

CAMPBELL

# BIOLOGY

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THIRD CANADIAN EDITION



# About the Authors



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# Preface

We are honoured to present the Third Canadian Edition of *CAMPBELL BIOLOGY*. For the last three decades, *CAMPBELL BIOLOGY* has been the leading university text in the biological sciences. It has been translated into 19 languages and has provided millions of students with a solid foundation in university-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.

Our goals for the Third Canadian Edition include:

- **increasing visual literacy** through new figures, questions, and exercises that build students' skills in understanding and creating visual representations of biological structures and processes
- asking students to **practise scientific skills** by applying scientific skills to real-world problems
- **supporting instructors** by providing teaching modules with tools and materials for introducing, teaching, and assessing important and often challenging topics
- **integrating text and media** to engage, guide, and inform students in an active process of inquiry and learning

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

## New to This Edition

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

- **Visualizing Figures** and **Visual Skills Questions** give students practice in interpreting and creating visual representations in biology. The Visualizing Figures have embedded questions that guide students in exploring how diagrams, photographs, and models represent and reflect biological systems and processes. Assignable questions are also available in Mastering Biology to give students practice with the visual skills addressed in the figures.
- **Numeracy Questions** and **Problem-Solving Exercises** challenge students to apply scientific skills and interpret data in solving real-world problems. These



exercises are designed to engage students through compelling case studies and provide practice with data analysis skills. Problem-Solving Exercises have assignable versions in Mastering Biology. Some also have more extensive “Solve It” investigations to further explore a given topic.

- **Ready-to-Go Teaching Modules** on key topics provide instructors with assignments to use before and after class, as well as in-class activities that use clickers or Learning Catalytics™ for assessment.

- **Integrated text and media:** Media references in the printed book direct students to the wealth of online self-study resources available

to them in the Study Area section of Mastering Biology. In the eText, these resources are integrated directly into the eText. The new online learning tools include:

- **Figure Walkthroughs** that guide students through key figures with narrated explanations, figure markups, and questions that reinforce important points. Additional questions can be assigned in Mastering Biology.
- **Animations and videos** that bring biology to life. These include resources from **HHMI BioInteractive** that engage students in topics from the discovery of the double helix to evolution.
- **Interviews** from the First Edition through the Third Canadian Edition of Campbell BIOLOGY are referenced in the chapter where they are most relevant. The interviews show students the human side of science by featuring diverse scientists talking about how they became interested in what they study, how they began, and what inspires them.
- The impact of climate change at all levels of the biological hierarchy is explored throughout the text, starting with a new figure (Figure 1.12) and discussion in Chapter 1 and concluding with a new Unit 8 Make Connections Figure and expanded coverage on causes and effects of climate change in Chapter 56.
- As in each new edition of Campbell BIOLOGY, the Third Canadian Edition incorporates new content and pedagogical improvements. These are summarized on pp. vi–viii, following this Preface. Content updates reflect rapid, ongoing changes in technology and knowledge in the fields of genomics, gene editing technology (CRISPR), evolutionary biology, microbiology, and more. In addition, significant



revisions to Unit 8, Ecology, improve the conceptual framework for core ecological topics (such as population growth, species interactions, and community dynamics) and more deeply integrate evolutionary principles.

## 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. Chief among the themes of *CAMPBELL BIOLOGY* is **evolution**. Chapters throughout the text include at least one Evolution section that explicitly focuses on evolutionary aspects of the chapter material, and chapters end with an Evolution Connection Question and a Write about a Theme Question.

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

In an effort to act on the Calls to Action from the Truth and Reconciliation Commissioners’ Report (2012), the Canadian authors were committed to including more Indigenous content in this text. Pearson’s first step in this third Canadian edition is to acknowledge and highlight terminologies that come from Indigenous origins and include references to how Traditional Ecological Knowledge (TEK) is being used in Chapter 21 and 54. The authors recognize this is just the beginning in a long process of responding to Truth and Reconciliation with Indigenous Peoples of this land.

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 Visualizing Figures, our popular Exploring Figures and Make Connections Figures epitomize this approach. Each Exploring Figure is a learning unit of core content that brings together related illustrations and text. Make Connections Figures reinforce fundamental conceptual connections throughout biology, helping students overcome tendencies to compartmentalize information. The Third Canadian Edition features two new Make Connections Figures. There are also Guided Tour Figures that walk students through complex figures as an instructor would.

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 reading 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. The answers to most of these questions require students to write as well as think and thus help develop the core competency of communicating science.

Finally, *CAMPBELL BIOLOGY* has always featured **scientific inquiry**, an essential component of any biology course. Complementing stories of scientific discovery in the text narrative, the unit-opening interviews, and our standard-setting Inquiry Figures all deepen the ability of students to understand how we know what we know. Scientific Inquiry Questions give students opportunities to practise scientific thinking, along with the Problem-Solving Exercises, Scientific Skills Exercises, and Interpret the Data Questions. Together, these activities provide students practice both in applying the process of science and in using quantitative reasoning.

## Mastering Biology®

**Mastering Biology**, 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 Figure Walkthroughs, Problem-Solving Exercises, and Visualizing Figures**, Mastering Biology offers Dynamic Study Modules, Adaptive Follow-Up Assignments, Scientific Skills Exercises, Interpret the Data Questions, Solve It Tutorials, HHMI Bio-Interactive Short Films, BioFlix. Tutorials with 3-D Animations, Experimental Inquiry Tutorials, Interpreting Data Tutorials, BLAST Tutorials, Make Connections Tutorials, Get Ready for Biology, Activities, Reading Quiz Questions, Student Misconception Questions, and 4500 Test Bank Questions. Mastering Biology also includes the *CAMPBELL BIOLOGY* eText, Study Area, and Instructor Resources. Go to [www.masteringbiology.com](http://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. 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 forms 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 Fiona Rawle, Lead Author, at [fiona.rawle@utoronto.ca](mailto:fiona.rawle@utoronto.ca), and Cathleen Sullivan, Executive Acquisitions Editor, [cathleen.sullivan@pearsoned.com](mailto:cathleen.sullivan@pearsoned.com)

# New and Featured Content

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

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

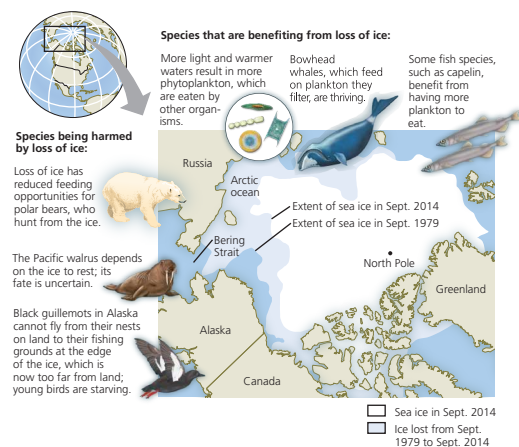
To help students focus on the big ideas of biology, we continue to emphasize five themes: Organization, Information, Energy and Matter, Interactions, and the core theme of Evolution. Chapter 1 opens with a new introduction to a case study about the Canadian Yew tree.

## UNIT 1 THE CHEMISTRY OF LIFE

In Unit 1, new content engages students in learning this foundational material. The new **Figure 3.7** shows organisms affected by **loss of Arctic sea ice**. Chapter 5 has updates on lactose intolerance, trans fats, the effects of diet on blood cholesterol, protein sequences and structures, and intrinsically disordered proteins. New Visualizing Figure 5.16 helps students understand various ways proteins are depicted. A new Problem-Solving Exercise engages students by having them compare DNA sequences in a case of possible fish fraud. Unit 1 also highlights research by the Department of Fisheries and Oceans,

discussion of Frances Oldham Kelsey and thalidomide, as well as work by Edward Fon and Kalle Gehring from McGill University on the structure of the parkin protein. A new interview featuring Roberta Hamme, from the University of Victoria, is also included.

**Figure 3.7** Effects of climate change on the Arctic.



## UNIT 2 THE CELL

Our main goal for this unit was to make the material more accessible and inviting to students. New Visualizing Figure 6.32 shows the profusion of molecules and structures in a cell, all drawn to scale. In Chapter 7, a new figure illustrates levels of LDL receptors in people with and without familial hypercholesterolemia. Chapter 8 includes a beautiful new photo of a geyser with thermophilic bacteria in Figure 8.17, bringing to life the graphs of optimal temperatures for enzyme function. Chapter 10 discusses current research trying to genetically modify rice (a C3 crop) so that it is capable of carrying out C4 photosynthesis to increase yields. Chapter 11 includes a new Problem-Solving Exercise that guides students through assessing possible new treatments for bacterial infections by

blocking quorum sensing. In Chapter 12, the mechanism of chromosome movement in bacteria has been updated and more cell cycle control checkpoints have been added, including one recently proposed by researchers. Unit 2 also features the identification of LHON mutations by Eric Shoubridge at McGill University; the International Cancer Genome Consortium, co-founded by Thomas Hudson, Scientific Director of the Ontario Institute of Cancer Research; and work on membrane proteins by Frances Sharom at the University of Guelph. A new interview featuring Jason Treberg, from the University of Manitoba, is also included.

## UNIT 3 GENETICS

In Chapters 13–17, we have incorporated changes that help students grasp the more abstract concepts of genetics and their chromosomal and molecular underpinnings. For example, a new Visual Skills Question with Figure 13.6 asks students to identify where in the three life cycles haploid cells undergo mitosis, and what type of cells are formed. Chapter 14 includes new information from a recent genomic study on the number of genes and genetic variants contributing to height. Chapters 14 and 15 are more inclusive, clarifying the meaning of the term “normal” in genetics and explaining that sex is no longer thought to be simply binary. Other updates in Chapter 15 include new research in sex determination and a technique being developed to avoid passing on mitochondrial diseases. New Visualizing Figure 16.7 shows students various ways that DNA is illustrated. To help students understand the Beadle and Tatum experiment, new Figure 17.2 explains how they obtained nutritional mutants. A new Problem-Solving Exercise asks students to identify mutations in the insulin gene and predict their effect on the protein. Chapters 18–21 are extensively updated, driven by exciting new discoveries based on DNA sequencing and gene-editing technology. Chapter 18 has updates on histone modifications, nuclear location and the persistence of transcription factories, chromatin remodelling by ncRNAs, long noncoding RNAs (lncRNAs), the role of master regulatory genes in modifying chromatin structure, and the possible role of p53 in the low incidence of cancer in elephants. Make Connections Figure 18.27, “Genomics, Cell Signalling, and Cancer,” has been expanded to include more information on cell signaling. Chapter 19 expands the section that covers bacterial defences against bacteriophages and describes the CRISPR-Cas9 system (Figure 19.8); updates include the Ebola, Chikungunya, and Zika viruses (Figure 19.12) and discovery of the largest virus known to date. A discussion has been added of mosquito transmission of diseases and concerns about the effects of global climate change on disease transmission. In Chapter 21, in addition to the usual updates of sequence-related data (speed of sequencing, number of species’ genomes sequenced, etc.), there are several research updates, including some early results from the new Roadmap Epigenomics Project and results from a 2015 study focusing on 414 important yeast genes.

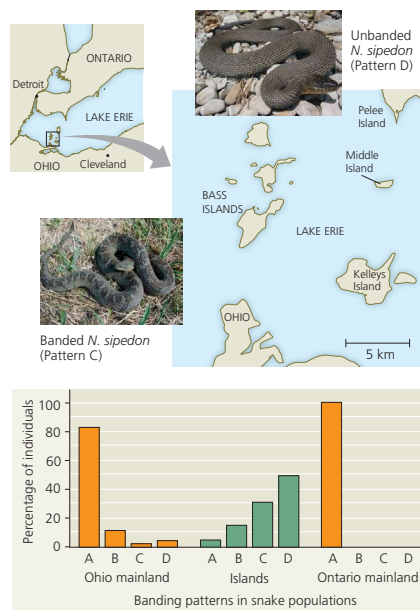
Unit 3 also features the work of Stephen Scherer, who produced a detailed annotated map and DNA sequence of human chromosome 7; Calvin Harley and the discovery of telomeres; Michael Houghton, whose research team recently developed a vaccine for the hepatitis C virus at the University of Alberta; the

Michael Smith Genome Sciences Centre in Vancouver, which generated the first genome sequence of SARS; Frank Plummer at the National Microbiology Laboratory in Winnipeg, whose team sequenced the full genome of H1N1 flu samples; James Till and Ernest McCulloch, the Canadian scientists who discovered stem cells; and Michael Rudnicki, who led the team that discovered adult muscle stem cells at the Sprott Centre for Stem Cell Research in Ottawa. In addition, a range of genomics research in Canada is featured in the updated Exploring Figure 21.6. A new interview featuring Julie Claycomb, from the University of Toronto, is also included.

## UNIT 4 MECHANISMS OF EVOLUTION

A major goal for this revision was to strengthen how we help students understand and interpret visual representations of evolutionary data and concepts. Toward this end, we have added a new figure (Figure 25.8), “Visualizing the Scale of Geologic Time,” and a new figure (Figure 23.11) on gene flow. Several figures have been revised to improve the presentation of data, including Figure 24.6 (on reproductive isolation in mosquitofish), Figure 24.10 (on allopolyploid speciation), and Figure 25.26 (on the origin of the insect body plan). A new Problem-Solving Exercise is included in Chapter 24 on how hybridization may have led to the spread of insecticide resistance genes in mosquitoes that transmit malaria. The unit also includes new chapter opening stories in Chapter 22 (expanding on the evolution of the bombardier beetle defence mechanism) and Chapter 23 (on the Vancouver Island marmot and population change over time). Additional changes include new text in Concept 22.3 emphasizing how populations can evolve over short periods of time, a new table (Table 23.1) highlighting the five conditions required for a population to be in Hardy-Weinberg equilibrium, and new material in Concept 25.1 describing how researchers recently succeeded for the first time in constructing a “protocell” in which replication of a template strand of RNA could occur. Unit 4 includes updated data on MRSA incidence at Canadian hospitals, and profiles the research of Darla Zelenitsky at the University of Calgary on the discovery of a winged dinosaur with feathers in the Badlands of Alberta, the research of Hans Larsson from McGill University on phenotype plasticity in tetrapods, and the research of Charles Henderson and others who pinpointed the end-Permian mass extinction. A new interview featuring Maydianne Andrade, from the University of Toronto Scarborough, is also included.

▼ **Figure 23.11 Gene flow and local adaptation in the Lake Erie water snake (*Nerodia sipedon*).**



## UNIT 5 THE EVOLUTIONARY HISTORY OF BIOLOGICAL DIVERSITY

In keeping with our goal of improving how students interpret and create visual representations in biology, we have added a new figure (Figure 26.6, “Visualizing Phylogenetic Relationships”) that introduces the visual conventions used in phylogenetic trees and helps students understand what such trees do and don’t convey. Students are also provided many opportunities to practise their visual skills, with more than ten new Visual Skills Questions on topics ranging from interpreting phylogenetic trees to predicting which regions of a bacterial flagellum are hydrophobic. The unit also contains new content on tree thinking, emphasizing such key points as how sister groups provide a clear way to describe evolutionary relationships and how trees do not show a “direction” in evolution. Other major content changes include new text in Concepts 26.6, 27.4, and 28.1 on the 2015 discovery of the Lokiarchaeota, a group of archaea that may represent the sister group of the eukaryotes, new text and a new figure (Figure 26.22) on horizontal gene transfer from prokaryotes to eukaryotes, new text in Concept 27.6 describing the CRISPR-Cas9 system and a new figure (Figure 27.22) that illustrates one example of how CRISPR-Cas 9 technology has opened new avenues of research on HIV, and new material in Concept 29.3 describing how early forests contributed to global climate change (in this case, global cooling). A new Problem-Solving Exercise in Chapter 34 engages students in interpreting data from a study investigating whether frogs can acquire resistance to a fungal pathogen through controlled exposure to it. Other updates include the revision of many phylogenies to reflect recent phylogenomic data, new chapter-opening stories in Chapter 28 (on the role of heterotrophy in establishing endosymbioses), Chapter 31 (on how mycorrhizae link trees of different species on the importance of yeast in creating ethanol, an important biofuel.) and Chapter 33 (on the visual perception by the eyes of the blue-eyed scallop). There is also new text and a new figure (Figure 34.38) on the adaptations of the kangaroo rat to its arid environment, and new material in Concept 34.7, including a new figure (Figure 34.52) describing fossil and DNA evidence indicating that humans and Neanderthals interbred, producing viable offspring. The discussion of human evolution also includes new text and a new figure (Figure 34.54) on *Homo naledi*, the most recently discovered member of the human evolutionary lineage. This unit also highlights research on mycorrhizal networks by Suzanne Simard at the University of British Columbia; research on early eukaryotic evolution by Patrick Keeling at the University of British Columbia; data from COSEWIC (Committee on the Status of Endangered Wildlife in Canada), a profile of the Banff spring snail, and endangered species; the Hydrocarbon Metagenome projects run out of the University of Calgary and the University of Alberta, and the Wildlife DNA Forensic

▼ **Figure 34.54 Fossils of hand bones and foot bones (top and side views) of *Homo naledi*.**





Laboratory at Trent University. A new interview featuring Laura Hug, from the University of Waterloo, is also included.

## UNIT 6 PLANT FORM AND FUNCTION

A major aim in revising Chapter 35 was to help students better understand how primary and secondary growth are related. New Visualizing Figure 35.11 enables students to picture growth at the cellular level. Also, the terms protoderm, procambium, and ground meristem have been introduced to underscore the transition of meristematic to mature tissues. A new flowchart (Figure 35.24) summarizes growth in a woody shoot. New text and a figure (Figure 35.26) focus on genome analysis of *Arabidopsis* ecotypes, relating plant morphology to ecology and evolution. In Chapter 36, new Figure 36.8 illustrates the fine branching of leaf veins, and information on phloem-xylem water transfer has been updated. New Make Connections Figure 37.10 highlights mutualism across kingdoms and domains. Figure 37.13 and the related text include new findings on how some soil nitrogen derives from weathering of rocks. New Figure 38.3 clarifies how the terms *carpel* and *pistil* are related. The text on flower structure and the angiosperm life cycle figure identify carpels as megasporophylls and stamens as microsporophylls, correlating with the plant evolution discussion in Unit 5. In Concept 38.3, the current problem of glyphosate-resistant crops is discussed in detail. A revised Figure 39.7 helps students visualize how cells elongate. Figure 39.8 now addresses apical dominance in a Guided Tour format. Information about the role of sugars in controlling apical dominance has been added. In Concept 39.4, a new Problem-Solving Exercise highlights how global climate change affects crop productivity. Figure 39.26 on defence responses against pathogens has been simplified and improved.

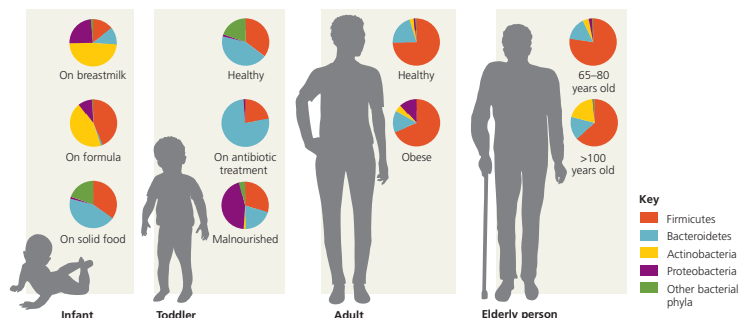
Amongst others, we highlight the work of Rob Guy at the University of British Columbia on balsam poplar trees; Doug Larson at the University of Guelph on cedars growing out of the rock face of the Niagara Escarpment; R. Keith Downey at the Ministry of Agriculture in Saskatoon and Baldur Stefansson at the University of Manitoba in Winnipeg on canola oil, and Mark Belmonte at the University of Manitoba on disease resistance in plants. An Inquiry Figure features the work of Bruce Greenberg and Bernie Glick at the University of Waterloo on the possible effects of soil bacteria. A new interview featuring Jacqueline Monaghan, from Queen's University, is also included.

## UNIT 7 ANIMAL FORM AND FUNCTION

A major goal of the Unit 7 revision was to transform how students interact with and learn from representations of anatomy and physiology. For example, gastrulation is now introduced with a Visualizing Figure (Figure 47.8) that provides a clear and carefully paced introduction to three-dimensional processes that may be difficult for students to grasp. In addition, a number of the new and revised figures help students explore spatial relationships in anatomical contexts, such as the interplay of lymphatic and cardiovascular circulation (Figure 42.15) and the relationship of the limbic system to overall brain structure (Figure 49.14). A new Problem-Solving Exercise in Chapter 45 taps into student interest in medical mysteries through a case study that explores the science behind laboratory testing and diagnosis. Content updates help students appreciate the continued evolution of our understanding of even familiar phenomena, such as the evolution of hemoglobin in high altitude

animals (Concept 42.7), the sensation of thirst (Concept 44.4) and the locomotion of kangaroos and jellies (Concept 50.6). Furthermore, new text and figures introduce students to cutting-edge technology relating to such topics as RNA-based antiviral defence in invertebrates (Figure 43.4) and rapid, comprehensive characterization of viral exposure (Figure 43.24), as well as recent discoveries regarding brown fat in adult humans (Figure 40.14), the microbiome (Figure 41.18), parthenogenesis (Concept 46.1), and magnetoreception (Concept 50.1). As always, there is fine-tuning of pedagogy, as in discussions of the complementary roles of inactivation and voltage gating of ion channels during action potential formation (Concept 48.3) and of the experimental characterization of genetic determinants in bird migration (Figure 51.24). Additional research highlighted in this unit includes Janet Rossant at the University of Toronto on cell fate determination; Naweel Syed at the University of Calgary on synaptic repair; University of British Columbia researchers exploring the impact of global warming trends on salmon; University of Manitoba explores the evolution of the thermogenin gene in mammals; Karen Kidd at the University of New Brunswick on environmental estrogens; Barrie Frost of Queen's University, who explored the navigational mechanisms used by monarch butterflies; and Suzie Currie of Mount Allison University on phenotypic plasticity and environmental stress. A new interview featuring Matt Vijayan, from the University of Calgary, is also included.

### ▼ Figure 41.18 Variation in human gut microbiome at different life stages.



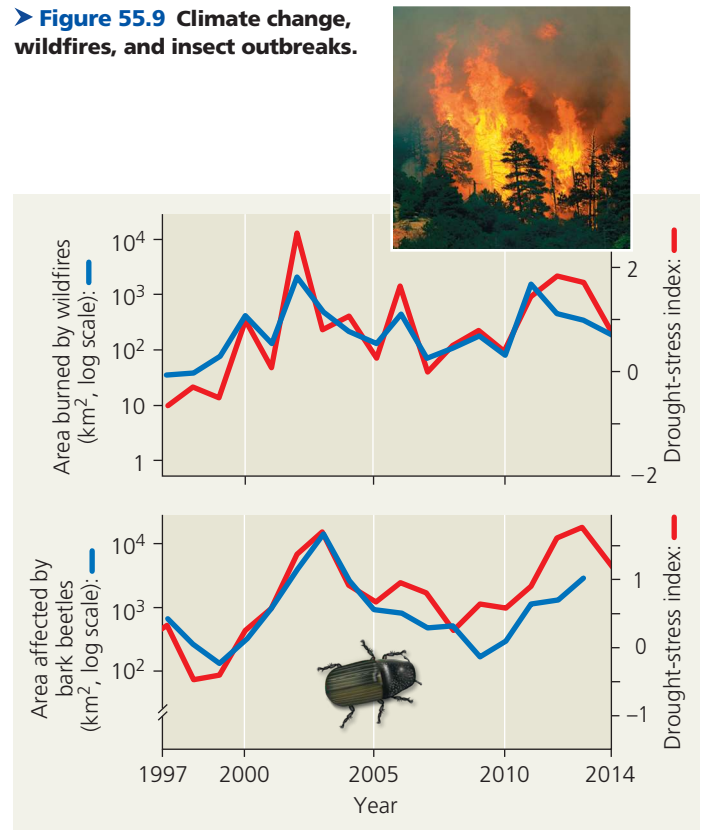
## UNIT 8 ECOLOGY

The Ecology Unit has been extensively revised for the Third Canadian Edition. We have reorganized and improved the conceptual framework with which students are introduced to the following core ecological topics: life tables, per capita population growth, intrinsic rate of increase ( $r$ ), exponential population growth, logistic population growth, density dependence, species interactions (in particular, parasitism, commensalism, and mutualism), and MacArthur and Wilson's island biogeography model. The revision also includes a deeper integration of evolutionary principles, including a new Key Concept (52.5) and two new figures (Figures 52.20 and 52.21) on the reciprocal effects of ecology and evolution, new material in Concept 52.4 on how the geographic distributions of species are shaped by a combination of evolutionary history and ecological factors, and five new Make Connections Questions that ask students to examine how ecological and evolutionary mechanisms interact. In keeping with our goal of expanding and strengthening our coverage of climate change, we have added a new discussion and a new figure (Figure 52.20) on how climate change has



affected the distribution of a keystone species, a new section of text in Concept 55.2 on how climate change affects NPP, a new figure (**Figure 55.9**) on how climate change has caused an increase in wildfires and insect outbreaks, a new Problem-Solving Exercise in Chapter 55 that explores how insect outbreaks induced by climate change can cause an ecosystem to switch from a carbon sink to a carbon source, a new figure (Figure 56.29) on the greenhouse effect, new text in Concept 56.4 on biological effects of climate change, and a new Unit 8 Make Connections Figure on how climate change affects all levels of biological organization. Additional updates include a new figure (Figure 53.26) on per capita ecological footprints, a new chapter-opening story in Chapter 54 on a seemingly unlikely mutualism between a shrimp and a much larger predatory fish, new text in Concept 54.1 emphasizing that each partner in a mutualism experiences both benefits and costs, new text in Concept 54.1 describing how the outcome of an ecological interaction can change over time, two new figures (Figures 54.29 and 54.30) on the island equilibrium model, a new figure (Figure 54.31) documenting two shrew species as unexpected hosts of the Lyme disease, new text in Concept 56.1 comparing extinction rates today with those typically seen in the fossil record, and a new discussion and figure (Figure 56.20) on the restoration of a degraded urban stream. Unit 8 also profiles the research of David Schindler from the University of Alberta, and Verena Tunnicliffe from the University of Victoria. A new interview featuring Erin Bertrand, from Dalhousie University, is also included. The book ends on a hopeful note, charging students to use biological knowledge to help solve problems and improve life on Earth.

► **Figure 55.9** Climate change, wildfires, and insect outbreaks.



# 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.

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



A Figure 44.1 How does an albatross drink salt water without ill effect?

### KEY CONCEPTS

- 44.1 Osmoregulation balances the uptake and loss of water and solutes
- 44.2 An animal's nitrogenous wastes reflect its phylogeny and habitat
- 44.3 Diverse excretory systems are variations on a tubular theme
- 44.4 The nephron is organized for stepwise processing of blood filtrate
- 44.5 Hormonal circuits link kidney function, water balance, and blood pressure

### A Balancing Act

Seabirds, such as the wandering albatross (*Diomedea exulans*) (Figure 44.1), spend most of their lives living near the ocean, eating marine organisms, and drinking seawater. Birds and reptiles have evolved unique adaptations that permit them to tolerate a high-salt diet and maintain the osmolarity of the fluids in a range similar to your own. In addition, ions that are abundant in seawater, such as sodium and calcium, must be eliminated to maintain their internal levels within a range that permits normal function of muscles, neurons, and other cells of the body. Homeostasis thus requires **osmoregulation**, the general term for the processes by which animals control solute concentrations and balance water gain and loss.

A number of mechanisms for water and solute control have arisen during evolution, reflecting the varied and often severe osmoregulatory challenges presented by an animal's surroundings. The arid environment of a desert, for instance, can quickly deplete an animal of body water. Despite a quite different environment, marine animals also face potential dehydration. The success of animals in an ocean environment depends critically on conserving water and, for marine birds and fishes, eliminating excess salts. In contrast, freshwater animals live in an environment that threatens to flood and dilute their body fluids. These organisms survive by conserving solutes and absorbing salts from their surroundings.

In safeguarding their internal fluid environment, animals must also deal with a hazardous metabolite produced by the



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**.

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

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

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

### CONCEPT CHECK 44.5

1. How does alcohol affect regulation of water balance in the body?
2. Why could it be dangerous to drink a very large amount of water in a short period of time?
3. **WHAT IF?** > Conn's syndrome is a condition caused by tumours of the adrenal cortex that secrete high amounts of aldosterone in an unregulated manner. What would you expect to be the major symptom of this disorder?

For suggested answers, see Appendix A.

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

## 4.4 Chapter Review

### SUMMARY OF KEY CONCEPTS

#### CONCEPT 44.1 Osmoregulation balances the uptake and loss of water and solutes (pp. 2–6)

Animal	Inflow/Outflow	Urine
<b>Freshwater fish.</b> Lives in water less concentrated than body fluids; fish tends to gain water, lose salt.	Does not drink water Salt in (active transport by gills) H <sub>2</sub> O in	Large volume of urine Urine is less concentrated than body fluids
<b>Marine bony fish.</b> Lives in water more concentrated than body fluids; fish tends to lose water, gain salt.	Drinks water Salt in H <sub>2</sub> O out Salt out (active transport by gills)	Small volume of urine Urine is slightly less concentrated than body fluids
<b>Terrestrial vertebrate.</b> Terrestrial environment; terrestrial animals tend to lose body water to air.	Drinks water Salt in (by mouth)	Moderate volume of urine Urine is more concentrated than body fluids

#### CONCEPT 44.2 An animal's nitrogenous wastes reflect its phylogeny and habitat (pp. 6–8)

- Protein and nucleic acid metabolism generates **ammonia**. Most aquatic animals excrete ammonia. Mammals and most adult amphibians convert ammonia to the less toxic **urea**, which is excreted with a minimal loss of water. Insects and many reptiles, including birds, convert ammonia to **uric acid**, a mostly insoluble waste excreted in a paste-like urine.
- The kind of nitrogenous waste excreted depends on an animal's evolutionary history and habitat. The amount of nitrogenous waste produced is coupled to the animal's energy budget and amount of dietary protein.

**DRAW IT** Construct a table summarizing the three major types of nitrogenous wastes and their relative toxicity, energy content, and associated water loss during excretion.

#### CONCEPT 44.3 Diverse excretory systems are variations on a tubular theme (pp. 8–11)

- Most excretory systems carry out **filtration**, **reabsorption**, **secretion**, and **excretion**. The **protonephridia** of the flatworm flame bulb excrete a dilute **filtrate**. An earthworm has pairs of open-ended **metanephridia** in each segment that produce urine. In insects, **Malpighian tubules** function in osmoregulation and removal of nitrogenous wastes. **Kidneys** function in both excretion and osmoregulation in vertebrates.
- Excretory tubules (consisting of **nephrons** and **collecting ducts**) and blood vessels pack the mammalian kidney. Blood pressure forces fluid from blood in the **glomerulus** into the lumen of **Bowman's capsule**. Following reabsorption and secretion, filtrate flows into a collecting duct. The **ureter** conveys urine from the **renal pelvis** to the **urinary bladder**.

**?** Given that a typical excretory system selectively absorbs and secretes materials, what function does filtration serve?

#### CONCEPT 44.4

**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 Mastering Biology® are also categorized by Bloom's Taxonomy.

**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:

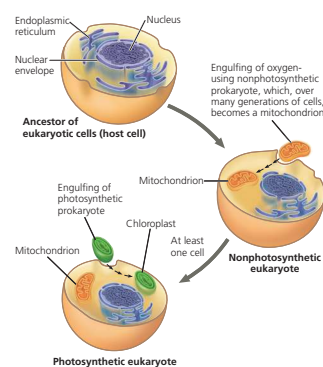
- Evolution
- Organization
- Information
- Energy and Matter
- Interactions

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

### EVOLUTION

Mitochondria and chloroplasts display similarities with bacteria that led to the **endosymbiont theory** illustrated in **Figure 6.16**. This theory, proposed by the Russian botanist Konstantin Mereschkowski and supported extensively with experiments conducted by American Lynn Margulis, states that an early ancestor of eukaryotic cells engulfed an oxygen-using nonphotosynthetic prokaryotic cell. Eventually, the engulfed cell formed a relationship with the host cell in which it was enclosed, becoming an **endosymbiont** (a cell living within another cell). Indeed, over the course of evolution, the host cell and its endosymbiont merged into a single organism, a eukaryotic cell with a mitochondrion. At least one of these cells may have then taken up a photosynthetic prokaryote, becoming the ancestor of eukaryotic cells that contain chloroplasts.

This is a widely accepted theory, which we will discuss in more detail in Concept 25.3. This theory is consistent with structural features of mitochondria and chloroplasts. First, rather than being bounded by a single membrane like organelles of an endomembrane system, mitochondria and typical chloroplasts have two membranes surrounding them. (Chloroplasts also have an internal system of membranous sacs.) There is evidence that



into the **renal medulla**, whereas mammals in moist habitats have shorter loops and excrete more dilute urine.

**?** How do cortical and juxtamedullary nephrons differ with respect to reabsorbing nutrients and concentrating urine?

#### CONCEPT 44.5 Hormonal circuits link kidney function, water balance, and blood pressure (pp. 18–20)

- The posterior pituitary gland releases **antidiuretic hormone (ADH)** when blood osmolarity rises above a set point, such as when water intake is inadequate. ADH increases permeability to water in collecting ducts through an increase in the number of epithelial water channels. When blood pressure or blood volume in the afferent arteriole drops, the **juxtaglomerular apparatus (JGA)** releases renin. **Angiotensin II** formed in response to renin constricts arterioles and triggers release of the hormone **aldosterone**, raising blood pressure and reducing the release of renin. The **renin-angiotensin-aldosterone system (RAAS)** has functions that overlap with those of ADH and are opposed to **atrial natriuretic peptide (ANP)**.

**?** Why can only some patients with diabetes insipidus be treated effectively with ADH?

### TEST YOUR UNDERSTANDING

#### Level 1: Knowledge/Comprehension

- Unlike an earthworm's metanephridia, a mammalian nephron (A) is intimately associated with a capillary network. (B) forms urine by changing fluid composition inside a tubule. (C) functions in both osmoregulation and excretion. (D) receives filtrate from blood instead of coelomic fluid.
- Which process in the nephron is *least* selective? (A) filtration (B) reabsorption (C) active transport (D) secretion
- Which of the following animals generally has the lowest volume of urine production? (A) a vampire bat (B) a salmon in freshwater (C) a marine bony fish (D) a freshwater bony fish

#### Level 2: Application/Analysis

- The high osmolarity of the renal medulla is maintained by all of the following *except* (A) diffusion of salt from the thin segment of the ascending limb of the loop of Henle. (B) active transport of salt from the thick segment of the ascending limb. (C) the spatial arrangement of juxtamedullary nephrons. (D) diffusion of salt from the descending limb of the loop of Henle.
- Natural selection should favor the highest proportion of juxtamedullary nephrons in which of the following species? (A) a river otter (B) a mouse species living in a tropical rain forest (C) a mouse species living in a temperate broadleaf forest (D) a mouse species living in a desert
- African lungfish, which are often found in small, stagnant pools of freshwater, produce urea as a nitrogenous waste. What is the advantage of this adaptation? (A) Urea takes less energy to synthesize than ammonia. (B) Small, stagnant pools do not provide enough water to dilute the toxic ammonia. (C) The highly toxic urea makes the pool uninhabitable to potential competitors. (D) Urea forms an insoluble precipitate.

22 UNIT SEVEN Animal Form and Function

#### Level 3: Synthesis/Evaluation

**7. INTERPRET THE DATA** Use the data below to draw four pie charts for water gain and loss in a kangaroo rat and a human.

	Kangaroo Rat	Human
<b>Water Gain (mL)</b>		
Ingested in food	0.2	750
Ingested in liquid	0	1500
Derived from metabolism	1.8	250
<b>Water Loss (mL)</b>		
Urine	0.45	1500
Feces	0.09	100
Evaporation	1.46	900

Which routes of water gain and loss make up a much larger share of the total in a kangaroo rat than in a human?

**8. EVOLUTION CONNECTION** Merriam's kangaroo rats (*Dipodomys merriami*) live in North American habitats ranging from moist, cool woodlands to hot deserts. Assuming that natural selection has resulted in differences in water conservation between *D. merriami* populations, propose a hypothesis concerning the relative rates of evaporative water loss by populations that live in moist versus dry environments. Using a humidity sensor to detect evaporative water loss by kangaroo rats, how could you test your hypothesis?

**9. SCIENTIFIC INQUIRY** You are exploring kidney function in kangaroo rats. You measure urine volume and osmolarity, as well as the amount of chloride (Cl<sup>-</sup>) and urea in the urine. If the water source provided to the animals were switched from tap water to a 2% NaCl solution, what change in urine osmolarity would you expect? How would you determine if this change was more likely due to a change in the excretion of Cl<sup>-</sup> or urea?

**10. WRITE ABOUT A THEME: ORGANIZATION** In a short essay (100–150 words), compare how membrane structures in the loop of Henle and collecting duct of the mammalian kidney enable water to be recovered from filtrate in the process of osmoregulation.

#### 11. SYNTHESIZE YOUR KNOWLEDGE



For selected answers, see Appendix A.

For additional practice questions, check out the **Dynamic Study Modules** in MasteringBiology. You can use them to study on your smartphone, tablet, or computer anytime, anywhere!

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

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



# Build Visual Skills

**NEW! Visualizing Figures** teach students how to interpret diagrams and models in biology. Embedded questions give students practice applying visual skills as they read the figure.

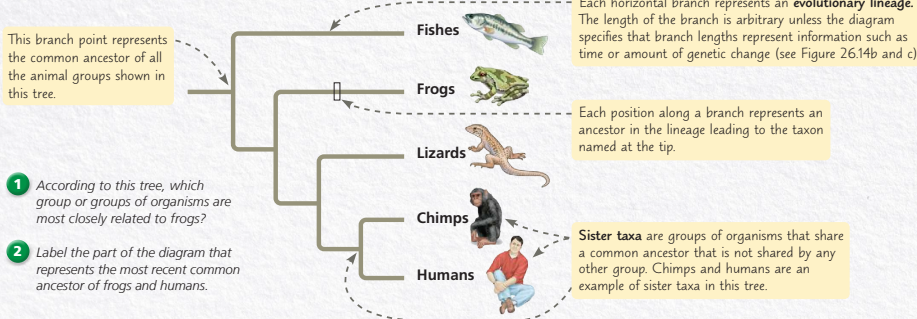
For more practice, each Visualizing Figure is accompanied by an automatically graded assignment in Mastering Biology with feedback for students.

## Figure 26.6 Visualizing Phylogenetic Relationships

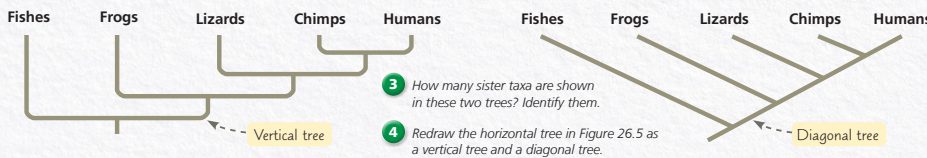
A phylogenetic tree visually represents a hypothesis of how a group of organisms are related. This figure explores how the way a tree is drawn conveys information.

**Instructors:** Additional questions related to this Visualizing Figure can be assigned in MasteringBiology.

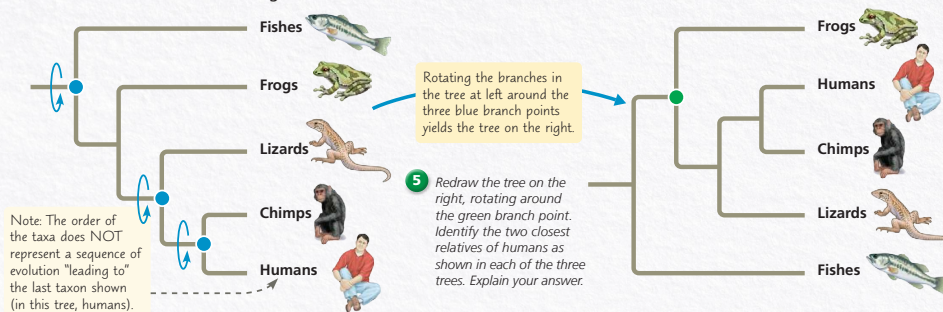
**Parts of a Tree** This tree shows how the five groups of organisms at the tips of the branches, called *taxa*, are related. Each **branch point** represents the common ancestor of the evolutionary lineages diverging from it.



**Alternative Forms of Tree Diagrams** These diagrams are referred to as “trees” because they use the visual analogy of branches to represent evolutionary lineages diverging over time. In this text, trees are usually drawn horizontally, as shown above, but the same tree can be drawn vertically or diagonally without changing the relationships it conveys.



**Rotating Around Branch Points** Rotating the branches of a tree around a branch point does not change what they convey about evolutionary relationships. As a result, the order in which taxa appear at the branch tips is not significant. What matters is the branching pattern, which signifies the order in which the lineages have diverged from common ancestors.



### Visualizing Figures include:

**Figure 5.16** Visualizing Proteins, p. 85

**Figure 6.32** Visualizing the Scale of the Molecular Machinery in a Cell, p. 132

**Figure 16.7** Visualizing DNA, p. 339

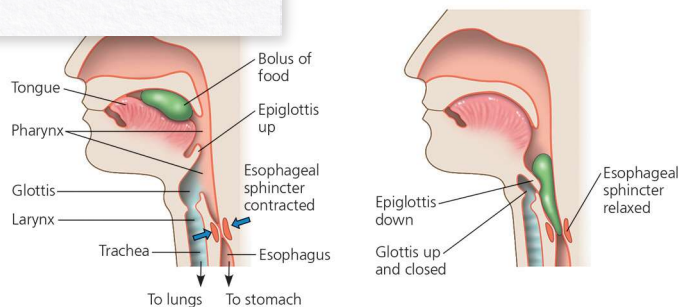
**Figure 25.8** Visualizing the Scale of Geologic Time, p. 562

**Figure 26.6** Visualizing Phylogenetic Relationships, shown at left and on, p. 590

**Figure 35.11** Visualizing Primary and Secondary Growth, p. 817

**Figure 47.8** Visualizing Gastrulation, p.1110

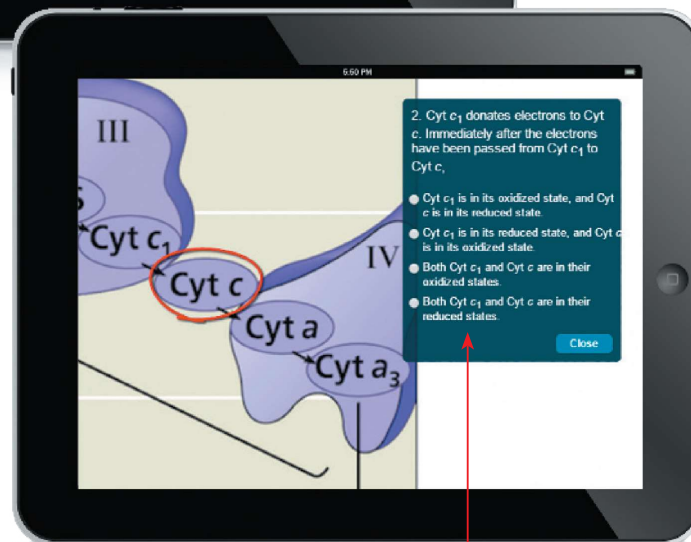
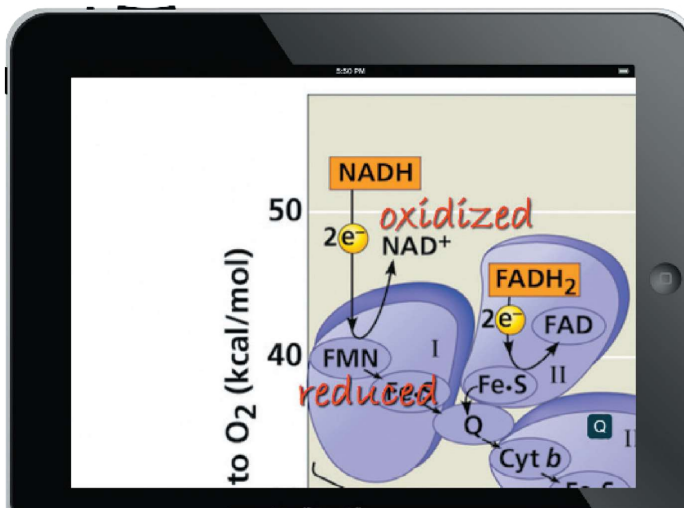
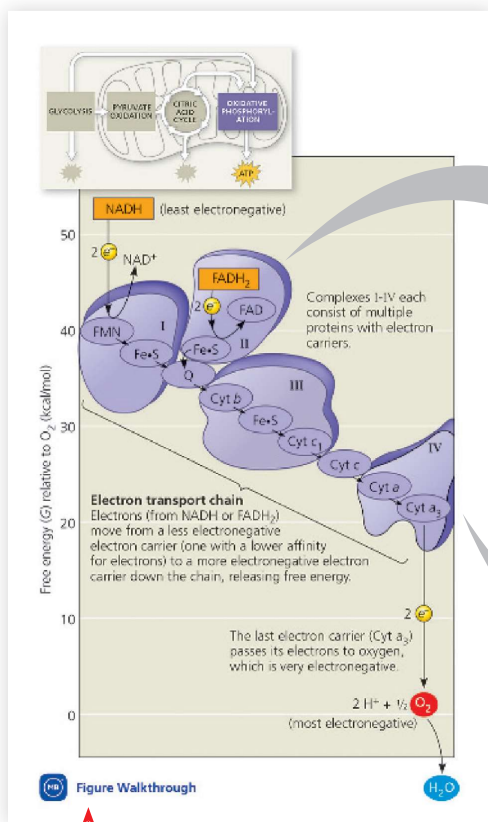
**Visual Skills Questions** give students practice interpreting illustrations and photos in the text.



**VISUAL SKILLS** ▶ If you laugh while drinking water, the liquid may be ejected from your nostrils. Use this diagram to explain why this happens, taking into account that laughing involves exhaling.



**Figure Walkthroughs** guide students through key figures with narrated explanations, figure markups, and questions that reinforce important points.



A note in the print book lets students and instructors know when a Figure Walkthrough animation is available in the eText.

Questions embedded in each Figure Walkthrough encourage students to be active participants in their learning. The Figure Walkthroughs can also be assigned in Mastering Biology with higher-level questions.

**Figure 2.17**

**Photosynthesis: a solar-powered rearrangement of matter.** *Elodea*, a freshwater plant, produces sugar by rearranging the atoms of carbon dioxide and water in the chemical process known as photosynthesis, which is powered by sunlight. Much of the sugar is then converted to other food molecules. Oxygen gas ( $O_2$ ) is a by-product of photosynthesis; notice the bubbles of  $O_2$  gas escaping from the leaves submerged in water.



**DRAW IT** Add labels and arrows on the photo showing the reactants and products of photosynthesis as it takes place in a leaf.

**EXPANDED! Draw It exercises** give students practice creating visuals. Students are asked to put pencil to paper and draw a structure, annotate a figure, or graph experimental data.

# Make Connections Visually

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

## Make Connections Figures include:

**Unit 1** Properties of Water pp. 28–29

**Figure 5.25** Contributions of Genomics and Proteomics to Biology p. 94

**Unit 2** The Working Cell pp. 100–101 →

**Unit 3** Mutations and Inheritance of Cystic Fibrosis pp. 268–269

**Figure 18.27** Genomics, Cell Signalling, and Cancer pp. 412–413

**Unit 4** The Sickle-Cell Allele pp. 496–497

**Unit 5** The Evolutionary History of Biological Diversity pp. 584–585

**Figure 33.9** Maximizing Surface Area p. 740

**Unit 6** Levels of Plant Defences Against Herbivores pp. 806–807

**Figure 37.10** Mutualism Across Kingdoms and Domains p. 864

**Unit 7** Life Challenges and Solutions pp. 926–927

**Figure 44.17** Ion Movement and Gradients p. 1051

**Unit 8** Climate Change Has Effects at All Levels of Biological Organization pp. 1228–1229

## UNIT 2 MAKE CONNECTIONS

### The Working Cell

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

