SECOND CANADIAN EDITION

CAMPBELL BIOLOGY

REECE • URRY • CAIN • WASSERMAN • MINORSKY • JACKSON
RAWLE • DURNFORD • MOYES • SCOTT • WALDE

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BIOLOGY

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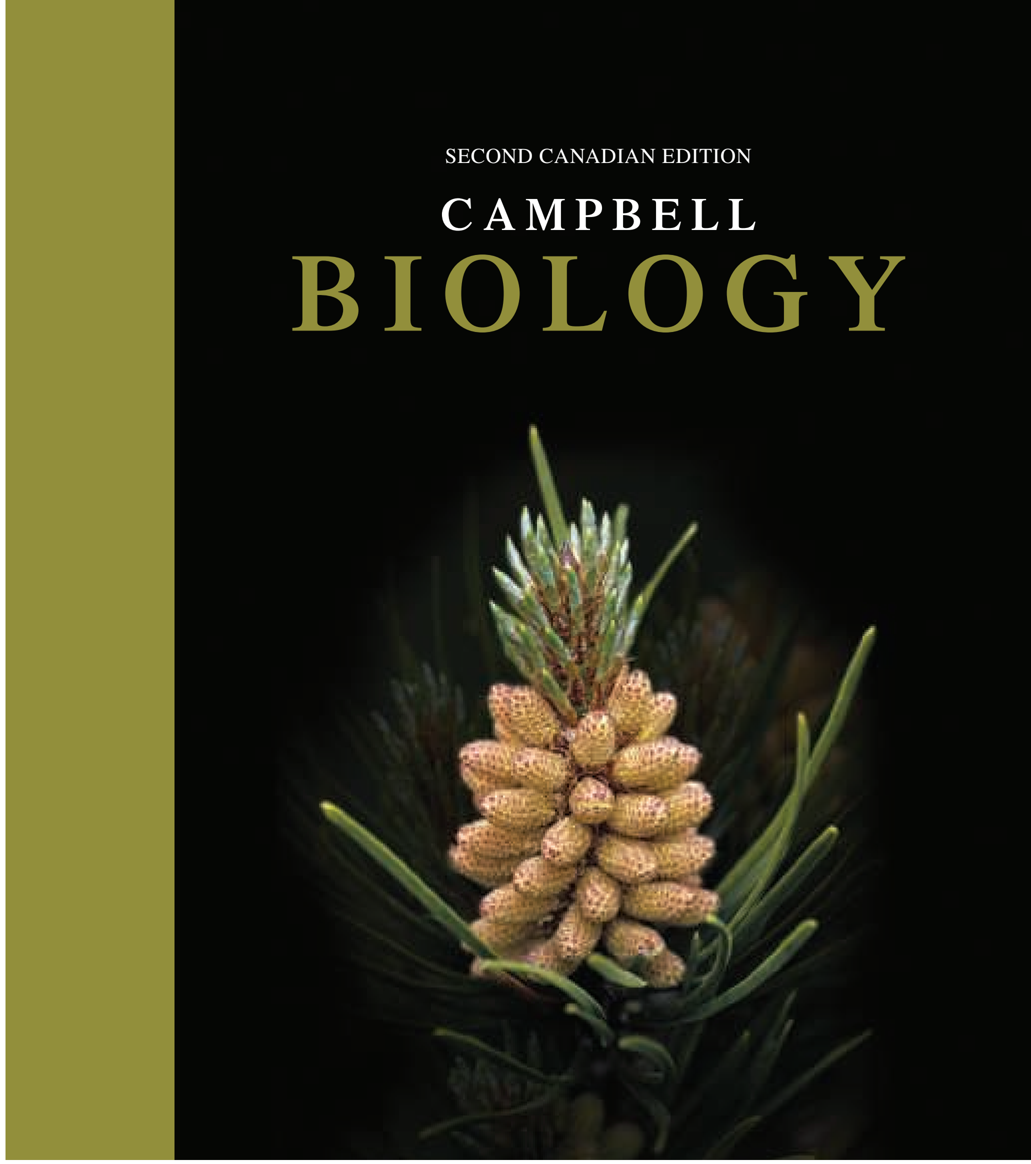

Jane B. Reece
Berkeley, California

Lisa A. Urry
Mills College, Oakland, California

Michael L. Cain
Bowdoin College, Brunswick, Maine

Steven A. Wasserman
University of California, San Diego

Peter V. Minorsky
Mercy College, Dobbs Ferry, New York

Robert B. Jackson
Stanford University, Stanford, California

Fiona E. Rawle
University of Toronto Mississauga, Mississauga, Ontario

Dion G. Durnford
University of New Brunswick, Fredericton, New Brunswick

Chris D. Moyes
Queen's University, Kingston, Ontario

Kevin Scott
University of Manitoba, Winnipeg, Manitoba

Sandra J. Walde
Dalhousie University, Halifax, Nova Scotia

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Cover image Caption: MALES CONES (PRODUCE POLLEN). LODGEPOLE PINE. Pinus contorta. The male cones produce copious amounts of pollen in the spring. Rocky Mountains, Yellowstone NP

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About the Authors

Jane B. Reece

Jane Reece was Neil Campbell's longtime collaborator, and she has participated in every edition of *CAMPBELL BIOLOGY*. Earlier, Jane taught biology at Middlesex County College and Queensborough Community College. She holds an A.B. in biology from Harvard University, an M.S. in microbiology from Rutgers University, and a Ph.D. in bacteriology from the University of California, Berkeley. Jane's research as a doctoral student at UC Berkeley and postdoctoral fellow at Stanford University focused on genetic recombination in bacteria. Besides her work on *CAMPBELL BIOLOGY*, she has been a co-author on *Campbell Biology in Focus*, *Campbell Biology: Concepts & Connections*, *Campbell Essential Biology*, and *The World of the Cell*.

Lisa A. Urry

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

Michael L. Cain

Michael Cain is an ecologist and evolutionary biologist who is now writing full-time. Michael earned a joint degree in biology and math at Bowdoin College, an M.Sc. from Brown University, and a Ph.D. in ecology and evolutionary biology from Cornell University. As a faculty member at New Mexico State University and Rose-Hulman Institute of Technology, he taught a wide range of courses, including introductory biology, ecology, evolution, botany, and conservation biology. Michael is the author of dozens of scientific papers on topics that include foraging behaviour in insects and plants, long-distance seed dispersal, and speciation in crickets. In addition to his work on *CAMPBELL BIOLOGY* and *Campbell Biology in Focus*, Michael is the lead author of an ecology textbook.

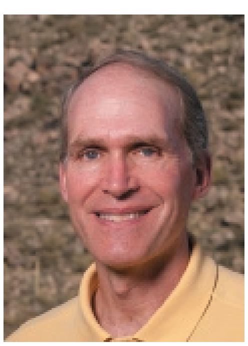
Steven A. Wasserman

Steve Wasserman is Professor of Biology at the University of California, San Diego (UCSD). He earned his A.B. in biology from Harvard University and his Ph.D. in biological sciences from MIT. Through his research on regulatory pathway mechanisms in the fruit fly *Drosophila*, Steve has contributed to the fields of developmental biology, reproduction, and immunity. As a faculty member at the University of Texas Southwestern Medical Center and UCSD, he has taught genetics, development, and physiology to undergraduate, graduate, and medical students. He currently focuses on teaching introductory biology. He has also served as the research mentor for more than a dozen doctoral students and more than 50 aspiring scientists at the undergraduate and high school levels. Steve has been the recipient of distinguished scholar awards from both the Markey Charitable Trust and the David and Lucile Packard Foundation. In 2007, he received UCSD's Distinguished Teaching Award for undergraduate teaching. Steve is also a co-author of *Campbell Biology in Focus*.

Peter V. Minorsky

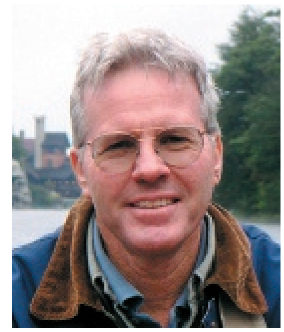
Peter Minorsky is Professor of Biology at Mercy College in New York, where he teaches introductory biology, evolution, ecology, and botany. He received his A.B. in biology from Vassar College and his Ph.D. in plant physiology from Cornell University. He is also the science writer for the journal *Plant Physiology*. After a postdoctoral fellowship at the University of Wisconsin at Madison, Peter taught at Kenyon College, Union College, Western Connecticut State University, and Vassar College. His research interests concern how plants sense environmental change. Peter received the 2008 Award for Teaching Excellence at Mercy College. Peter is also a co-author of *Campbell Biology in Focus*.

Robert B. Jackson



Rob Jackson is the Douglas Professor of Environment and Energy in the Department of Environmental Earth System Science at Stanford University. Rob holds a B.S. in chemical engineering from Rice University, as well as M.S. degrees in ecology and statistics and a Ph.D. in ecology from Utah State University. While a biology professor at Duke University, Rob directed the university's Program in Ecology and was Vice President of Science for the Ecological Society of America. He has received numerous awards, including a Presidential Early Career Award in Science and Engineering from the National Science Foundation. Rob is a Fellow of both the Ecological Society of America and the American Geophysical Union. He also enjoys popular writing, having published a trade book about the environment, *The Earth Remains Forever*, and two books of poetry for children, *Animal Mischief* and *Weekend Mischief*. Rob is also a co-author of *Campbell Biology in Focus*.

Neil A. Campbell



Neil Campbell (1946–2004) combined the investigative nature of a research scientist with the soul of an experienced and caring teacher. He earned his M.A. in zoology from the University of California, Los Angeles, and his Ph.D. in plant biology from the University of California, Riverside, where he received the Distinguished Alumnus Award in 2001. Neil published numerous research articles on desert and coastal plants and how the sensitive plant (*Mimosa*) and other legumes move their leaves. His 30 years of teaching in diverse environments included introductory biology courses at Cornell University, Pomona College, and San Bernardino Valley College, where he received the college's first Outstanding Professor Award in 1986. Neil was a visiting scholar in the Department of Botany and Plant Sciences at the University of California, Riverside.

Fiona Rawle

Fiona Rawle: (Units 1-3; editor Units 1-8) received her Ph.D. from Queen's University in Kingston, Ontario. She is an Associate Professor, Teaching Stream, at the University of Toronto Mississauga, where she teaches Introduction to Evolution and Evolutionary Genetics, Introductory Genetics, and Molecular Basis of Disease. Fiona's teaching and pedagogical research interests focus on several areas: (1) the development of case studies to immerse students in real-world biological challenges and allow students to connect with material from different perspectives; (2) the development of active learning techniques that can be used in large class settings; and (3) the development of scientific literacy interventions that can be used across the undergraduate biology curriculum. Fiona was the recipient of the 2016 University of Toronto Mississauga Teaching Excellence Award, a 2015 University of Toronto Early Career Teaching Award, and a 2010 Faculty Award for Teaching Excellence while at Wilfrid Laurier University.

Dion Durnford

Dion Durnford (Unit 5) is a professor at the University of New Brunswick, in Fredericton. He earned a B.Sc. in Biology from Dalhousie University and a Ph.D. in Botany from the University of British Columbia. His research has focused on the evolution of light-harvesting antenna systems and the role of these proteins in light harvesting and photo-protection in microalgae. His recent work is examining how microalgae age and their strategies for increasing longevity. Dion was the recipient of the 2002 Faculty of Science Excellence in Teaching award and the 2010 Allan P. Stewart Award for Excellence in Teaching.

Chris Moyes

Chris Moyes (Unit 7) is a comparative physiologist, focusing on the muscle biochemistry and energetics. He received his Ph.D. in Zoology from the University of British Columbia (1991) and is currently a Professor in the Department of Biology, Queen's University. He has published more than 100 research papers and contributed to four books. He is co-author of *Principles of Animal Physiology,* first published in 2006.

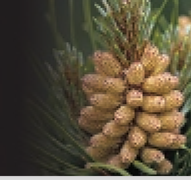
Kevin Scott

Kevin Scott (Units 4 and 6) is a senior instructor at the University of Manitoba where he teaches introductory biology for both biology majors and nonbiology majors; human physiology; and environmental physiology of animal laboratories. In the past, he has also taught courses in ecology for nonbiology majors, immunology, parasitology, and microbiology. He received a B.Sc. in Zoology and a Ph.D. joint between Zoology and Cellular, Molecular, and Microbial Biology at the University of Calgary. As an educator, Dr. Scott's career is centred on teaching and the classroom, where he shares his excitement for biology. His interest in plant biology has grown during his professional career and is a favourite topic in his classroom. Kevin was a co-author of *Campbell Biology: Concepts and Connections*, Canadian Edition.

Sandra Walde

Sandra Walde (Unit 8) is a professor of biology and associate dean of science at Dalhousie University. She received her B.Sc. in Biology and Ph.D. in Ecology from the University of Calgary, and then went to the University of California, Santa Barbara, as a post-doctoral fellow. At Dalhousie, she teaches general ecology to first- and second-year students and population ecology to upper-year students. Sandy's research has focused on dispersal and ecological interactions in aquatic and terrestrial communities. She feels lucky that her field work has taken her to some beautiful places, including studies of stream invertebrate communities in Alberta and Nova Scotia, and research on native fishes in the lakes of the Patagonian Andes.

Brief Contents



Detailed Contents

Preface

We are honoured to present the Second 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 more than a dozen 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 Second Canadian Edition include:

- increasing visual literacy through figures, tutorials, and problems that guide students to a deeper understanding of the ways in which figures represent biological structure and function.
- 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, 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 Second Canadian Edition; we invite you to explore pages xxviii–xxxv for more information and examples.

- **Scientific Skills Exercises** in every chapter use real data to help students learn and practise data interpretation, graphing, experimental design, and math skills. 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 Second Canadian Edition with examples that reveal how our ability to rapidly sequence DNA and proteins on a massive scale is transforming all areas of biology, from molecular and cell biology to phylogenetics, physiology, and ecology.
- **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, thought-provoking photograph leads to a question that helps students realize that what they have learned in the chapter connects to their world and provides understanding and insight into natural phenomena.
- **The impact of climate change** is explored throughout the text, starting with an introduction in Chapter 1, and concluding with the Exploring Climate Change Figure 56.27.
- **The Second Canadian 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, students can use the **Dynamic Study Modules** to study anytime and anywhere with their smartphone, tablet, or computer.
  - **Learning Catalytics™** allows students to use their smartphone, tablet, or laptop to respond to questions in class.
  - As in each new edition of *CAMPBELL BIOLOGY*, the Second Canadian Edition incorporates **new content** and **organizational improvements**. These are summarized on pp. xxv–xxvii, following this Preface. Additional content updates reflect rapid, ongoing changes in technology and knowledge in the fields of genomics, gene editing technology (CRISPR), and more.

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 MasteringBiology all reinforce these main ideas and essential facts.

Because text and illustrations are equally important for learning biology, **integration of text and figures** has been a hallmark of this text since the first edition. The 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, whereas Make Connections Figures use art and text to illustrate how key ideas link together what might appear to be discrete and disparate topics in introductory biology.

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 new 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.

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, Visualizing the Concept activities, Video Field Trips, HHMI Short Files, Make Connections Tutorials, 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 xxxvi–xxxix 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. xl–xli). 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, and Cathleen Sullivan, Executive Acquisitions Editor, cathleen.sullivan@pearsoned.com

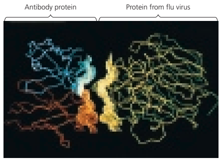
New and Featured Content

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

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

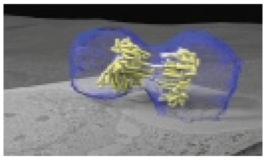
To help students focus on the big ideas of biology, we now emphasize five themes: Organization, Information, Energy and Matter, Interactions, and the core theme of Evolution. A new figure on gene expression (Figure 1.9) equips students from the outset with an understanding of how gene sequences determine an organism's characteristics. Concept 1.3 has been reframed to more accurately reflect the scientific process, including a new figure on the complexity of the practice of science (Figure 1.26). A new case study (Figures 1.27 and 1.28) examines research on evolution of colouration in mice.

UNIT 1 The Chemistry of Life



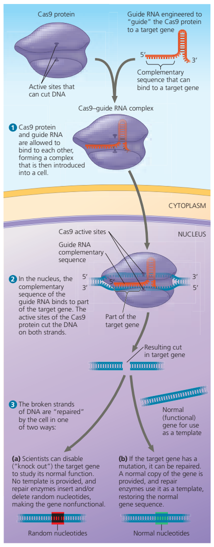
In Unit 1, new content engages students in learning this foundational material. In Chapter 3, the discussion of organisms affected by loss of Arctic sea ice has been expanded. Chapter 5 has updates on trans fats, the effects of diet on blood cholesterol, protein sequences and structures, and intrinsically disordered proteins. The Make Connections Figure, "Contributions of Genomics and Proteomics to Biology" (Figure 5.26) has also been revised. Unit 1 also highlights research by the Department of Fisheries and Oceans, work of David Wishart at the University of Alberta on characterizing small molecules in the human body, as well as work by Edward Fon and Kalle Gehring from McGill University on the structure of the parkin protein.

UNIT 2 The Cell



Our main goal in this unit was to make the material more accessible and inviting 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 the big-picture context of photosynthesis. Concept 12.3 has been streamlined, with a new Figure 12.17 that covers the M checkpoint as well as the G_1 checkpoint. Unit 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; work on membrane proteins by Frances Sharom at the University of Guelph; and work on the impact of environment on metabolism by Helga Guderley at Université Laval.

UNIT 3 Genetics



In Chapters 13–17, we have incorporated changes that help students grasp the more abstract concepts of genetics and their molecular underpinnings. For example, Chapter 13 includes a new figure (Figure 13.9) showing details 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, with the changes driven by exciting new discoveries based on DNA sequencing and gene-editing technology. Chapter 18 includes a new figure (Figure 18.15) on the role of siRNAs in chromatin remodelling. A new Make Connections Figure (Figure 18.27) details four subtypes of breast cancer that have recently been proposed, based on gene expression in tumour cells. Chapter 19 features a new section that covers bacterial defences against bacteriophages and describes the CRISPR-Cas9 system (Figure 19.7). 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. A new section titled Editing Genes and Genomes has been added describing the CRISPR-Cas9 system (Figure 20.14) that has been developed to edit genes in living cells. Information has also been added later in the chapter on use of the CRISPR-Cas9 system, including a study in which a genetic mutation for the disease tyrosinemia was corrected in mice. Finally, the discussion of ethical considerations has been updated to include a recent report of scientists using the CRISPR-Cas9 system to edit a gene in human embryos, along with a discussion of the ethical questions raised by such experiments, such as its usage along with the gene drive approach to combat carrying of diseases by mosquitoes. Chapter 21 has been updated to reflect new research, including the ENCODE project and the Cancer Genome Atlas. A new figure (Figure 21.15) compares the 3-D structures of lysozyme and α-lactalbumin and their amino acid sequences, providing support for the common evolutionary origin of these proteins.

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; Michael Rudnicki, who led the team that discovered adult muscle stem cells at the Sprott Centre for Stem Cell Research in Ottawa; and Charlie Boone, from the University of Toronto, who maps genetic interactions in yeast. In addition, a range of genomics research in Canada is featured in the updated Exploring Figure 21.6.

UNIT 4 Mechanisms of Evolution

One goal of this revision was to highlight connections among fundamental evolutionary concepts. For example, 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 23.3) that shows variability at the level of DNA. 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).

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.

UNIT 5 The Evolutionary History of Biological Diversity

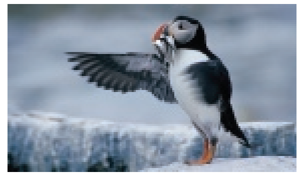
In keeping with our Second Canadian Edition goals, we have expanded the coverage of genomic and other molecular studies and how they inform our understanding of phylogeny. Examples include a new Inquiry Figure (Figure 34.50) on the Neanderthal genome and presentation of new evidence that mutualistic 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.

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 Laboratory at Trent University.

UNIT 6 Plant Form and Function

In developing the Second Canadian 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). 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.

UNIT 7 Animal Form and Function

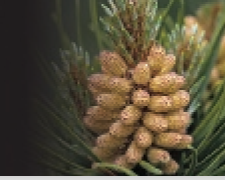


In revising this unit, we strove to enhance student appreciation of the core concepts and ideas that apply across diverse organisms and varied organ systems. To help students recognize the central concept of homeostasis, figures were revised across six chapters to provide a consistent organization that facilitates interpretation of individual hormone pathways as well as the comparison of pathways across organisms. Homeostasis and endocrine regulation are highlighted by 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). 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.

An Inquiry Figure features the work of Sarah Iverson at Dalhousie University on the analysis of lipid profiles to dissect food webs in free-roaming animals, and an Impact Figure features Ralph Steinman's Nobel Prize work on dendritic cells. There is a description of the work of Brenda Milner, the McGill researcher who introduced the world of neuropsychology to patient HM. Additional research highlighted in this unit includes Janet Rossant at the University of Toronto on cell fate determination; Naweed 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 research that explores structure/function relationships in hemoglobin of woolly mammoths; 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.

UNIT 8 Ecology

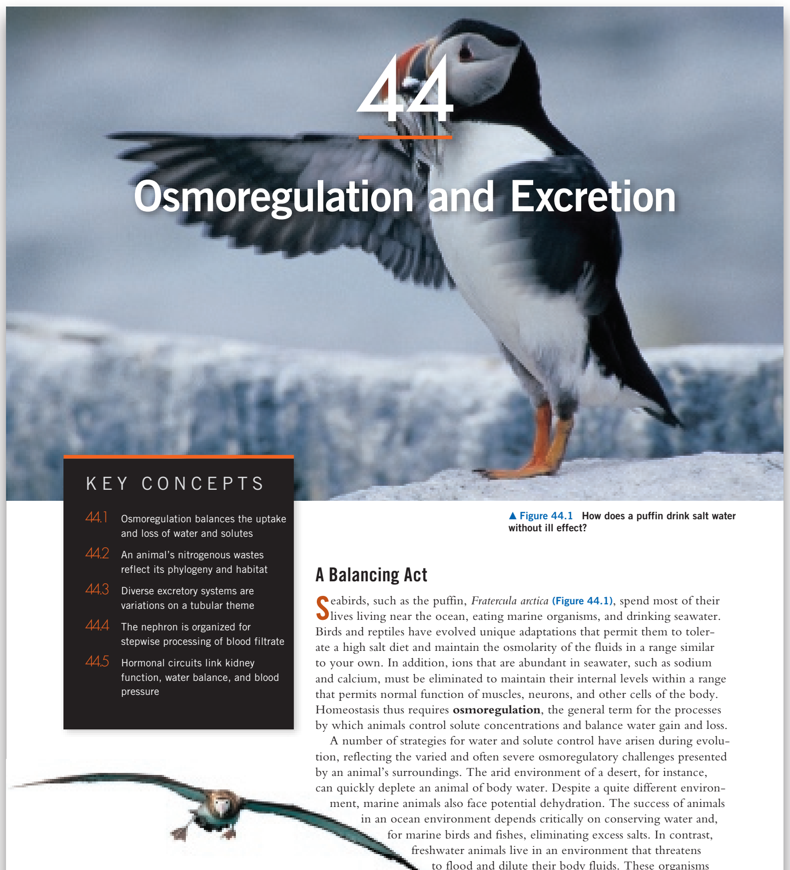
Unit 8 focuses on how ecologists apply biological knowledge and ecological theory to understand and solve problems in the world around them. The Second Canadian Edition introduces the global nature of climate and its effects on life in Chapter 52, providing a logical foundation for the rest of this unit, and the science behind climate change is explored throughout the Unit, including an Exploring Figure dedicated to climate change. In addition, Chapter 52 highlights blacklegged ticks and Lyme disease, and includes a new Inquiry figure on sugar maple and climate change. Chapter 53 profiles research on moose and wolf populations on Isle Royal. In Chapter 54, text and a figure (Figure 54.6) examine the mimic octopus, a recently discovered species that illustrates how predators use mimicry. This chapter also profiles an arctic tundra food web, the mountain pine beetle outbreak and lodgepole pine, and has a new Research Method figure on studying winter ecology of Arctic foxes. Chapter 55 has a new Impact figure on the Canadian oil sands. 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 of pharmaceuticals in the environment, and incorporates a new Concept section (Concept 56.4) on global change as a result of human actions. Unit 8 also profiles the research of David Schindler from the University of Alberta, and Verena Tunnicliffe from the University of Victoria. 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.



44

Osmoregulation and Excretion

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

▲ Figure 44.1 How does a puffin drink salt water without ill effect?

A Balancing Act

Seabirds, such as the puffin, *Fratercula arctica* (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 strategies 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

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

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

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

CONCEPT CHECK 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?
4. MAKE CONNECTIONS Compare the activity of renin and ACE in the renin-angiotensin-aldosterone system with that of the protein kinases in a phosphorylation cascade, such as the one shown in Figure 11.10. How are the roles of these enzymes similar and different in the two regulated response pathways?

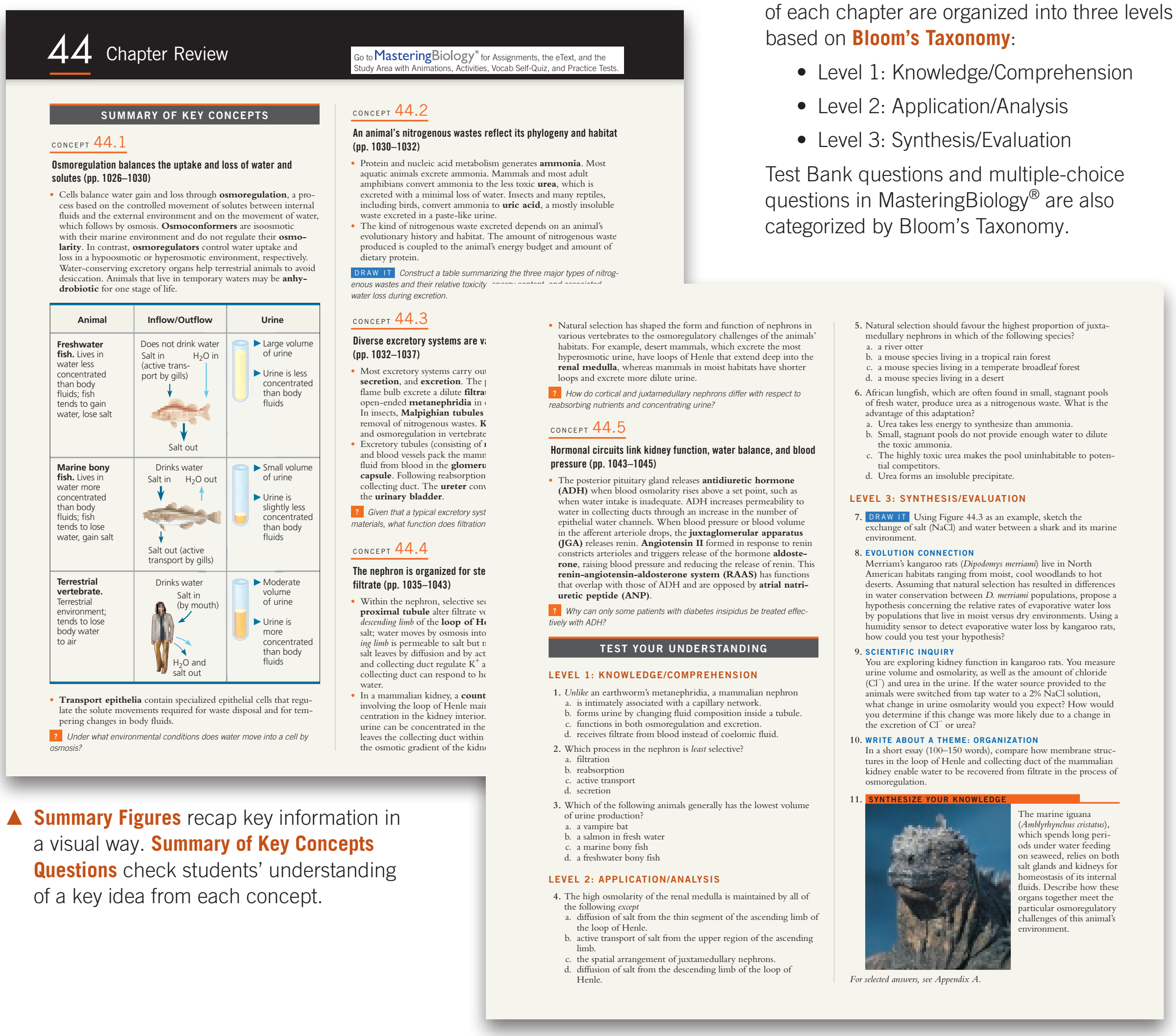
For suggested answers, see Appendix A.

◀ 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. ▶

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



▼ **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.

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

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

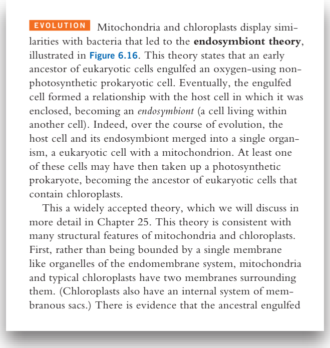
▲ To reinforce the themes, every chapter ends with an **Evolution Connection Question** and a **Write About a Theme Question.**

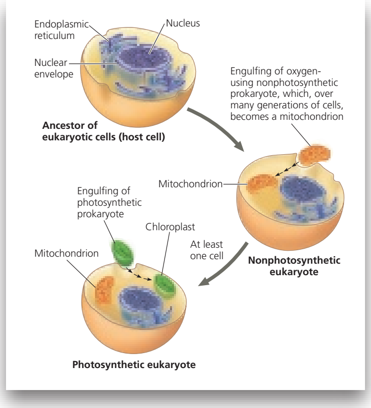
THEMES

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.





Make Connections Visually

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

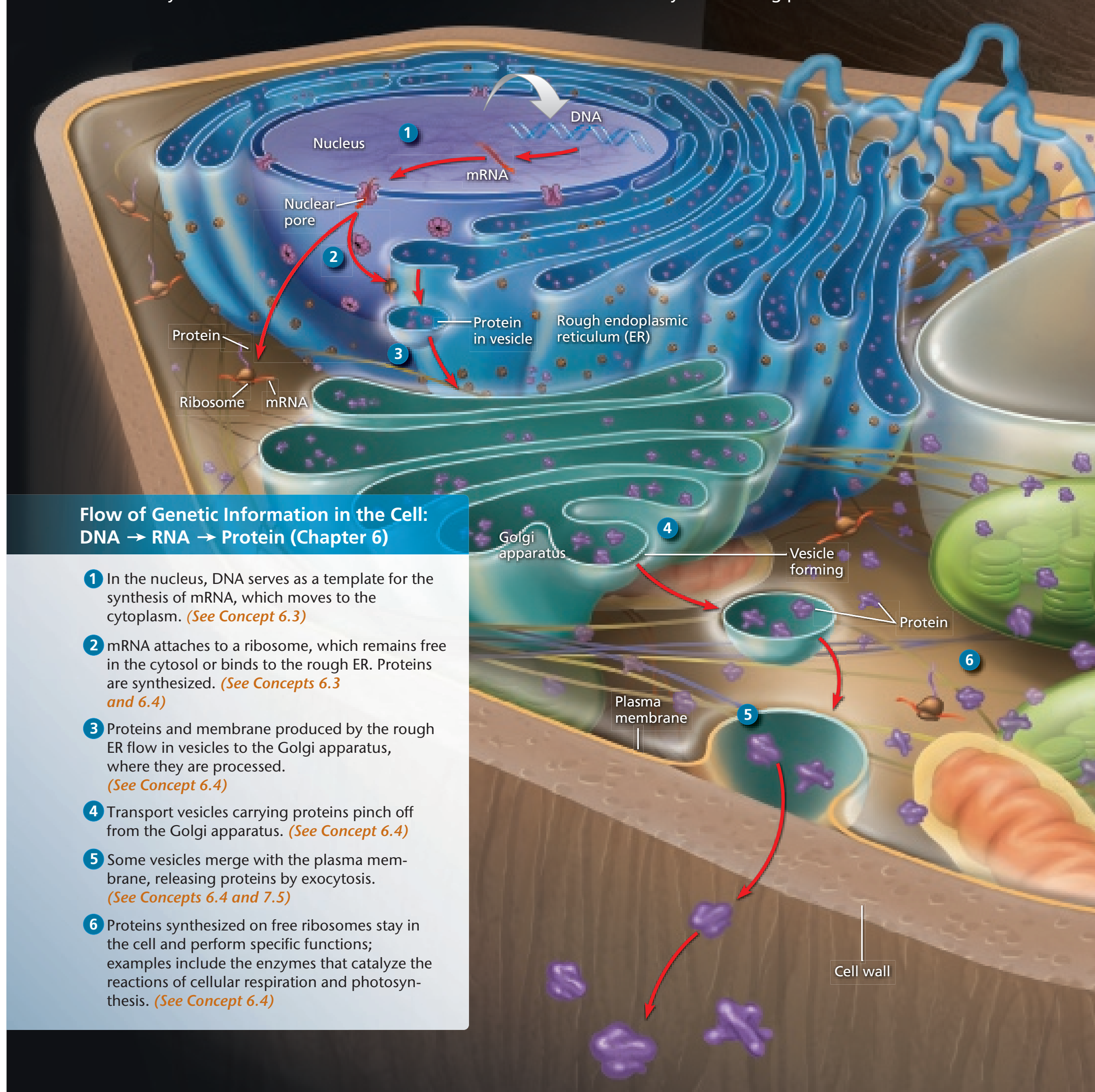
Make Connections Figures include:

▼ Unit 2

MAKE CONNECTIONS

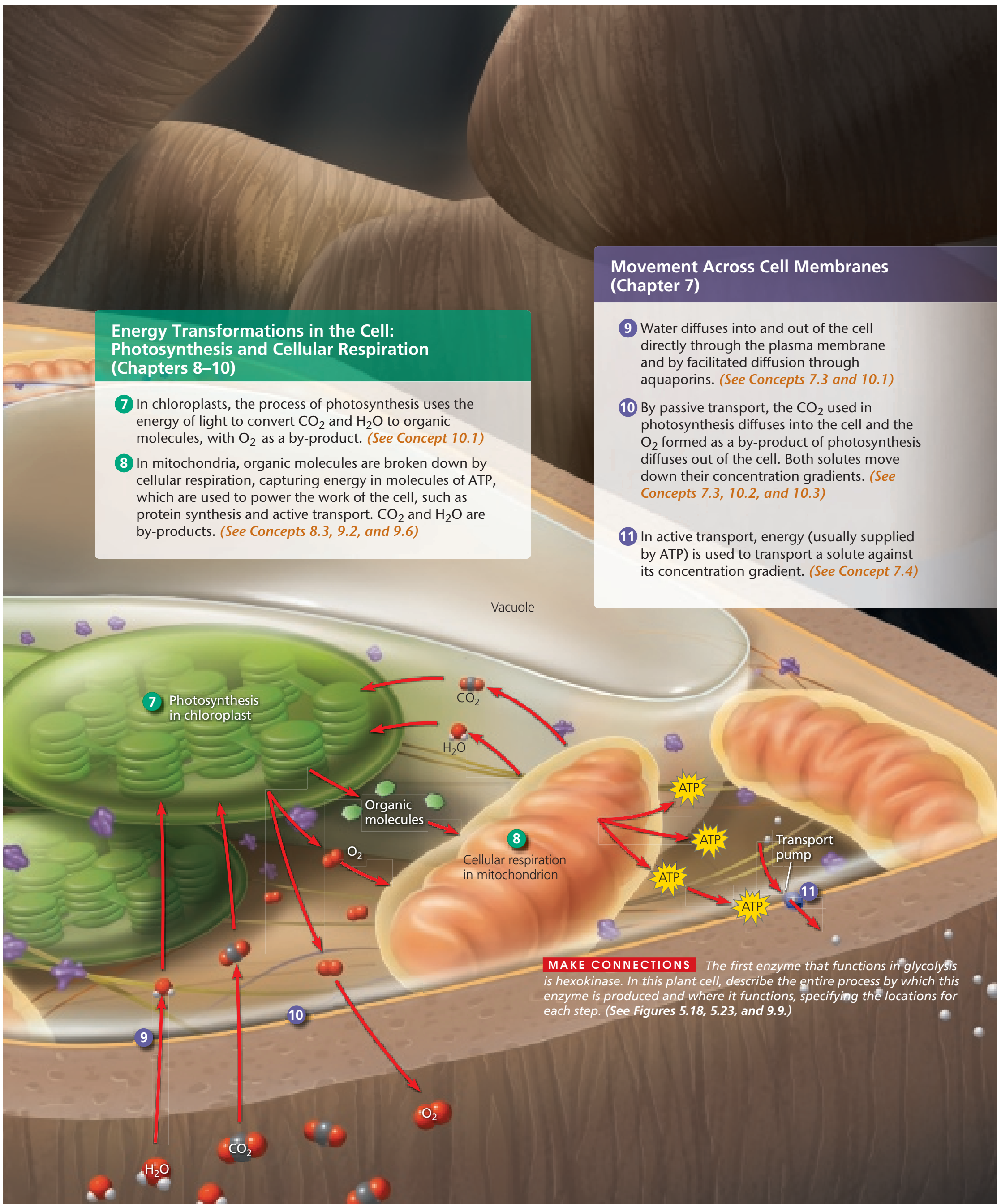
The Working Cell

This unit explores the structure and function of cells, including how cells communicate, divide, and carry out other roles necessary for life. This figure illustrates how the cellular activities you will learn about in this unit relate to each other in a fully functioning plant cell.



Flow of Genetic Information in the Cell: DNA → RNA → Protein (Chapter 6)

1. In the nucleus, DNA serves as a template for the synthesis of mRNA, which moves to the cytoplasm. *(See Concept 6.3)*
2. mRNA attaches to a ribosome, which remains free in the cytosol or binds to the rough ER. Proteins are synthesized. *(See Concepts 6.3 and 6.4)*
3. Proteins and membrane produced by the rough ER flow in vesicles to the Golgi apparatus, where they are processed. *(See Concept 6.4)*
4. Transport vesicles carrying proteins pinch off from the Golgi apparatus. *(See Concept 6.4)*
5. Some vesicles merge with the plasma membrane, releasing proteins by exocytosis. *(See Concepts 6.4 and 7.5)*
6. Proteins synthesized on free ribosomes stay in the cell and perform specific functions; examples include the enzymes that catalyze the reactions of cellular respiration and photosynthesis. *(See Concept 6.4)*



◀ **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.

Practise 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.

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.

Photos provide visual interest and context.

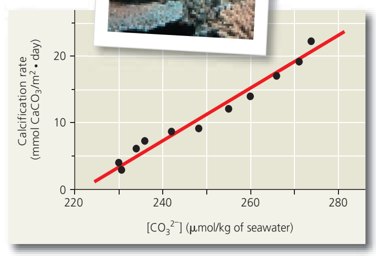
SCIENTIFIC SKILLS EXERCISE

Interpreting a Scatter Plot with a Regression Line

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

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

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



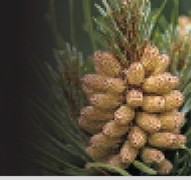
Interpret the Data

1. When presented with a graph of experimental data, the first step in analysis is to determine what each axis represents. (a) In words, explain what is being shown on the *x*-axis. Be sure to include the units. (b) What is being shown on the *y*-axis (including units)? (c) Which variable is the independent variable—the variable that was *manipulated* by the researchers? (d) Which variable is the dependent variable—the variable that responded to or depended on the treatment, which was *measured* by the researchers? (For additional information about graphs, see the Scientific Skills Review in Appendix E and in the Study Area in MasteringBiology.)
2. Based on the data shown in the graph, describe in words the relationship between carbonate ion concentration and calcification rate.
3. (a) If the seawater carbonate ion concentration is 270 μmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square metre of reef to accumulate 30 mmol of calcium carbonate ($CaCO_3$)? (b) If the seawater carbonate ion concentration is 250 μmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square metre of reef to accumulate 30 mmol of calcium carbonate? (c) If carbonate ion concentration decreases, how does the calcification rate change, and how does that affect the time it takes coral to grow?
4. (a) Referring to the equations in Figure 3.12, determine which step of the process is measured in this experiment. (b) Are the results of this experiment consistent with the hypothesis that increased atmospheric $[CO_2]$ will slow the growth of coral reefs? Why or why not?

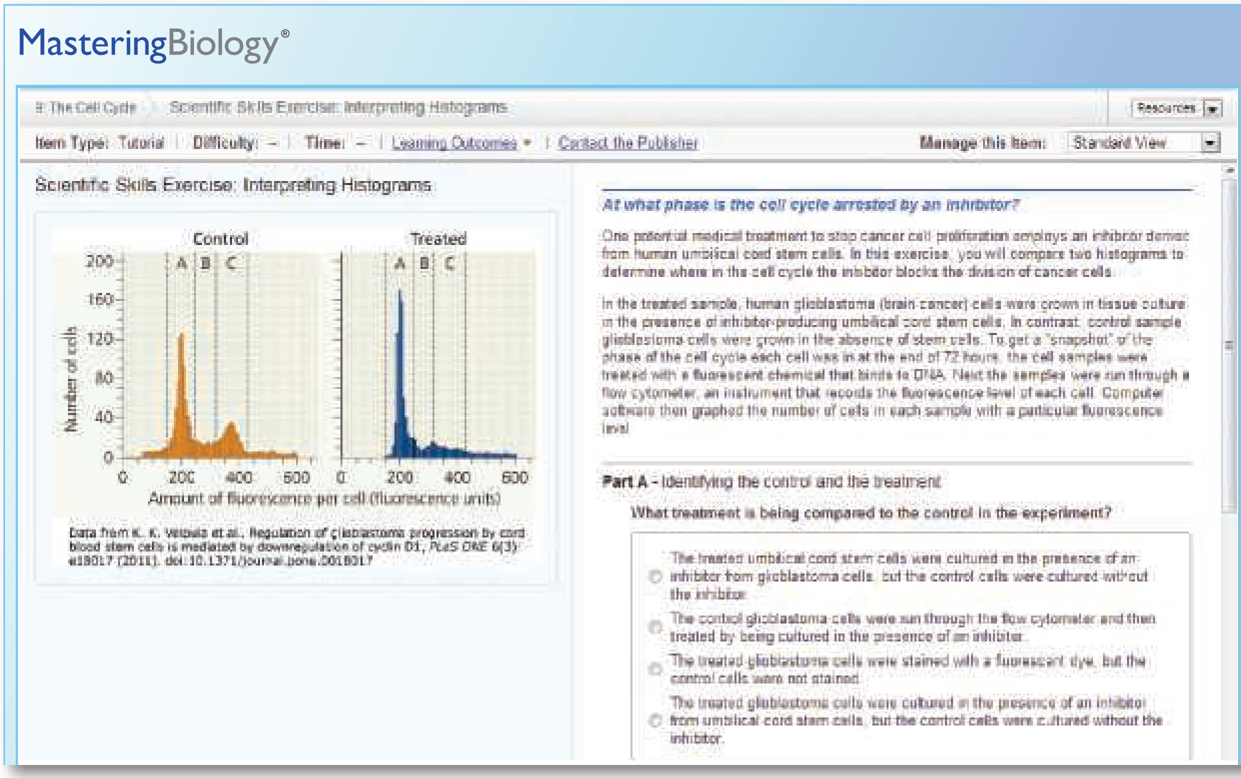
Data from C. Langdon et al., Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef, *Global Biogeochemical Cycles* 14:639–654 (2000).

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

Every chapter has a Scientific Skills Exercise



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



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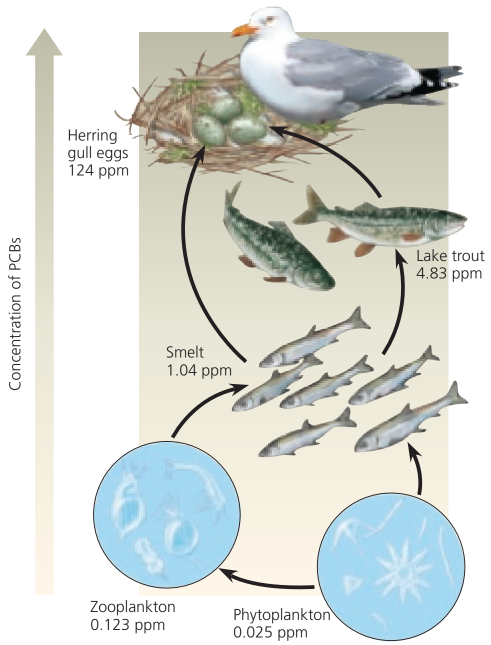
Interpret Data

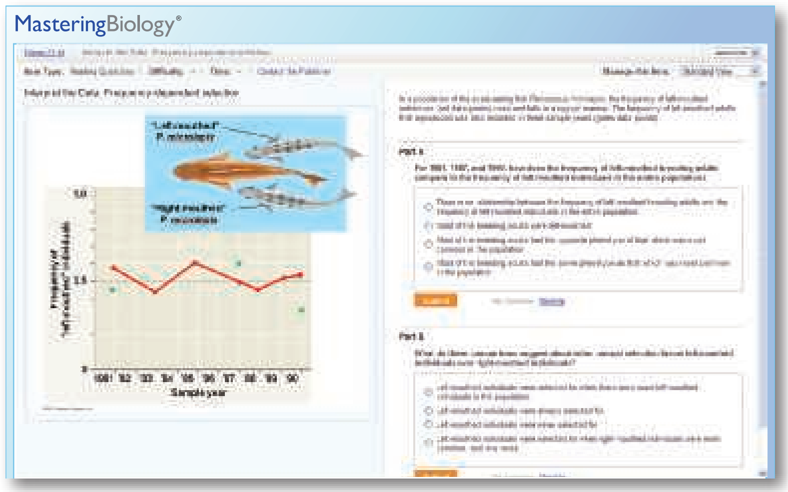
Campbell BIOLOGY, Second Canadian Edition, and MasteringBiology®
offer a wide variety of ways for students to move beyond memorization
and **think like a scientist.**



▲ **Figure 56.24 Biological magnification of PCBs in a Great Lakes food web.**

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 4500 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. How many smelt would the new trout have to consume to attain a pcb level equivalent to existing trout in the Great University. (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! Interpret the Data Question** from the text is assignable in **MasteringBiology**.

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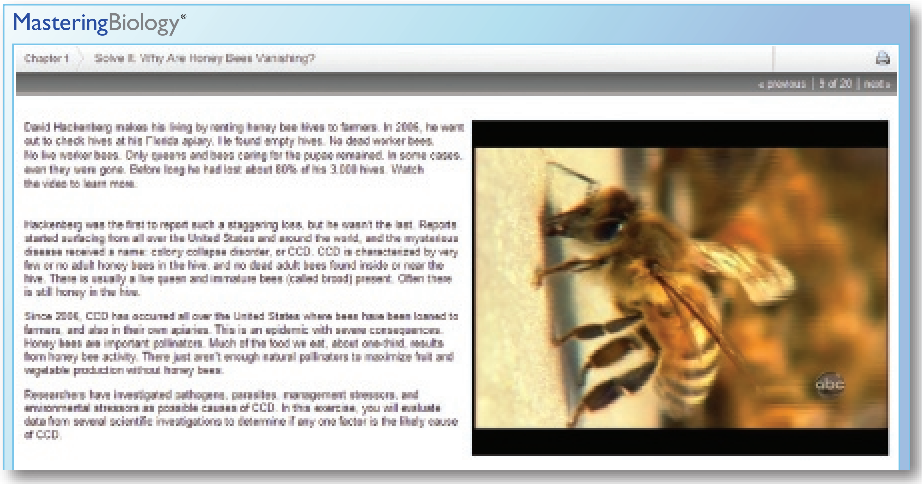
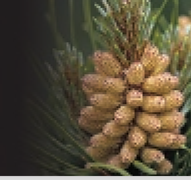


◄ **NEW! Solve It Tutorials** engage students in a multistep investigation of a "mystery" or open question in which they must analyze real data. These are assignable in **MasteringBiology**.

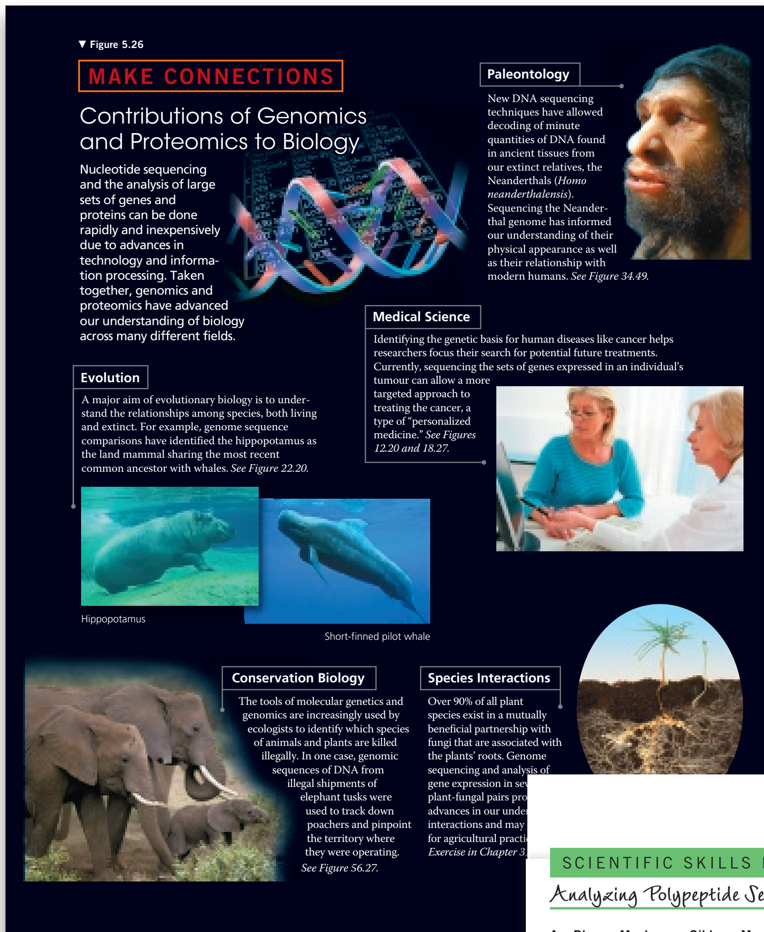
Topics include:

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



Explore the Impact of Genomics

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



▼ Figure 5.26

MAKE CONNECTIONS

Contributions of Genomics and Proteomics to Biology

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

Paleontology

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

Medical Science

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

Evolution

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

Hippopotamus

Short-finned pilot whale

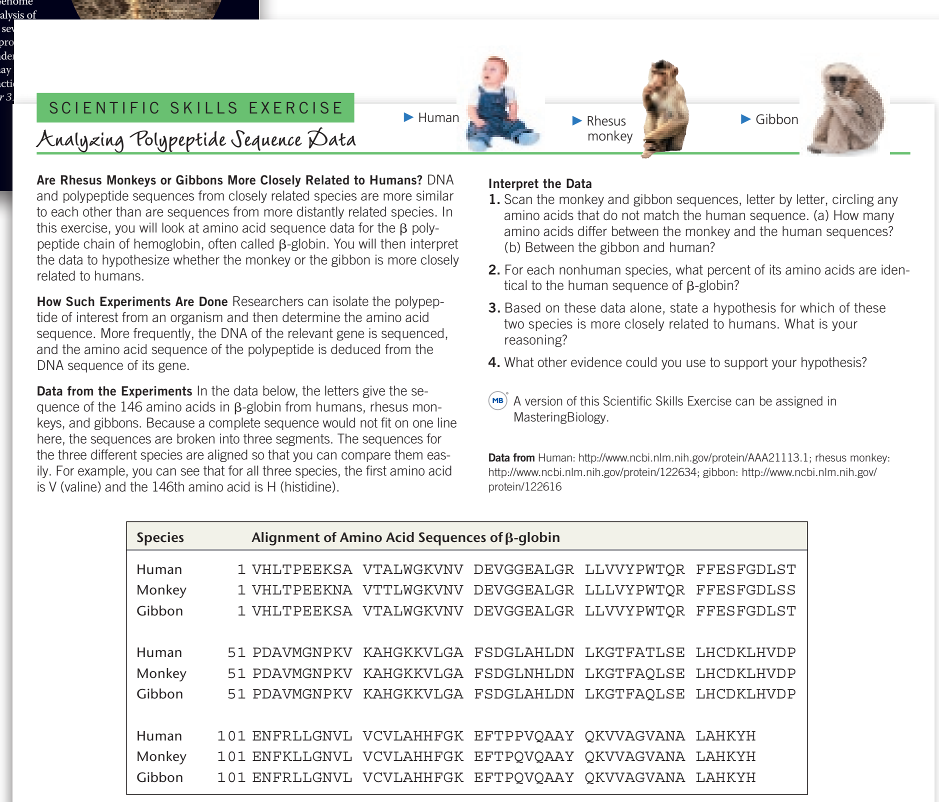
Conservation Biology

The tools of molecular genetics and genomics are increasingly used by ecologists to identify which species of animals and plants are killed illegally. In one case, genomic sequences of DNA from illegal shipments of elephant tusks were used to track down poachers and pinpoint the territory where they were operating. *See Figure 56.27.*

Species Interactions

Over 90% of all plant species exist in a mutually beneficial partnership with fungi that are associated with the plants' roots. Genome sequencing and analysis of gene expression in sev plant-fungal pairs pro advances in our under interactions and may for agricultural practi *Exercise in Chapter 3*

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



SCIENTIFIC SKILLS EXERCISE

Analyzing Polypeptide Sequence Data

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

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

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

Interpret the Data

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

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

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

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

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

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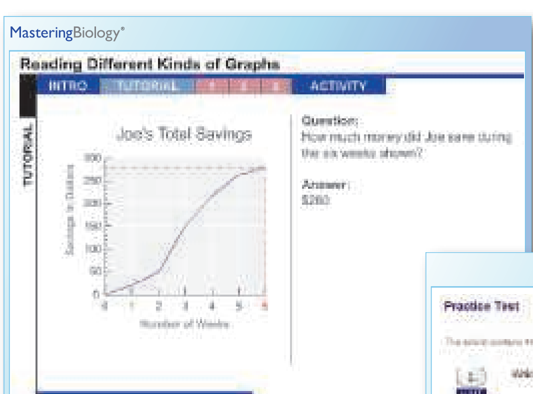
STUDY AREA

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



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

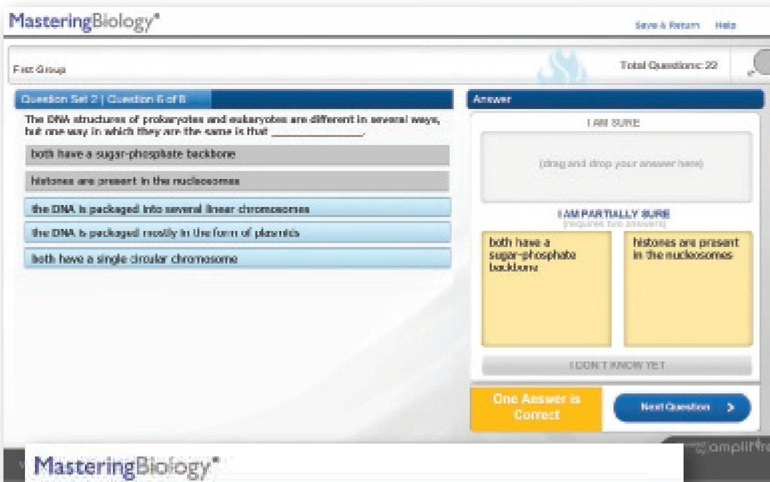
BioFlix® 3-D Animations explore the most difficult biology topics, reinforced with tutorials, quizzes, and more. ▶

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

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

DYNAMIC STUDY MODULES

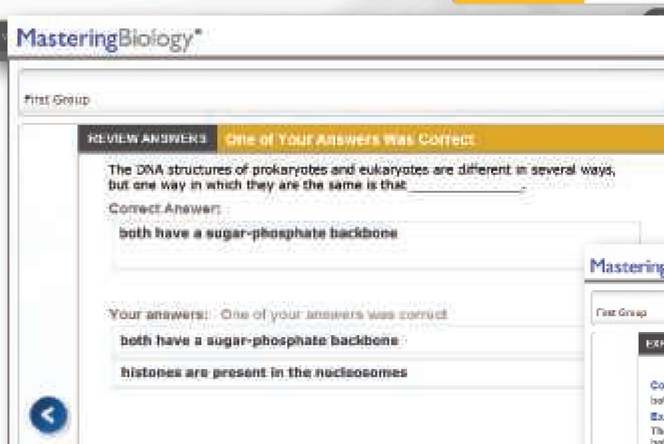
NEW! Dynamic Study Modules, designed to enable students to study effectively on their own, help students quickly access and learn the information they need to be more successful on quizzes and exams.



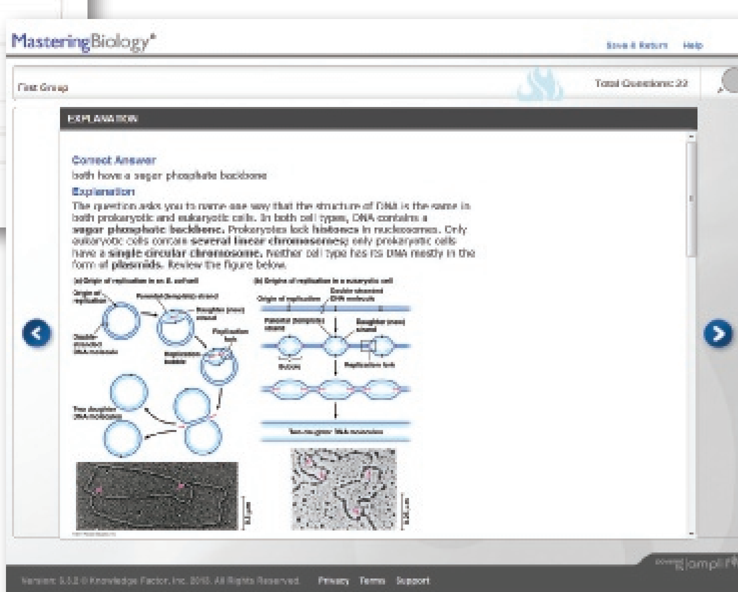
How it works:

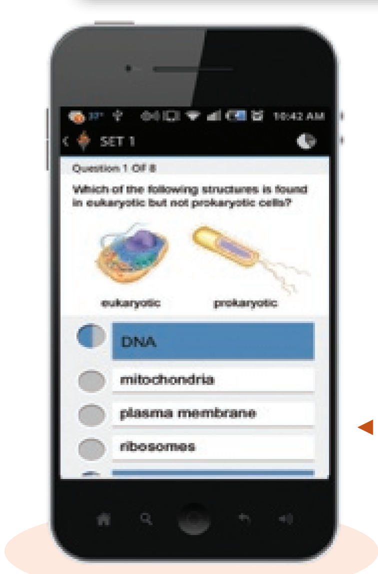
1. Students receive an initial **set of questions**.

◀ 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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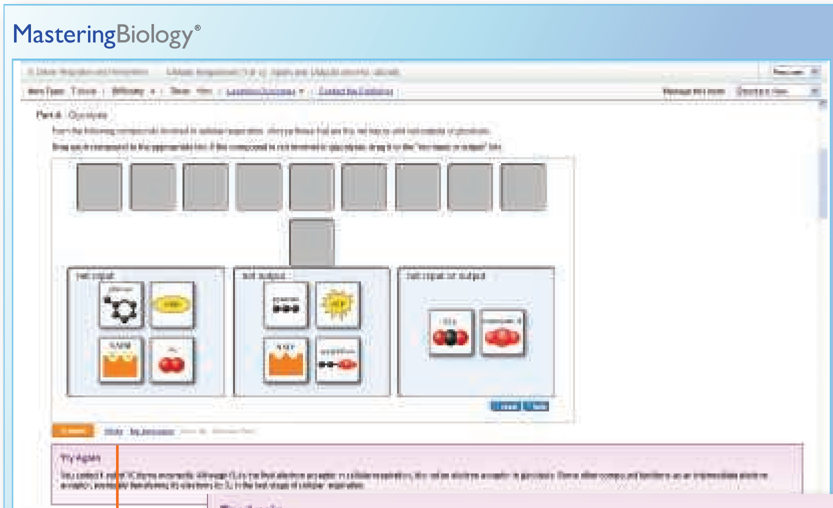
Learn Through Assessment

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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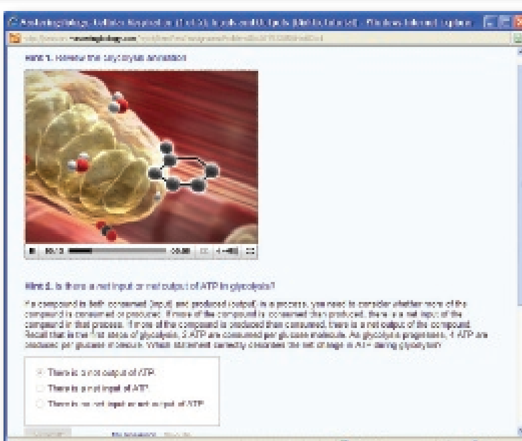
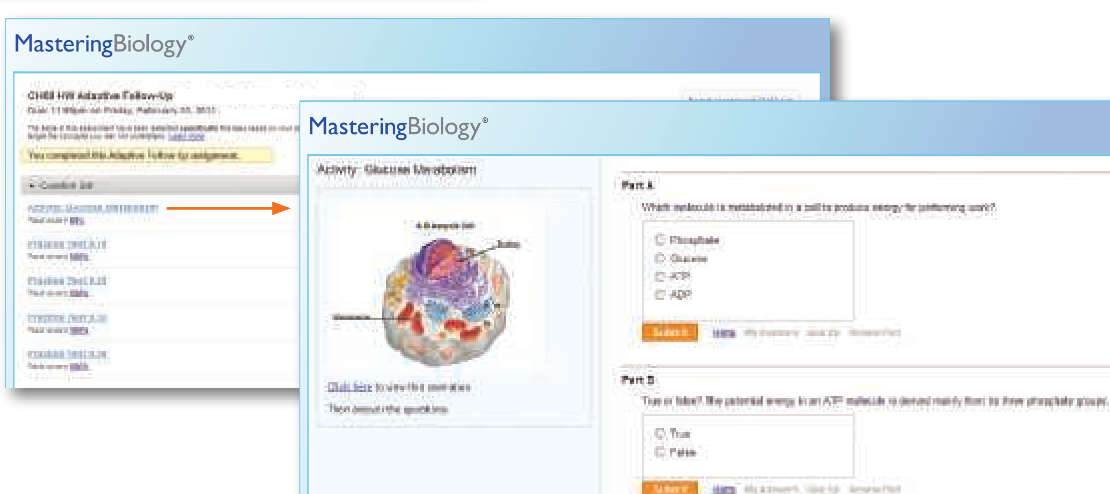
1. If a student gets stuck ...

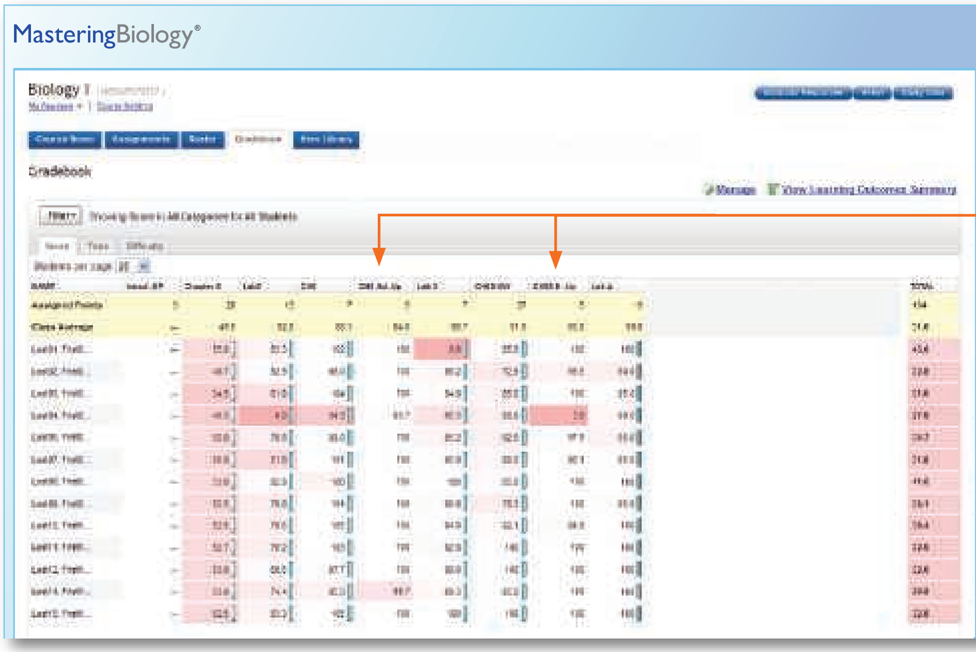


2. specific wrong-answer **feedback** appears in the purple feedback box.
3. **Hints** coach the student to the correct response.
4. Optional **Adaptive Follow-Up Assignments** are based on each student's performance on the original homework assignment and provide additional coaching and practice as needed.

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



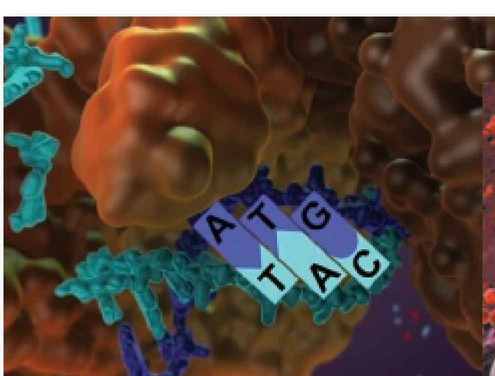
The MasteringBiology® Gradebook provides instructors with quick results and easy-to-interpret insights into student performance. Every assignment is automatically graded. Shades of red highlight vulnerable students and challenging assignments.

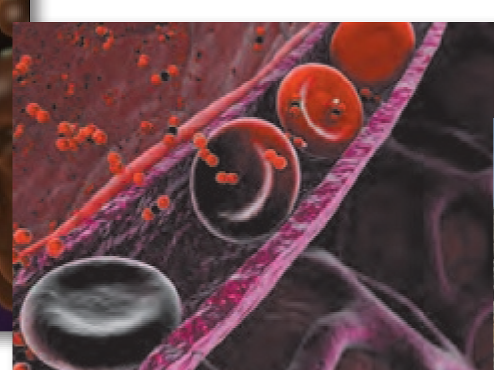


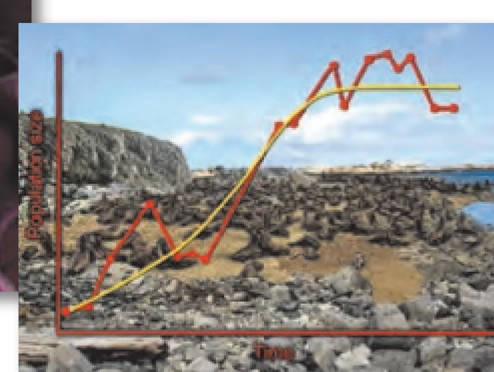
Student scores on the optional **Adaptive Follow-Up Assignments** are recorded in the gradebook and offer additional diagnostic information for instructors to monitor learning outcomes and more.

BioFlix®

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

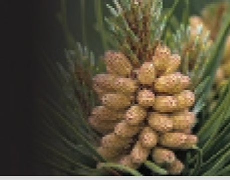






BioFlix Tutorials and 3-D Animations include:

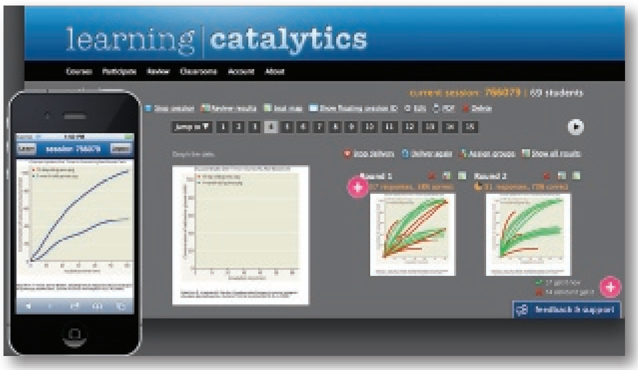
- A Tour of the Animal Cell
- A Tour of the Plant Cell
- Membrane Transport
- Cellular Respiration
- Photosynthesis
- Mitosis
- Meiosis
- DNA Replication
- Protein Synthesis
- Mechanisms of Evolution
- Water Transport in Plants
- Homeostasis: Regulating Blood Sugar
- Gas Exchange
- How Neurons Work
-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



Supplements

FOR INSTRUCTORS

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



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This area includes:

- PowerPoint Lecture Presentations
- Videos and Animations, including BioFlix®
- JPEG Images of most Art and Photos (labelled and unlabelled)
- Test Bank Files
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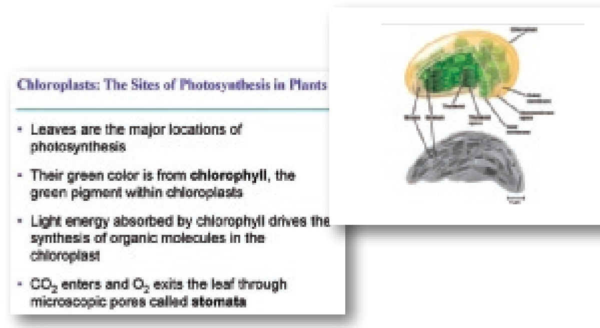

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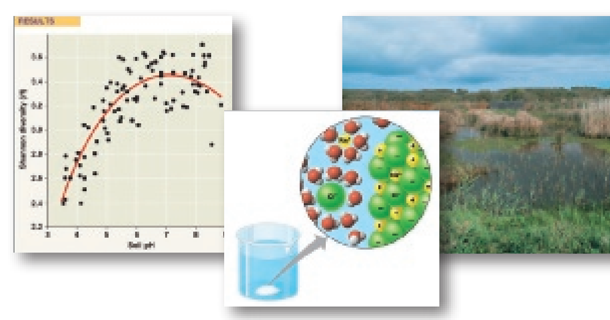

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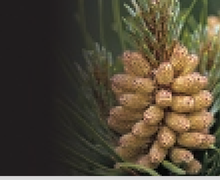

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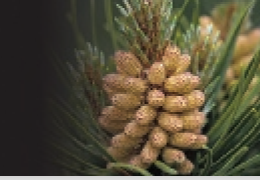

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1

Evolution, the Themes of Biology, and Scientific Inquiry

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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

Robert J Erwin/Science Source/ Getty Images

▲ **Release of pollen by a lodgepole pine.**

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

Inquiring About Life

The lodgepole pine (*Pinus contorta,* subspecies *latifolia*) tree is found extensively throughout western North America. This tree's male cones, shown in **Figure 1.1**, produce massive amounts of pollen, which travel by air to the female cones, also called seed cones **(Figure 1.2)**. Interestingly, some lodgepole pines produce seed cones that are adapted to fire and are sealed with a hard resin. The mature cones will only open if they are exposed to temperatures greater than 45°C, causing the resin bond to melt. The subsequent seed release allows for rapid tree regrowth after a fire, and could be an evolutionary adaptation to forest fires. Currently, lodgepole pine forests are experiencing extensive tree mortality due to mountain pine beetle outbreaks, which you'll learn more about in Chapters 31 and 54.

An organism's adaptations to its environment, such as adaptations for seed survival and dispersal, are the result of **evolution**, the process of change over time that has resulted in the astounding array of organisms found on Earth. Evolution is the fundamental principle of biology; it is the core theme of this text.

Although biologists know a great deal about life on Earth, many mysteries remain. Posing questions about the living world and seeking answers through scientific inquiry are the central activities of **biology**, the scientific study of life.

Kathy Merrifield/Science Source

◀ **Figure 1.2 Lodgepole pine pollen cones (above) and seed cone (below).**

Biologists' questions can be ambitious. They may ask how a dog or a tree develops from a single cell, how the human mind works, or how the different forms of life in a forest interact. When questions occur to you as you observe the natural world, you are 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 1.3** highlights some of the properties and processes we associate with life.

While limited to a handful of images, Figure 1.3 reminds us that the living world is wondrously varied. How do

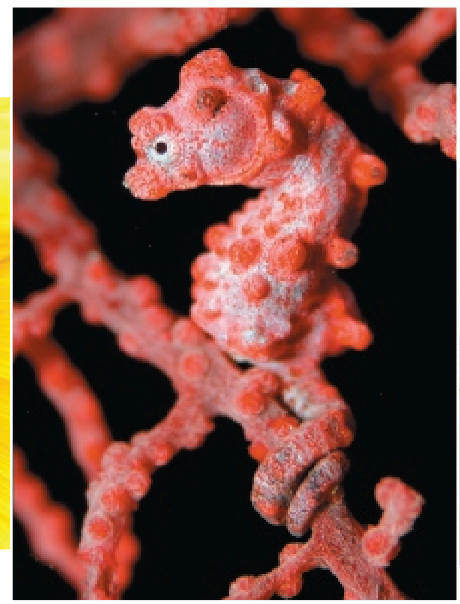
▼ **Order.** This close-up of a sunflower illustrates the highly ordered structure that characterizes life.

Tim Gainey/Alamy Stock Photo

ondrejprosicky/Fotolia

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

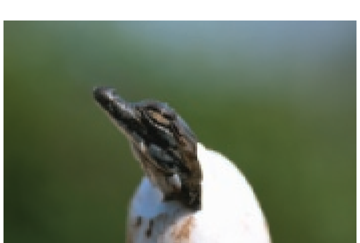
R. Dirscherl/OceanPhoto/Frank Lane Picture Agency Limited



▲ **Evolutionary adaptation.** The appearance of this pygmy seahorse 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.

Henry Ausloos/Photononstop/Getty Images

▲ **Regulation.** The regulation of blood flow through the blood vessels of this white-tailed jackrabbit's ears helps maintain a constant body temperature by adjusting heat exchange with the surrounding air.



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

▶ **Response to the environment.** Venus fly trap with trapped insect prey.

Nature Production/Nature Picture Library

▼ **Reproduction.** Organisms (living things) reproduce their own kind. Here, two baby polar bear cubs rest by their mother.

Francois Gohier/Science Source

▲ **Figure 1.3 Some properties of life.**

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 biology? Focusing on a few big ideas—ways of thinking about life that will still hold true decades from now—will help. Here, we'll describe five unifying themes to serve as touchstones as you proceed through this text:

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

Theme: New Properties Emerge at Successive Levels of Biological Organization

ORGANIZATION The study of life extends from the microscopic scale of the molecules and cells that make up organisms to the global scale of the entire living planet. As biologists, we can divide this enormous range into different levels of biological organization.

Imagine zooming in from space to take a closer and closer look at life on Earth. It is spring in Ontario, Canada, and our destination is a local forest, where we will eventually narrow our focus down to the molecules that make up a maple leaf. **Figure 1.4** narrates this journey into life, as the numbers guide you through photographs illustrating 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. Although it has propelled many major discoveries, reductionism provides a necessarily incomplete view of life on Earth, as we'll discuss next.

Emergent Properties

Let's reexamine Figure 1.4, beginning this time at the molecular level and then zooming out. Viewed this way, we see that at each level, novel properties emerge 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 to such nonliving examples, furthermore, 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 modelling the dynamic behaviour 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

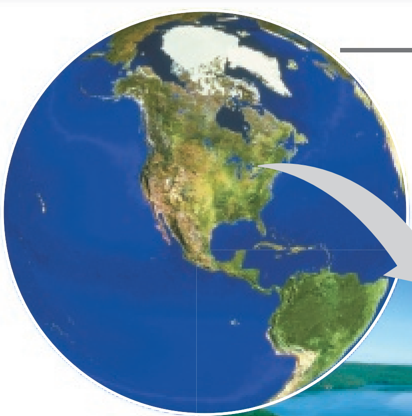
At each level of the biological hierarchy, we find a correlation of structure and function. Consider the leaf shown in Figure 1.4: Its thin, flat shape maximizes the capture of sunlight by chloroplasts. More generally, analyzing a biological structure gives us clues about what it does and how it works. 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 required activities. In fact, the actions of organisms are all based on the functions 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

▼ **Figure 1.4**

Exploring Levels of Biological Organization



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◀ 1 The Biosphere

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

Bill Brooks/Alamy Stock Photo

◀ 2 Ecosystems

Our first scale change brings us to a North American forest with many deciduous trees (trees that lose their leaves and grow new ones each year). A deciduous forest is an example of an ecosystem, as are grasslands, deserts, and coral reefs. An ecosystem consists of all the living things in a particular area, along with all the nonliving components of the environment with which life interacts, such as soil, water, atmospheric gases, and light.

Linda Freshwaters Arndt/Alamy Stock Photo

▶ 3 Communities

The array of organisms inhabiting a particular ecosystem is called a biological community. The community in our forest ecosystem includes many kinds of trees and other plants, various animals, mushrooms and other fungi, and enormous numbers of diverse microorganisms, which are living forms, such as bacteria, that are too small to see without a microscope. Each of these forms of life is called a *species*.

Michael Orton/Photographer's Choice/Getty Images

▶ 4 Populations

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

Ross M. Horowitz/The Image Bank/Getty Images

▲ 5 Organisms

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

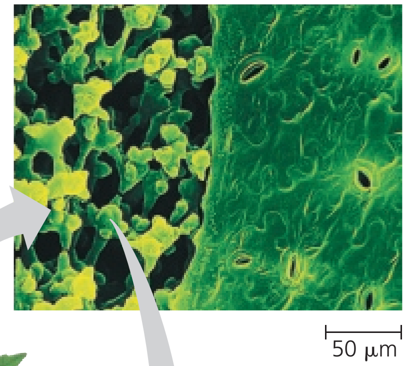
process that occurs on a global scale, such as the recycling of carbon atoms, is the product of cellular functions, including the photosynthetic activity of chloroplasts in leaf cells.

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

▼ 6 Organs and Organ Systems

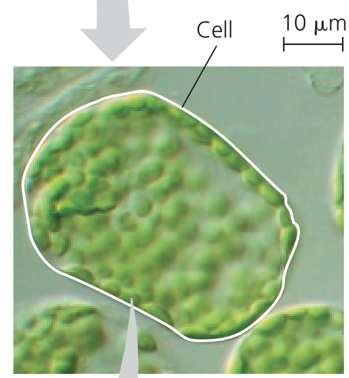
The structural hierarchy of life continues to unfold as we explore the architecture of more complex organisms. A maple leaf is an example of an organ, a body part that carries out a particular function in the body. Stems and roots are the other major organs of plants. The organs of complex animals and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

Jeremy Burgess/Science Source



◀ 7 Tissues

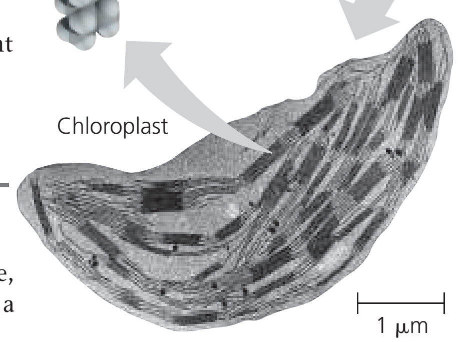
Viewing the tissues of a leaf requires a microscope. Each tissue is a group of cells that work together, performing a specialized function. The leaf shown here has been cut on an angle. The honeycombed tissue in the interior of the leaf (left side of photo) is the main location of photosynthesis, the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



Andreas Holzenburg/Stanislav Vitha, Dept. of Biology and Microscopy, Imaging Center, Texas A&M University, College Station

▲ 8 Cells

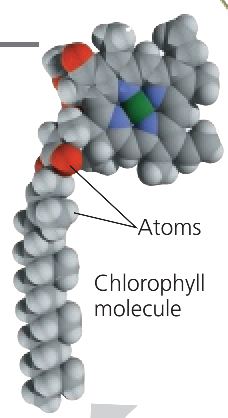
The cell is life's fundamental unit of structure and function. Some organisms are single cells, while others are multicellular. A single cell performs all the functions of life, while a multicellular organism has a division of labour among specialized cells. Here we see a magnified view of cells in a leaf tissue. One cell is about 40 micrometres (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.



E. H. Newcomb/W. P. Wergin/Biological Photo Service

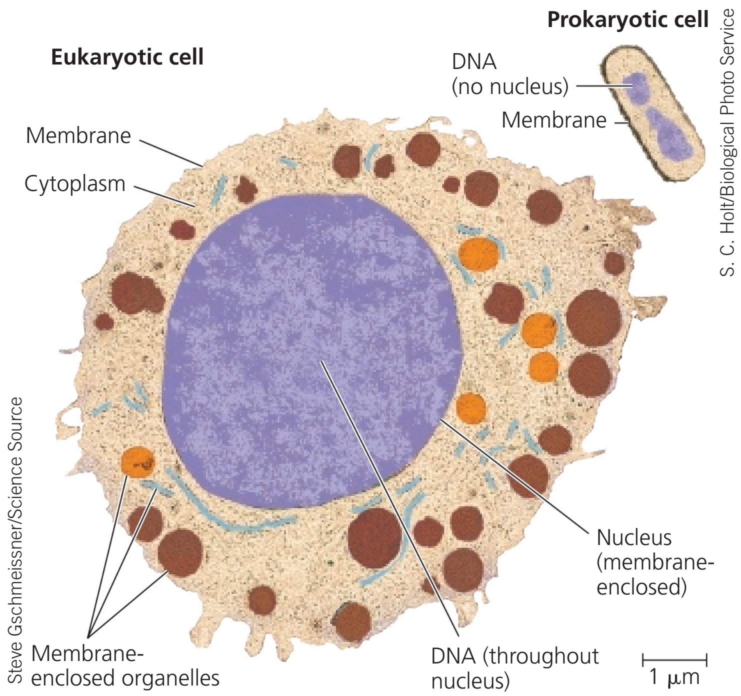
▶ 9 Organelles

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



▶ 10 Molecules

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



▲ **Figure 1.5 Contrasting eukaryotic and prokaryotic cells in size and complexity.**

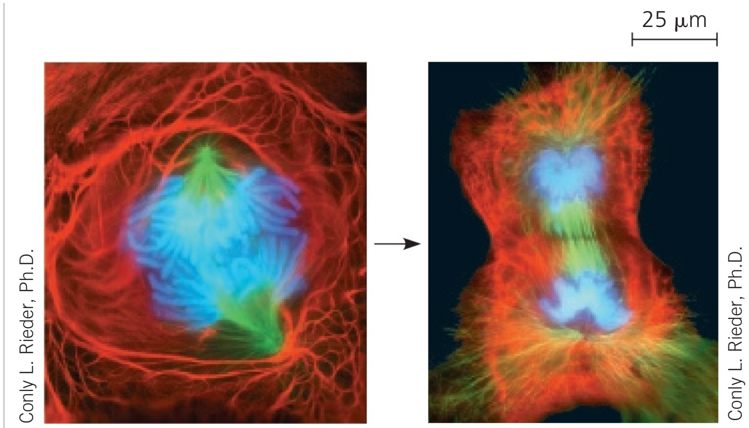
A **eukaryotic cell** contains membrane-enclosed organelles **(Figure 1.5)**. Some organelles, such as the DNA-containing nucleus, are found in the cells of all eukaryotes; other organelles are specific to particular cell types. For example, the chloroplast in Figure 1.4 is an organelle found only in eukaryotic cells that carry out photosynthesis. In contrast to eukaryotic cells, a **prokaryotic cell** lacks a nucleus and other membrane-enclosed organelles. Another distinction is that prokaryotic cells are generally smaller than eukaryotic cells, as shown in Figure 1.5.

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 1.6)**.

DNA, the Genetic Material

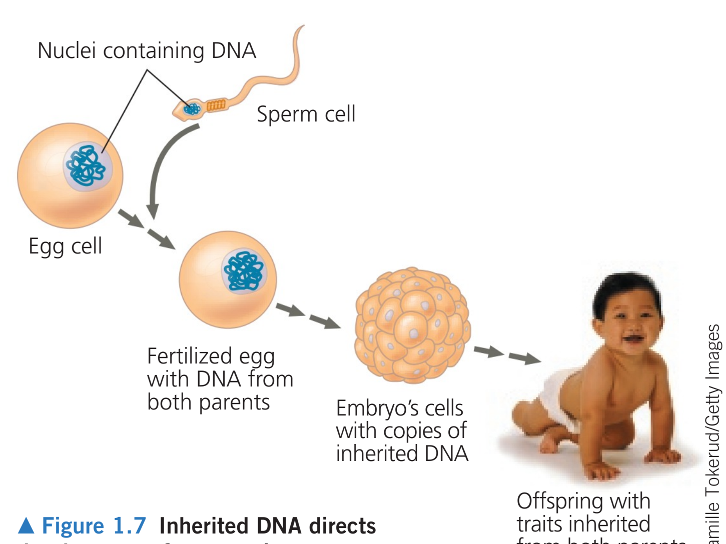
Each time a cell divides, the DNA is first replicated, or copied, and each of the two cellular offspring inherits a complete set of chromosomes, identical to that of the parent cell. Each chromosome contains one very long DNA molecule with hundreds or thousands of **genes**, each a stretch of DNA that is part 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



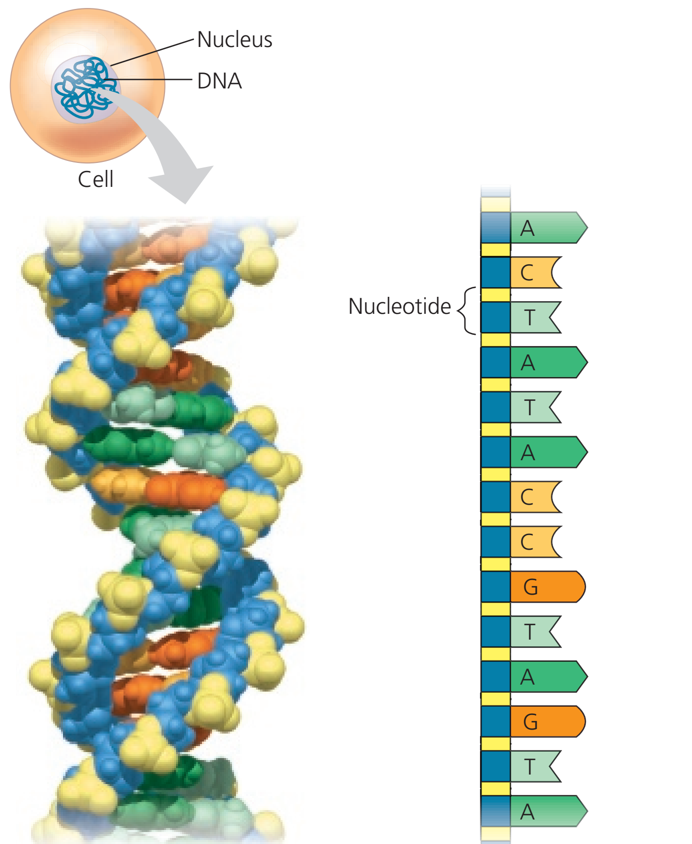
▲ **Figure 1.6 A lung cell from a newt divides into two smaller cells that will grow and divide again.**

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 1.7)**.

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 1.8)**. 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.



▲ **Figure 1.7 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 1.8 DNA: The genetic material.**

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 ribonucleic acid (RNA) as an intermediary (Figure 1.9). 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. Together, this results in a specific protein with a unique shape and function. This 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

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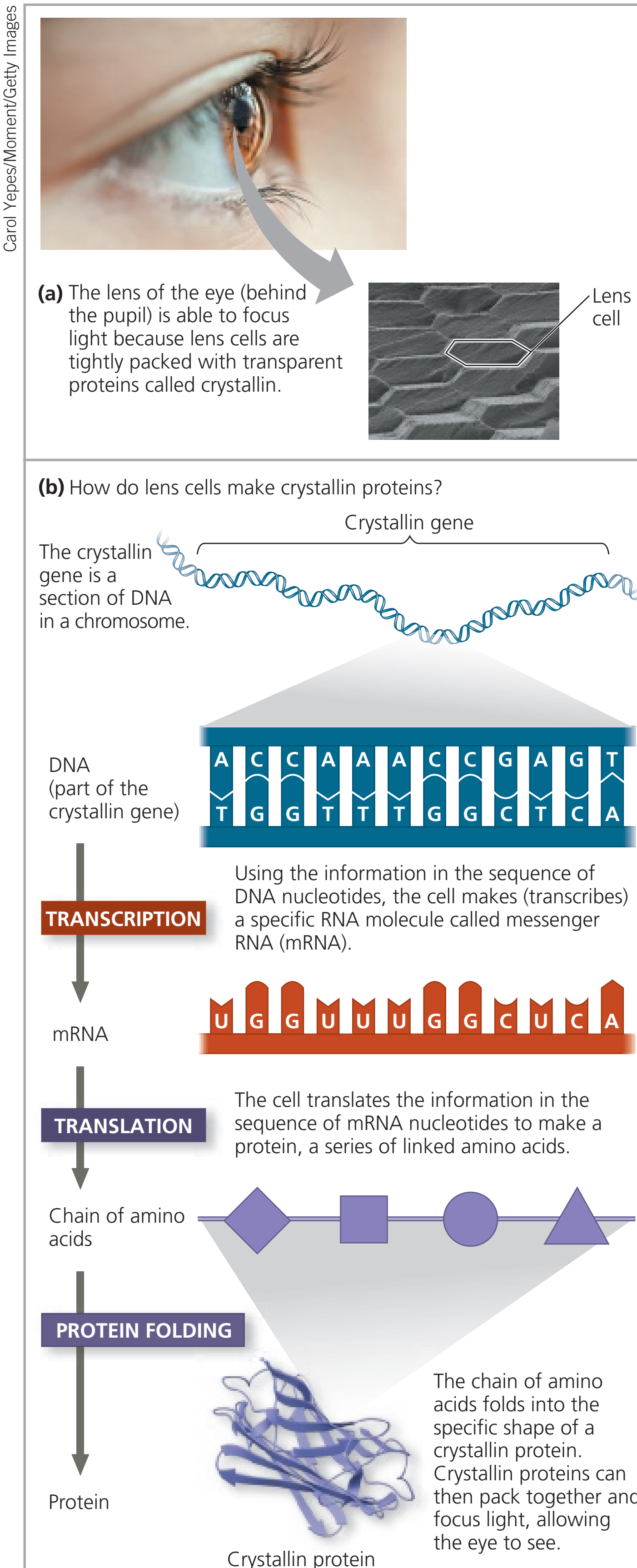


▲ **Figure 1.9 Gene expression: The transfer of information from a gene results in a functional protein.**

in another. Differences among organisms reflect differences among their nucleotide sequences rather than among 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.

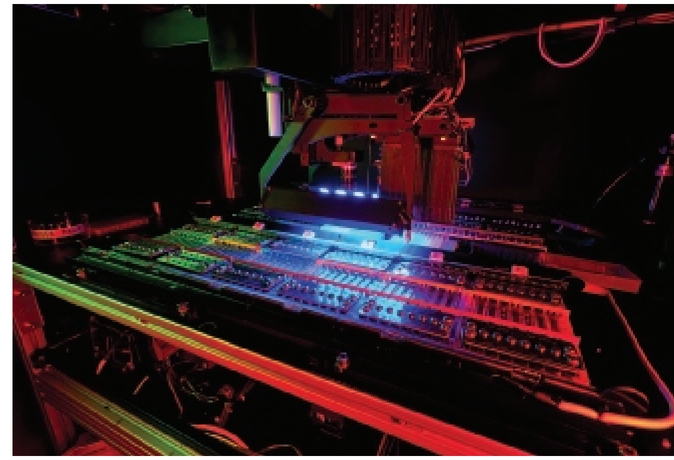
In addition to RNA molecules that are translated into proteins, some RNAs in the cell carry out other important tasks. For example, we have known for decades that some types of RNA are actually components of the cellular machinery that manufactures proteins. Recently, scientists have discovered whole 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 one strand in a set were written in letters the size of those you are now reading, the genetic text would fill about 700 biology textbooks.

Since the early 1990s, the pace at which researchers can determine the sequence of a genome has accelerated at an almost unbelievable 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 catalogue 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 in one or more species—an approach called **genomics**. Along similar lines, the term **proteomics** refers to the study of whole sets of proteins encoded by the genome (known as **proteomes**) and their interactions.

Three important research developments have made the genomic and proteomic approaches possible. One is "high-throughput" technology that can analyze many biological samples very rapidly (**Figure 1.10**). 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.



Martin Krzywinski/Science Source

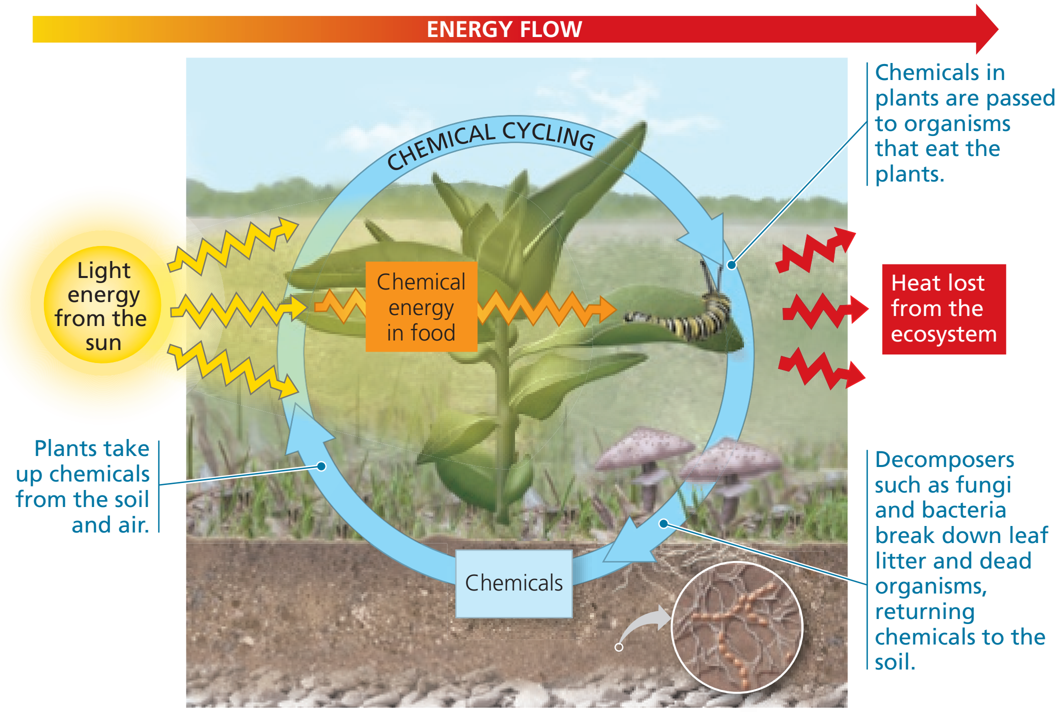
▲ **Figure 1.10 Biology as an information science.** Automatic DNA-sequencing machines and abundant computing power make the sequencing of genomes possible. This robotic DNA-sequencing machine is selecting DNA fragments for sequencing at Canada's Michael Smith Genome Sciences Centre in British Columbia.

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 chlorophyll 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 cells moving or cells dividing, 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 1.11**). 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, organic debris, and the bodies of dead organisms. The chemicals are then available to be taken up by plants again, thereby completing the cycle.

▶ **Figure 1.11 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 Molecules to Ecosystems, Interactions Are Important in Biological Systems

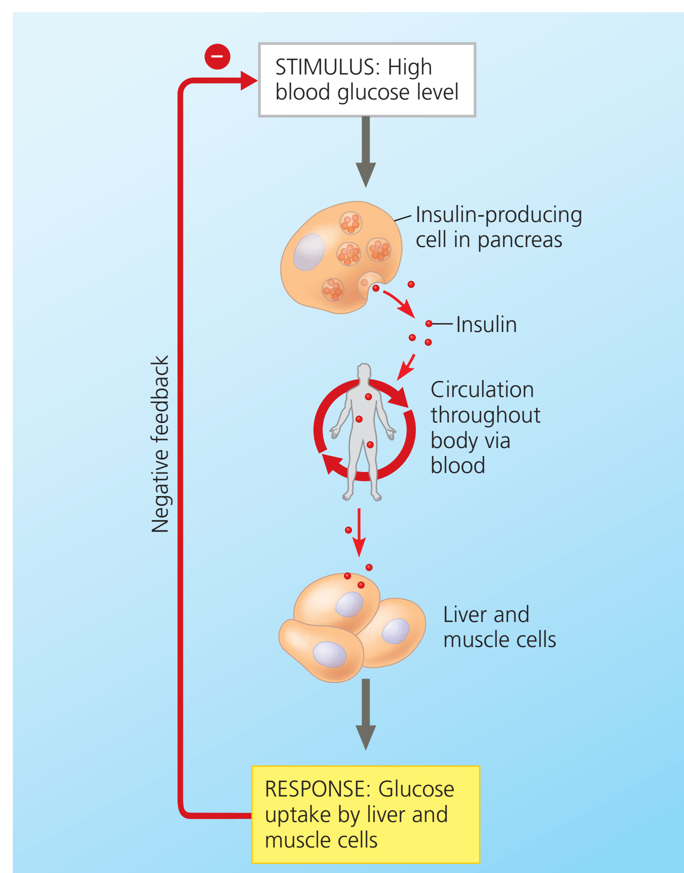
INTERACTIONS At any level of the biological hierarchy, interactions between the components of the system ensure smooth integration of all the parts, such that they function as a whole. This holds true equally well for molecules in a cell and the components of an ecosystem; we'll discuss both as examples.

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 regulation of blood sugar levels, for instance. Cells in the body must match the supply of fuel (sugar) to demand, regulating the opposing processes of sugar breakdown 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 signalling **(Figure 1.12)**, after a meal the level of the sugar glucose in your blood rises, which stimulates cells of the pancreas to secrete insulin. Insulin, in turn, causes body cells to take up glucose, thus decreasing blood glucose levels. This eliminates the stimulus for insulin secretion, 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



▲ **Figure 1.12 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.