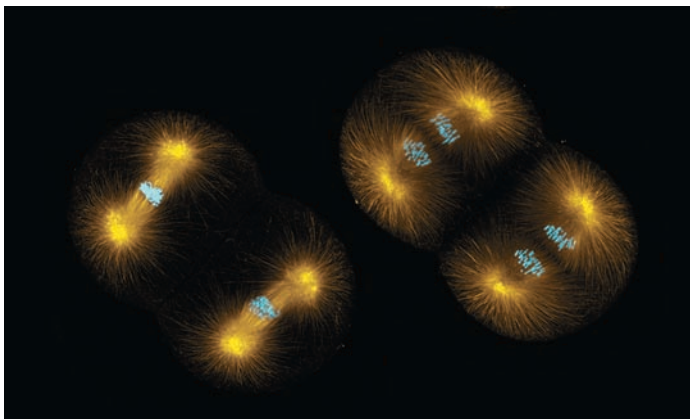
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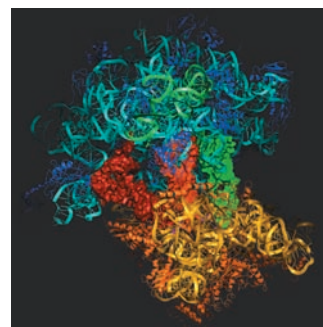
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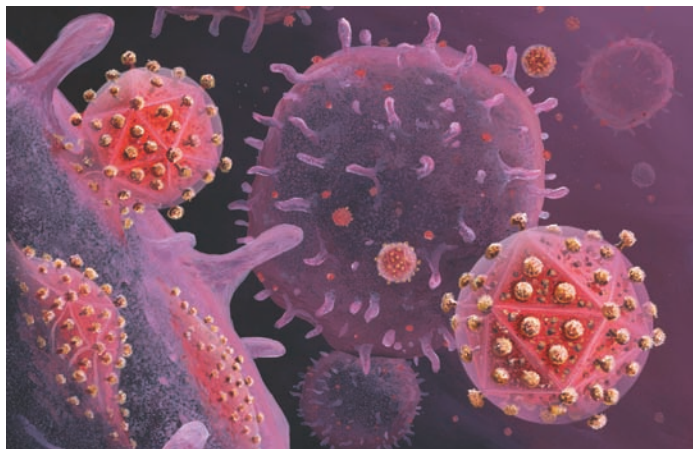
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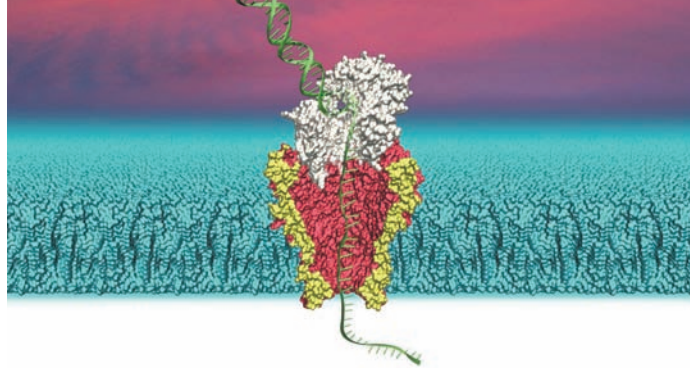
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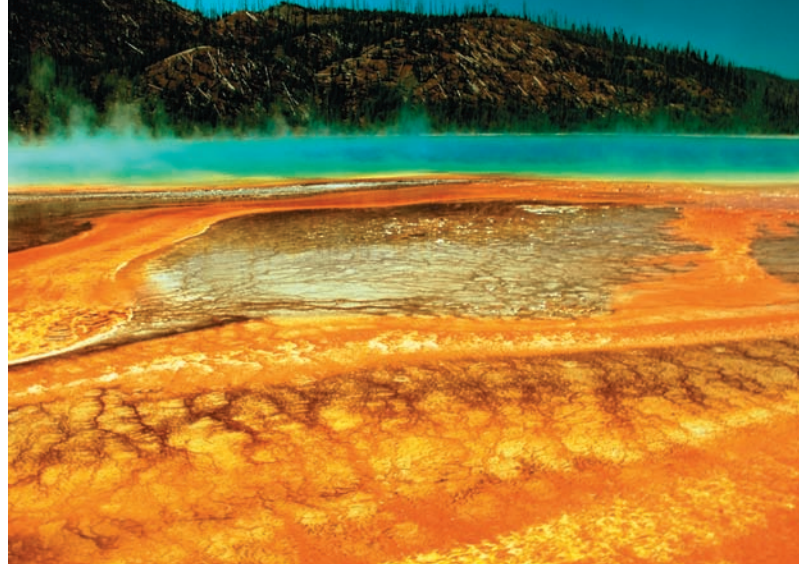
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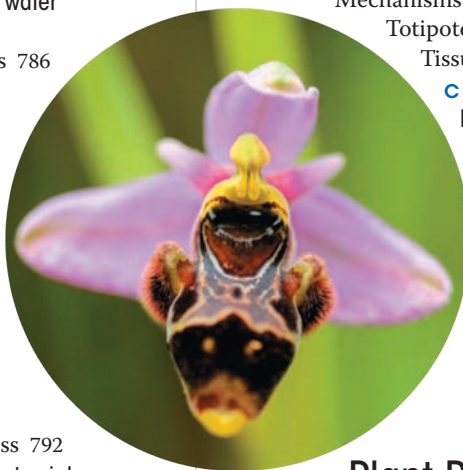
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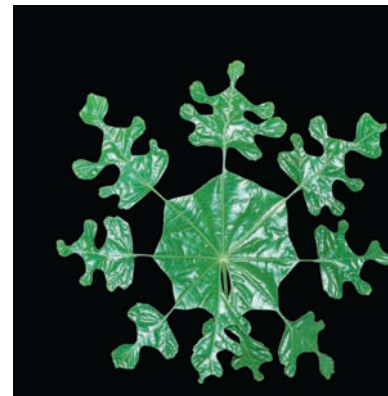
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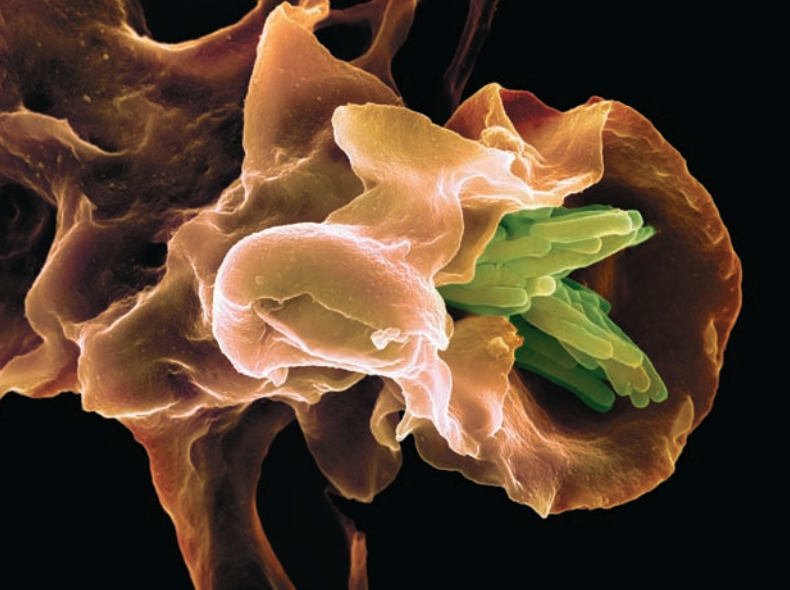
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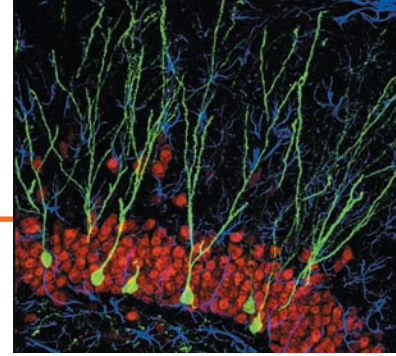
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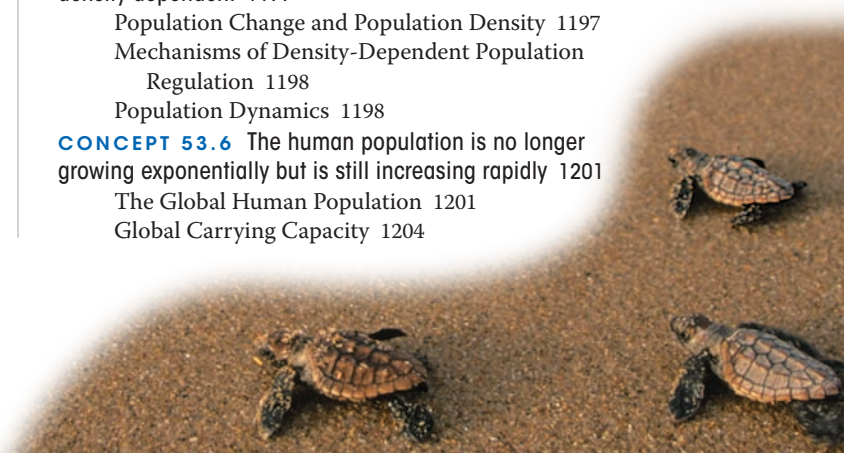
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1

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



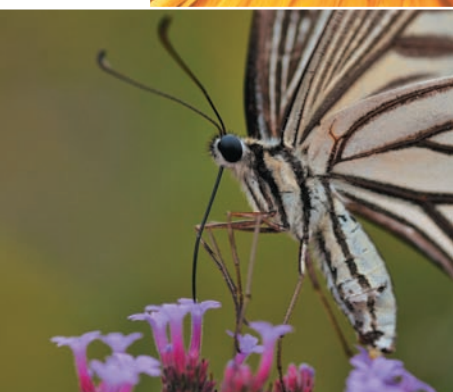
▼ **Order.** This close-up of a sunflower illustrates the highly ordered structure that characterizes life.



▲ **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

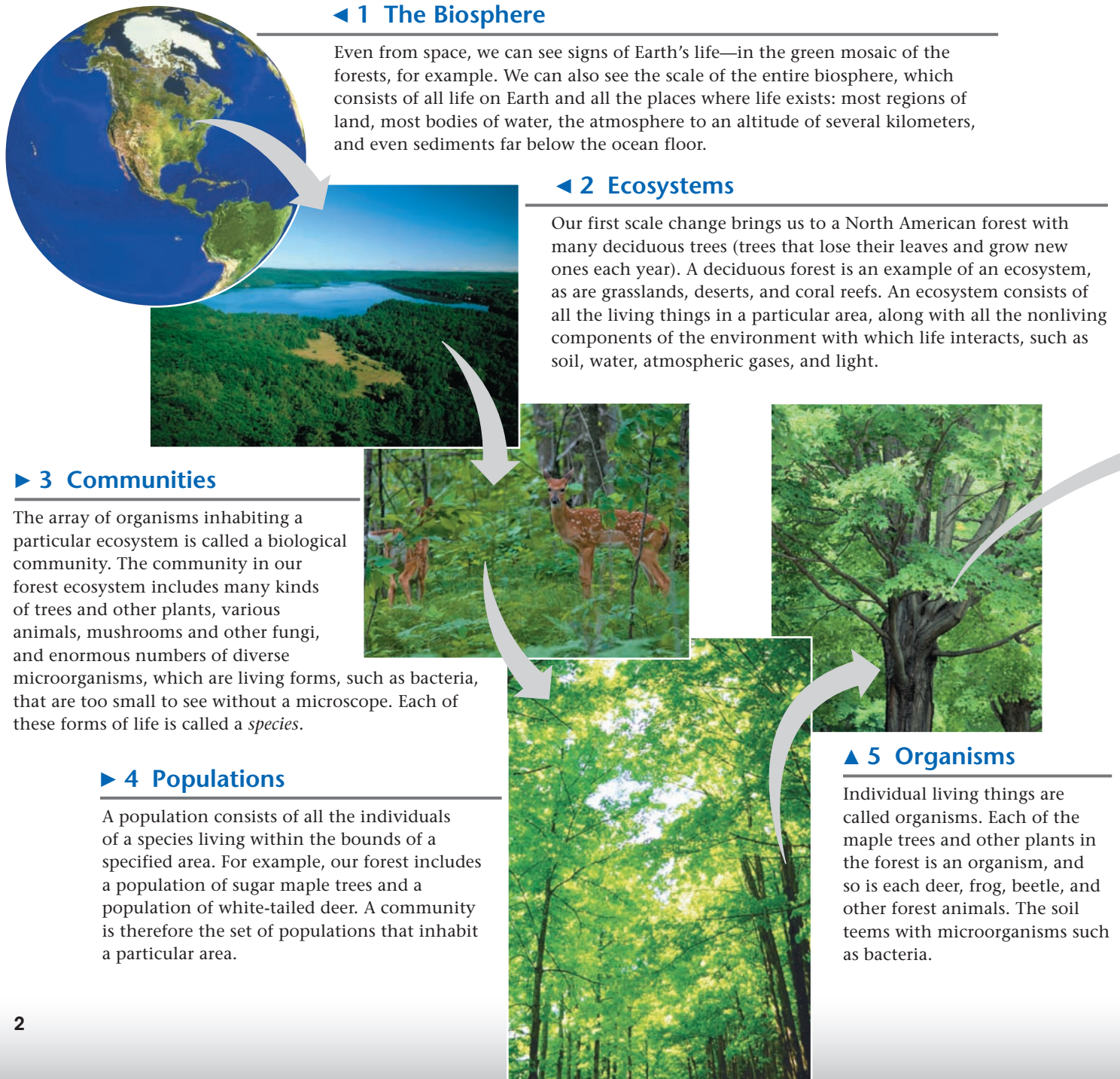
Biology is a subject of enormous scope, and exciting new biological discoveries are being made every day. How can you organize into a comprehensible framework all the information you'll encounter as you study the broad range of topics included in biology? Focusing on a few big ideas will

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



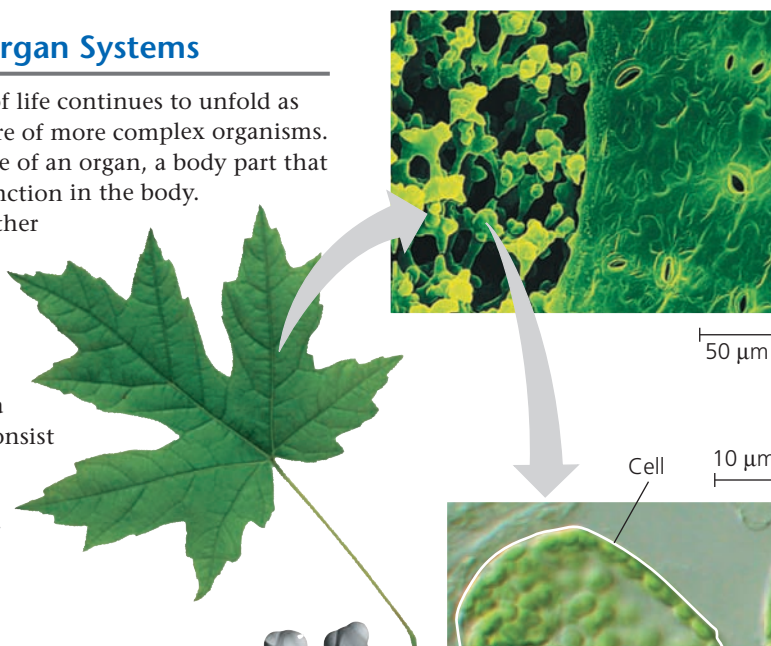
Theme: New Properties Emerge at Successive Levels of Biological Organization

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.

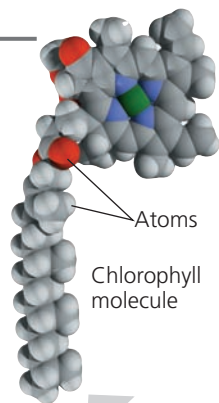


◀ 7 Tissues

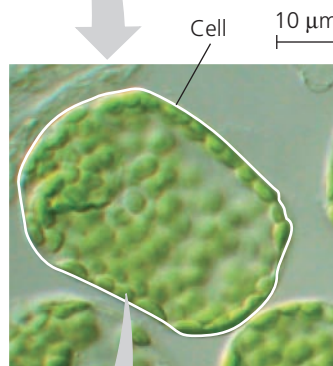
Viewing the tissues of a leaf requires a microscope. Each tissue is a group of cells that work together, performing a specialized function. The leaf shown here has been cut on an angle. The honeycombed tissue in the interior of the leaf (left side of photo) is the main location of photosynthesis, the 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.

▶ 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.



Chloroplast

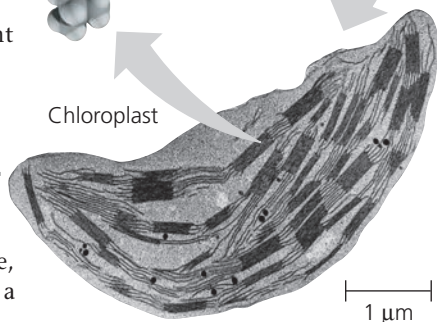


▲ 8 Cells

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.



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



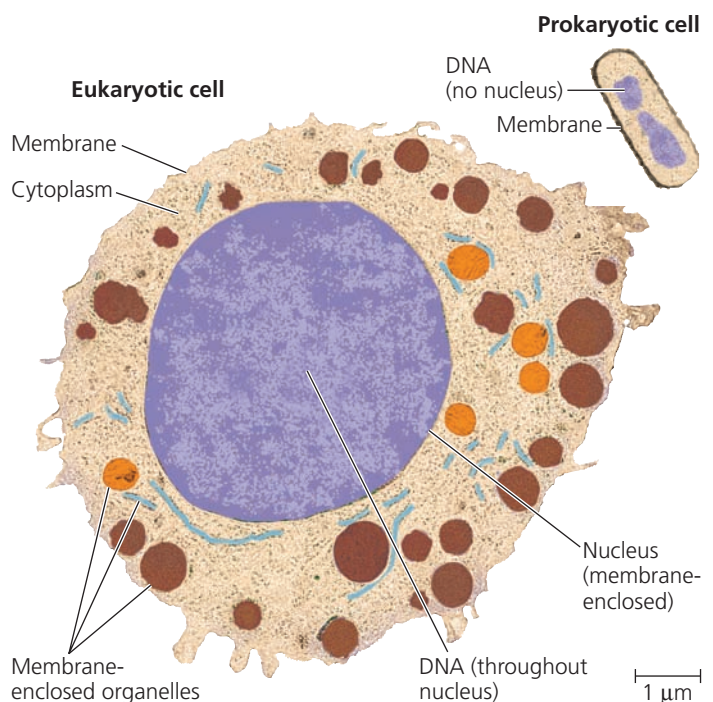
in place. While hovering, the birds can extend their long, slender beaks into flowers and feed on nectar. The elegant match of form and function in the structures of life is explained by natural selection, which we'll explore shortly.

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, *archaeon*)—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

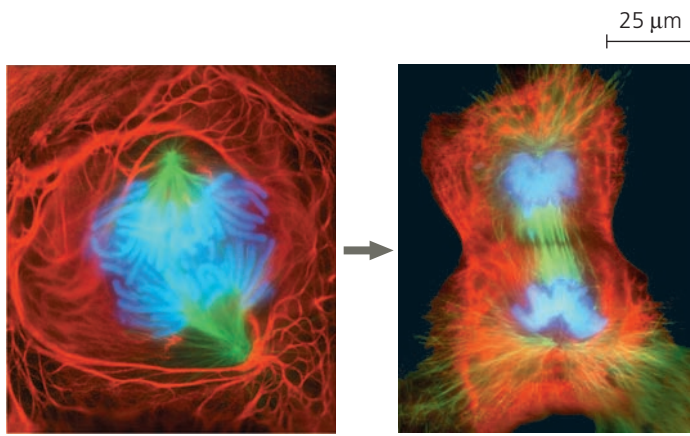


▲ **Figure 1.4** Contrasting eukaryotic and prokaryotic cells in size and complexity.

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**).

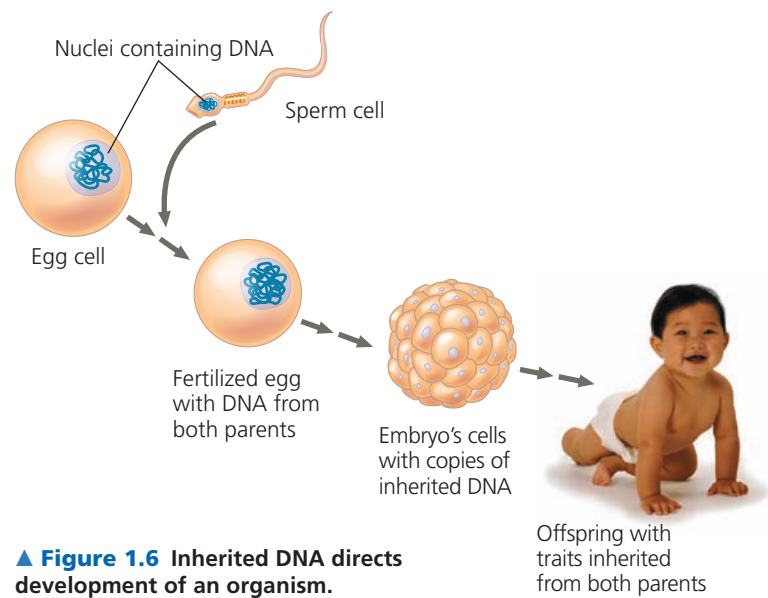


▲ **Figure 1.5** A lung cell from a newt divides into two smaller cells that will grow and divide again.

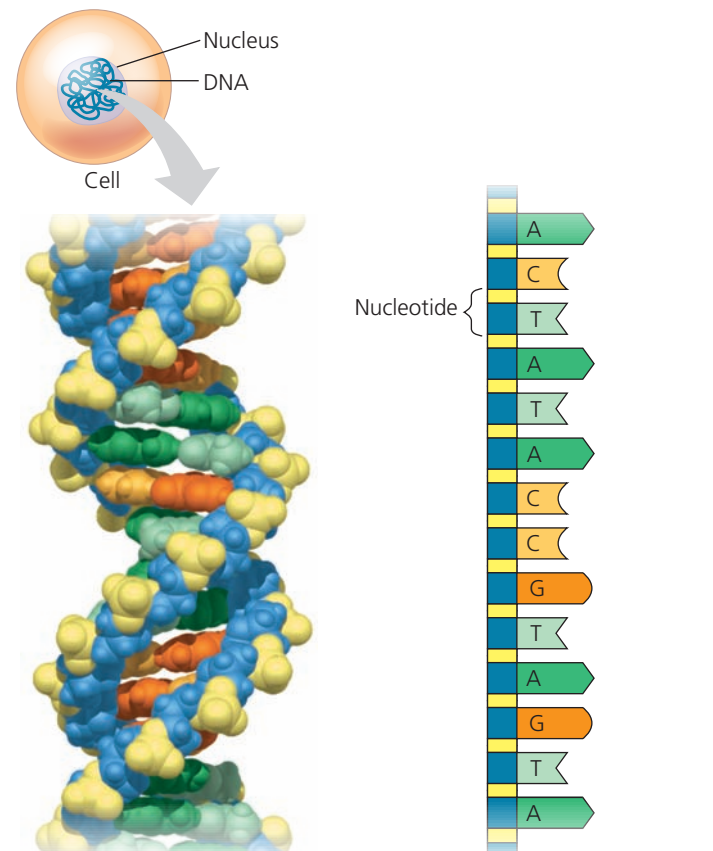
DNA, the Genetic Material

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.

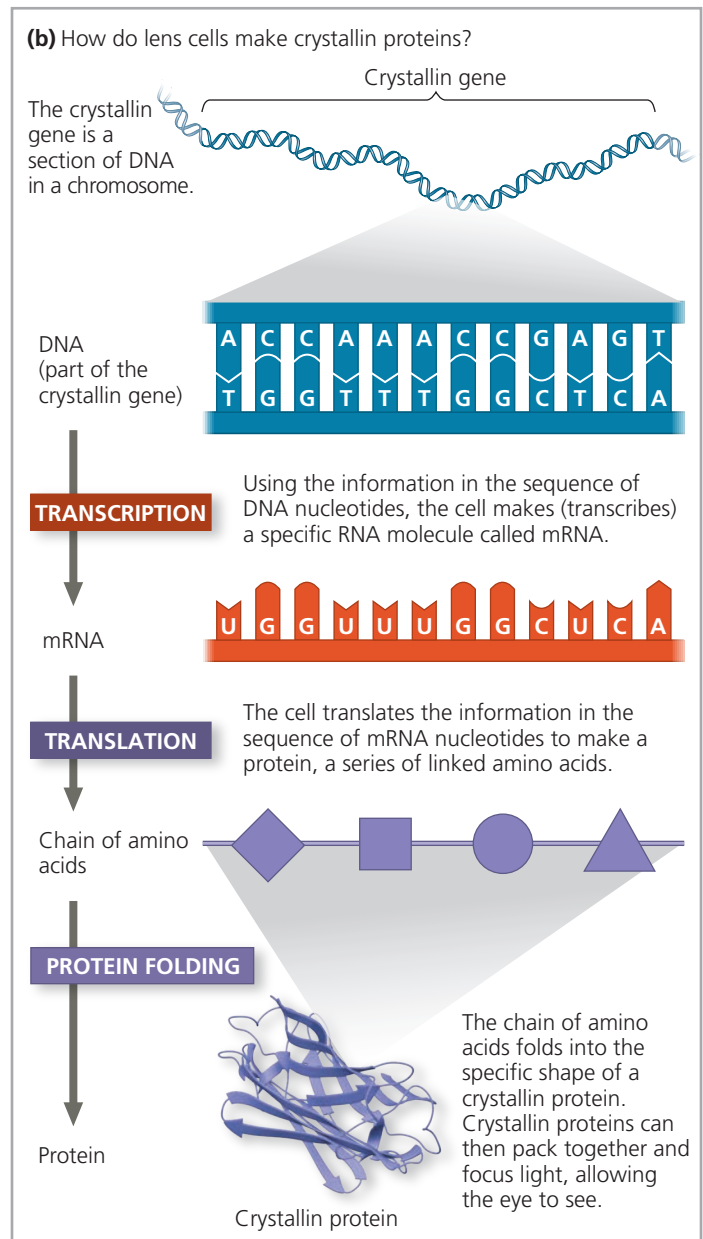
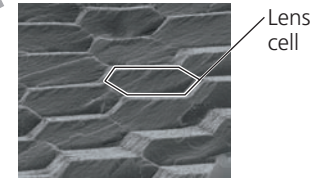
In addition to RNA molecules (called mRNAs) that are translated into proteins, some RNAs in the cell carry out other important tasks. For example, we have known for decades that some types of RNA are actually components of the cellular machinery that manufactures proteins. Recently, scientists have discovered 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.



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



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

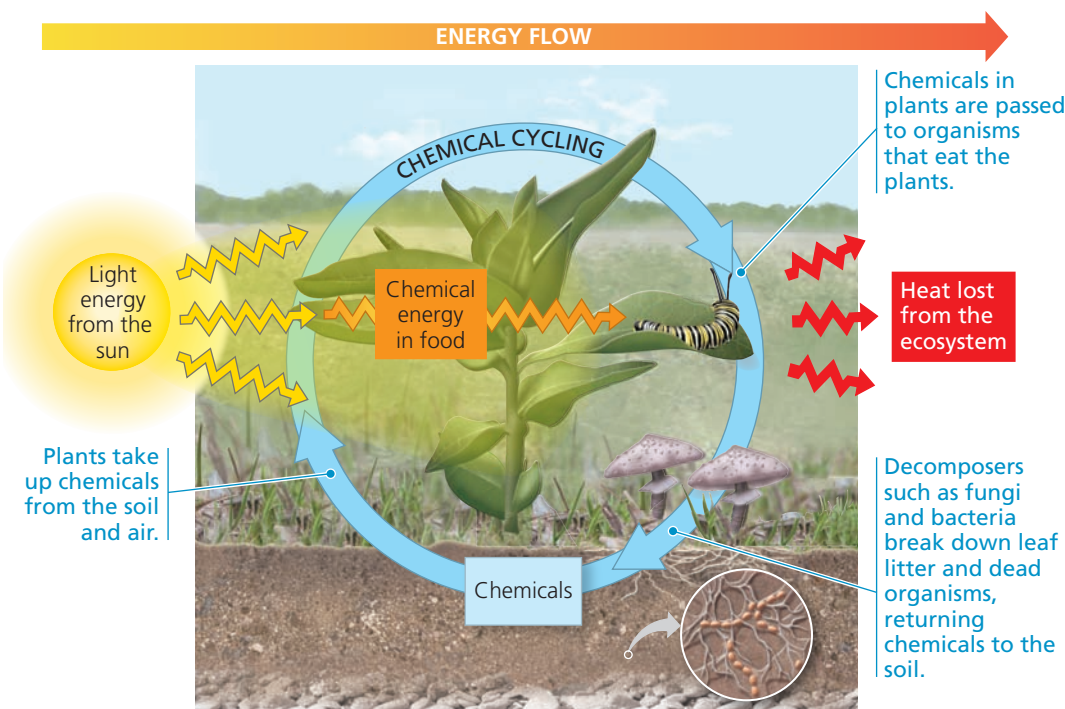
Since the early 1990s, the pace at which researchers can determine the sequence of a genome has accelerated at an astounding rate, enabled by a revolution in technology. The entire sequence of nucleotides in the human genome is now known, along with the genome sequences of many other organisms, including 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,

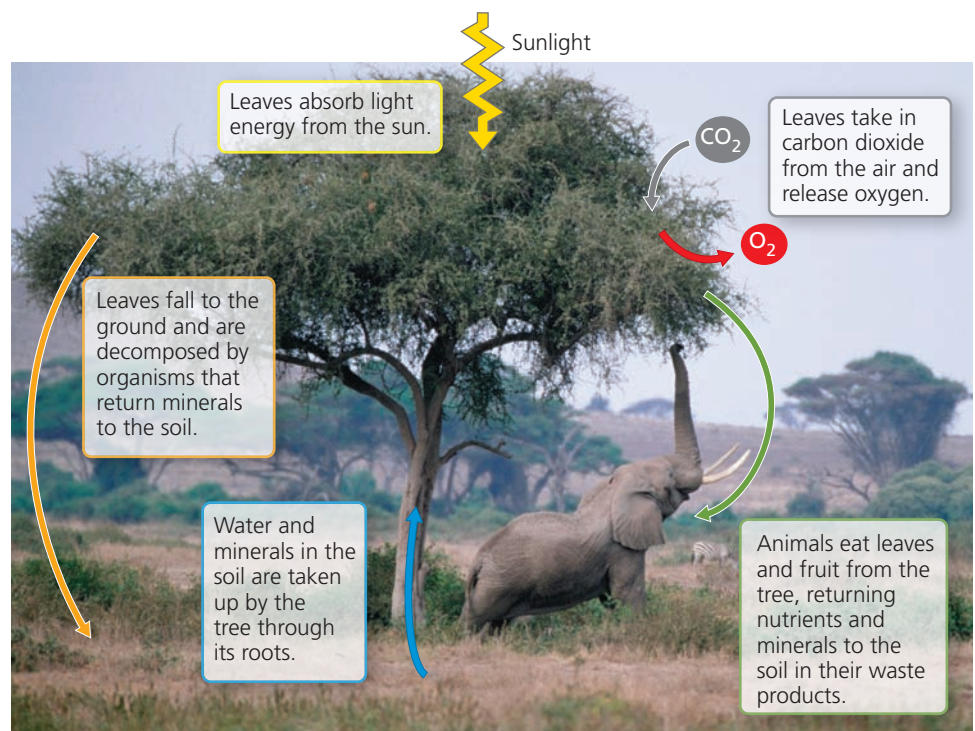
absorb light from the sun, take in carbon dioxide from the air, and release oxygen to the air (see Figure 1.10). The environment is also affected by the organisms living there. For instance, in addition to taking up water and minerals from the soil, the roots of a plant break up rocks as they grow, thereby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

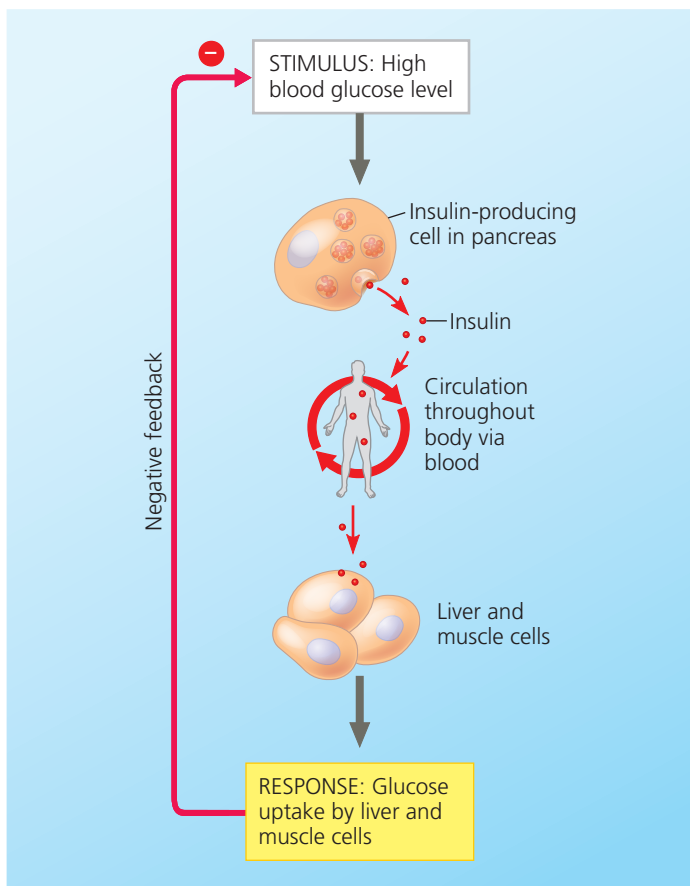
Molecules: Interactions Within Organisms

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

- 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.
- 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.
- WHAT IF?** For each theme discussed in this section, give an example not mentioned in the text.

For suggested answers, see Appendix A.