GLOBAL EDITION

Campbell Essential Biology with Physiology

SIXTH EDITION

Simon • Dickey • Reece

Brief Contents

CAMPBELL

essential biology 6e

with physiology

GLOBAL EDITION

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KAO Two
KAO Park
Harlow
CM17 9SR
United Kingdom

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British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

ISBN 10: 1-292-30728-5
ISBN 13: 978-1-292-30728-2
eBook ISBN 13: 978-1-292-30729-9

Typeset by Integra Software Services Private Limited
Printed and bound by Vivar in Malaysia

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To my lifelong friends BZ, SR, and SR, who have taught me the value of loyalty and trust during decades of unwavering friendship

JEAN L. DICKEY

is Professor Emerita of Biological Sciences at Clemson University (Clemson, South Carolina). After receiving her B.S. in biology from Kent State University, she went on to earn a Ph.D. in ecology and evolution from Purdue University. In 1984, Dr. Dickey joined the faculty at Clemson, where she devoted her career to teaching biology to nonscience majors in a variety of courses. In addition to creating content-based instructional materials, she developed many activities to engage lecture and laboratory students in discussion, critical thinking, and writing, and implemented an investigative laboratory curriculum in general biology. Dr. Dickey is the author of *Laboratory Investigations for Biology*, 2nd Edition, and is a coauthor of *Campbell Biology: Concepts & Connections*, 9th Edition.

To my mother, who taught me to love learning, and to my daughters, Katherine and Jessie, the twin delights of my life

JANE B. REECE

was Neil Campbell's longtime collaborator and a founding author of *Campbell Essential Biology* and *Campbell Essential Biology with Physiology*. Her education includes an A.B. in biology from Harvard University (where she was initially a philosophy major), an M.S. in microbiology from Rutgers University, and a Ph.D. in bacteriology from the University of California, Berkeley. At UC Berkeley, and later as a postdoctoral fellow in genetics at Stanford University, her research focused on genetic recombination in bacteria. Dr. Reece taught biology at Middlesex County College (New Jersey) and Queensborough Community College (New York). Dr. Reece's publishing career began in 1978 when she joined the editorial staff of Benjamin Cummings, and since then, she played a major role in a number of successful textbooks. She was the lead author of *Campbell Biology* Editions 8–10 and a founding author of *Campbell Biology: Concepts & Connections*.

To my wonderful coauthors, who have made working on our books a pleasure

NEIL A. CAMPBELL

(1946–2004) combined the inquiring nature of a research scientist with the soul of a caring teacher. Over his 30 years of teaching introductory biology to both science majors and nonscience majors, many thousands of students had the opportunity to learn from him and be stimulated by his enthusiasm for the study of life. He is greatly missed by his many friends in the biology community. His coauthors remain inspired by his visionary dedication to education and are committed to searching for ever-better ways to engage students in the wonders of biology.

Preface

Biology education has been transformed in the last decade. The non-majors introductory biology course was (in most cases) originally conceived as a slightly less deep and broad version of the general biology course. But a growing recognition of the importance of this course—one that is often the most widely enrolled within the department, and one that serves as the sole source of science education for many students—has prompted a reevaluation of priorities and a reformulation of pedagogy. Many instructors have narrowed the focus of the course from a detailed compendium of facts to an exploration of broader themes within the discipline—themes such as the central role of evolution and an understanding of the process of science. For many educators, the goals have shifted from communicating a great number of bits of information toward providing a deep understanding of fewer, but broader, principles. Luckily for anyone teaching or learning biology, opportunities to marvel at the natural world and the life within it abound. Furthermore, nearly everyone realizes that the subject of biology has a significant impact on his or her own life through its connections to medicine, biotechnology, agriculture, environmental issues, forensics, and many other areas. Our primary goal in writing *Campbell Essential Biology with Physiology* is to help teachers motivate and educate the next generation of citizens by communicating the broad themes that course through our innate curiosity about life.

Goals of the Book

Although our world is rich with "teachable moments" and learning opportunities, an explosion of knowledge threatens to bury a curious person under an avalanche of information. "So much biology, so little time" is the universal lament of biology educators. Neil Campbell conceived of *Campbell Essential Biology with Physiology* as a tool to help teachers and students focus on the most important areas of biology. To that end, the book is organized into six core areas: cells, genes, evolution, ecology, animal physiology, and plant physiology. Dr. Campbell's vision, which we carry on and extend in this edition, has enabled us to keep *Campbell Essential Biology with Physiology* manageable in size and thoughtful in the development of the concepts that are most fundamental to understanding life. We've aligned this new edition with today's "less is more" approach in biology education for nonscience majors—where the emphasis is on fewer topics but broader themes—while never allowing the important content to be diluted.

We formulated our approach after countless conversations with teachers and students in which we noticed some important trends in how biology is taught. In particular, many instructors identify three goals: (1) to engage students by relating biology content to their lives and the greater society; (2) to help students understand the process of science by teaching critical thinking skills that can be used in everyday life; and (3) to demonstrate how biology's broader themes—such as evolution and the relationship of structure to function—serve to unify the entire subject. To help achieve these goals, every chapter of this book includes several important features. First, a chapter-opening essay called Biology and Society highlights a connection between the chapter's core content and students' lives. Second, an essay called The Process of Science (in the body of the chapter) describes how the scientific process has illuminated the topic at hand, using a classic or modern experiment as an example. Third, a chapter-closing Evolution Connection essay relates the chapter to biology's unifying theme of evolution. Fourth, the broad themes that unify all subjects within biology are explicitly called out (in blue) multiple times within each chapter. Finally, to maintain a cohesive narrative throughout each chapter, the content is tied together with a unifying chapter thread, a relevant high-interest topic that is touched on several times in the chapter and woven throughout the three feature essays. Thus, this unifying chapter thread ties together the pedagogical goals of the course, using a topic that is compelling and relevant to students.

New to This Edition

This latest edition of *Campbell Essential Biology with Physiology* goes even further than previous editions to help students relate the material to their lives, understand the process of science, and appreciate how broad themes unify all aspects of biology. To this end, we've added significant new features and content to this edition:

- **A new approach to teaching the process of science.** Conveying the process of science to nonscience-major undergraduate students is one of the most important goals of this course. Traditionally, we taught the scientific method as a predefined series of steps to be followed in an exact order (observation, hypothesis, experiment, and so forth). Many instructors have shifted away from such a specific flow chart to a more nuanced approach that involves multiple pathways, frequent restarts, and other features that more accurately reflect how science is actually undertaken. Accordingly, we have revised the way that the process of science is discussed within our text, both in Chapter 1 (where the process is discussed in detail) and in The Process of Science essay in every chapter of the textbook. Rather than using specific terms in a specific order to describe the process, we now divide it into three broad interrelated areas: background, method, and results. We believe that this new approach better conveys how science actually proceeds and demystifies the topic for non-scientists. Chapter 1 also contains important information that promotes critical thinking, such as discussion of control groups, pseudoscience, and recognizing reliable sources of information. We believe that providing students with such critical-thinking tools is one of the most important outcomes of the nonscience-major introductory course.
- **Major themes in biology incorporated throughout the book.** In 2009, the American Association for the Advancement of Science published a document that served as a call to action in undergraduate biology education.

The principles of this document, which is titled "Vision and Change," are becoming widely accepted throughout the biology education community. "Vision and Change" presents five core concepts that serve as the foundation of undergraduate biology. In this edition of *Campbell Essential Biology with Physiology,* we repeatedly and explicitly link book content to themes multiple times in each chapter, calling out such instances with boldfaced blue text. For example, in Chapter 4 (A Tour of the Cell), the interrelationships of cellular structures are used to illustrate the theme of interactions within biological systems. The plasma membrane is presented as an example of the relationship between structure and function. The cellular structures in the pathway from DNA to protein are used to illustrate the importance of information flow. The chloroplasts and mitochondria serve as an example of the transformations of energy and matter. The DNA within these structures is also used to illustrate biology's overarching theme of evolution. Students will find three to five examples of themes called out in each chapter, which will help them see the connections between these major themes and the course content. To reinforce these connections, this edition of *Campbell Essential Biology with Physiology* includes new end-of-chapter questions and Mastering Biology activities that promote critical thinking relating to these themes. Additionally, PowerPoint® lecture slides have been updated to incorporate chapter examples and offer guidance to faculty on how to include in these themes within classroom lectures.

- **Updated connections to students' lives.** In every edition of *Campbell Essential Biology with Physiology*, we seek to improve and extend the ways that we connect the course content to students' lives. Accordingly, every chapter begins with an improved feature called Why It Matters showing the relevance of the chapter content from the very start. Additionally, with every edition, we introduce some new unifying chapter threads intended to improve student relevance. For example, this edition includes new threads that discuss evolution in a human-dominated world (Chapter 14) and the importance of biodiversity to human affairs (Chapter 20). As always, we include some updated Biology and Society chapter-opening essays (such as "A Solar Revolution" in Chapter 7), The Process of Science sections (such as a recent experiment investigating the efficacy of radiation therapy to treat prostate cancer, in Chapter 2), and Evolution Connection chapter-closing essays (such as an updated discussion of biodiversity hot spots in Chapter 20). As we always do, this edition includes many content updates that connect to students' lives, such as information on cutting-edge cancer therapies (Chapter 8) and recent examples of DNA profiling (Chapter 12).
- **Developing data literacy through infographics.** Many nonscience-major students express anxiety when faced with numerical data, yet the ability to interpret data can help with many important decisions we all face. Increasingly, the general public encounters information in the form of infographics, visual images used to represent data. Consistent with our goal of preparing students to approach important issues critically, this edition includes a series of new infographics, or Visualizing the Data figures. Examples include the elemental composition of the human body (Chapter 2), a comparison of calories burned through exercise versus calories consumed in common foods (Chapter 5), and ecological footprints (Chapter 19). In addition to the printed form, these infographics are available as assignable tutorial questions within Mastering Biology.
- **Helping students to understand key figures.** For this new edition, a key figure in each chapter is supplemented by a short video explaining the concept to the student. These Figure Walkthrough videos will be assignable in Mastering Biology. The animations are written and narrated by authors Eric Simon and Jean Dickey, as well as teacher and contributor Rebecca Burton.

Attitudes about science and scientists are often shaped by a single, required science class—*this* class. We hope to nurture an appreciation of nature into a genuine love of biology. In this spirit, we hope that this textbook and its supplements will encourage all readers to make biological perspectives a part of their personal worldviews. Please let us know how we are doing and how we can improve the next edition of *Campbell Essential Biology with Physiology*.

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The following Visual Walkthrough highlights key features of *Campbell Essential Biology with Physiology* 6e.

Develop and practice science literacy skills

Learn how to view your world using scientific reasoning with *Campbell Essential Biology with Physiology*. See how concepts from class and an understanding of how science works can apply to your everyday life. Engage with the concepts and practice science literacy skills with Mastering Biology and Pearson eText.

NEW! New and updated Process of Science essays present scientific discovery as a flexible and non-linear process.

Each essay summarizes the **background, method,** and **results** from a scientific study.

New Thinking Like a Scientist questions appear at the end of each Process of Science essay and involve applying a scientific reasoning skill.

Examples of new Process of Science topics include:

- Chapter 4: How Was the First 21st-Century Antibiotic Discovered? p. 95
- Chapter 9: What Is the Genetic Basis of Short Legs in Dogs? p.190
- Chapter 11: Can Avatars Improve Cancer Treatment? p.244
- Chapter 16: What Killed the Pines? p.364
- Chapter 20: Does Biodiversity Protect Human Health? p.480

9 PATTERNS OF INHERITANCE

THE PROCESS OF SCIENCE Dog Breeding

What Is the Genetic Basis of Short Legs in Dogs?

BACKGROUND

It's obvious that dogs come in a wide variety of physical types. In fact, domesticated dogs display the greatest range of phenotypes of any mammal. One of the most striking features that distinguishes some breeds is chondrodysplasia, a condition that affects the growth of bones in the leg. The resulting shortened, curved bones are a defining characteristic of a few dog breeds **(Figure 9.16a)**. Through test crosses, breeders have long known that the short-legged trait is dominant, but nothing was known about the cause of the phenotype.

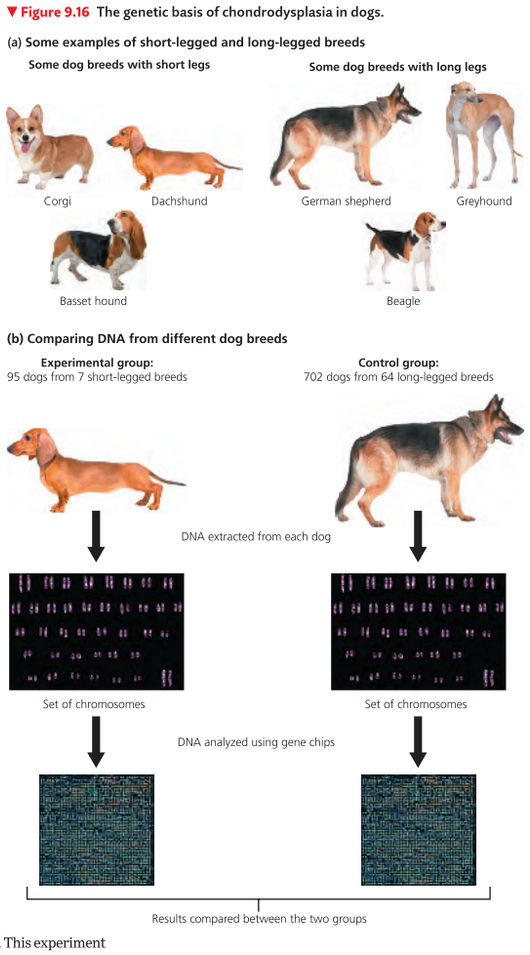
METHOD

A group of researchers set out to discover the genetic basis of the short-legged phenotype. They used an automated gene chip (see Figure 11.10) to examine the DNA of 95 dogs from 7 short-legged breeds (the experimental group) and 702 dogs from 64 breeds with long legs (the control group). They compared the results to identify any differences between the two groups at thousands of sites across the dog genome **(Figure 9.16b)**.

RESULTS

One location on chromosome 18 stood out for being strongly associated with short legs. Closer examination of the region surrounding that location revealed a gene that codes for a protein called fibroblast growth factor 4. The protein produced by this gene is known to be associated with the growth of legs during embryonic development. The researchers identified a specific change in the chromosome that corresponded to short legs. Interestingly, they were able to link the effect of this gene in dogs to a related protein associated with the most common form of human dwarfism. This experiment shows how animal models may provide insight into genetic conditions in humans.

▼ **Figure 9.16** The genetic basis of chondrodysplasia in dogs.



Thinking Like a Scientist

Why might it be easier to find the genetic basis for a physical condition in dogs than to do so in humans?

For the answer, see Appendix D.

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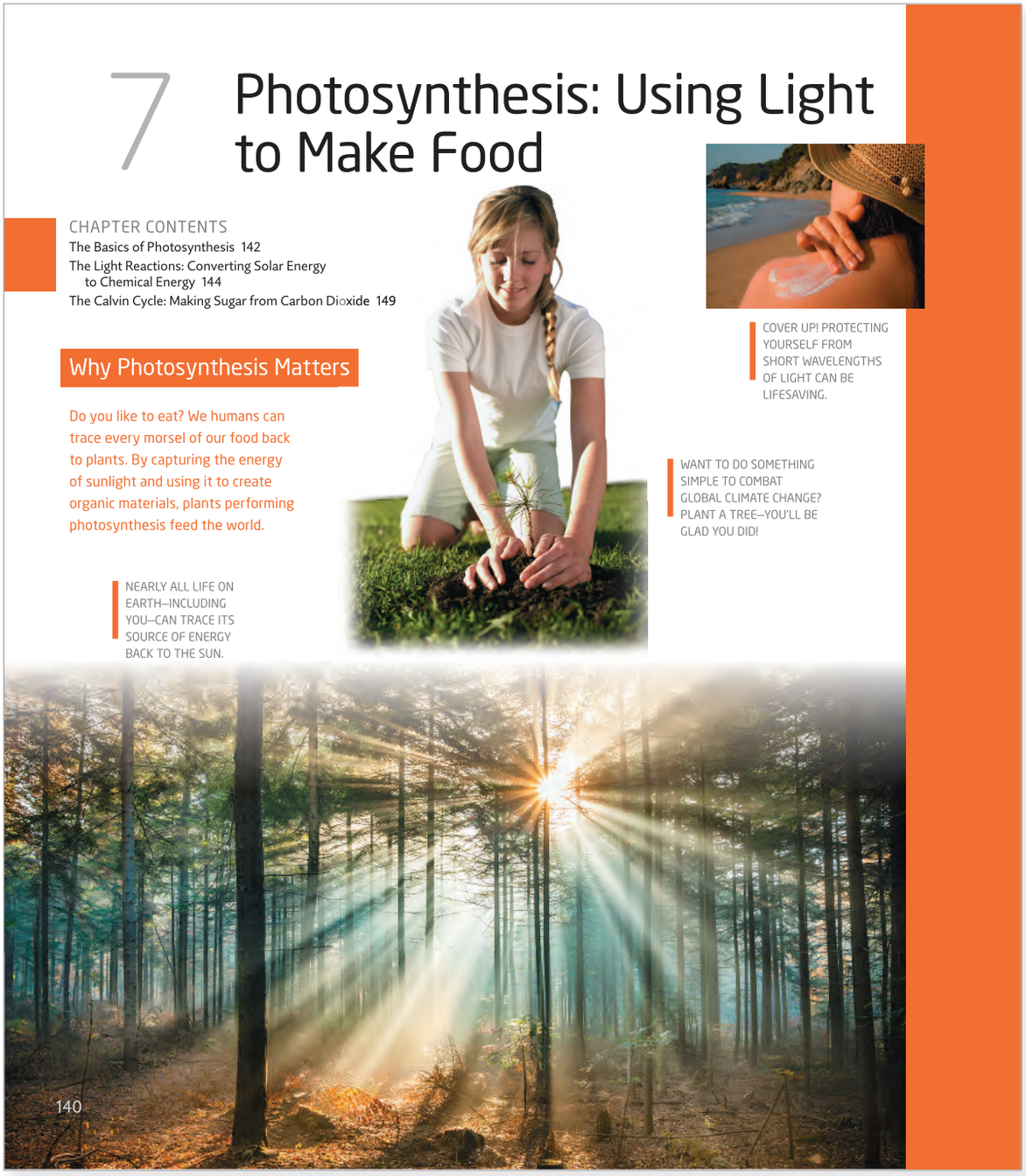
NEW! A new organization and new content in Chapter 1 focus on science literacy skills to introduce the process of science right from the start.

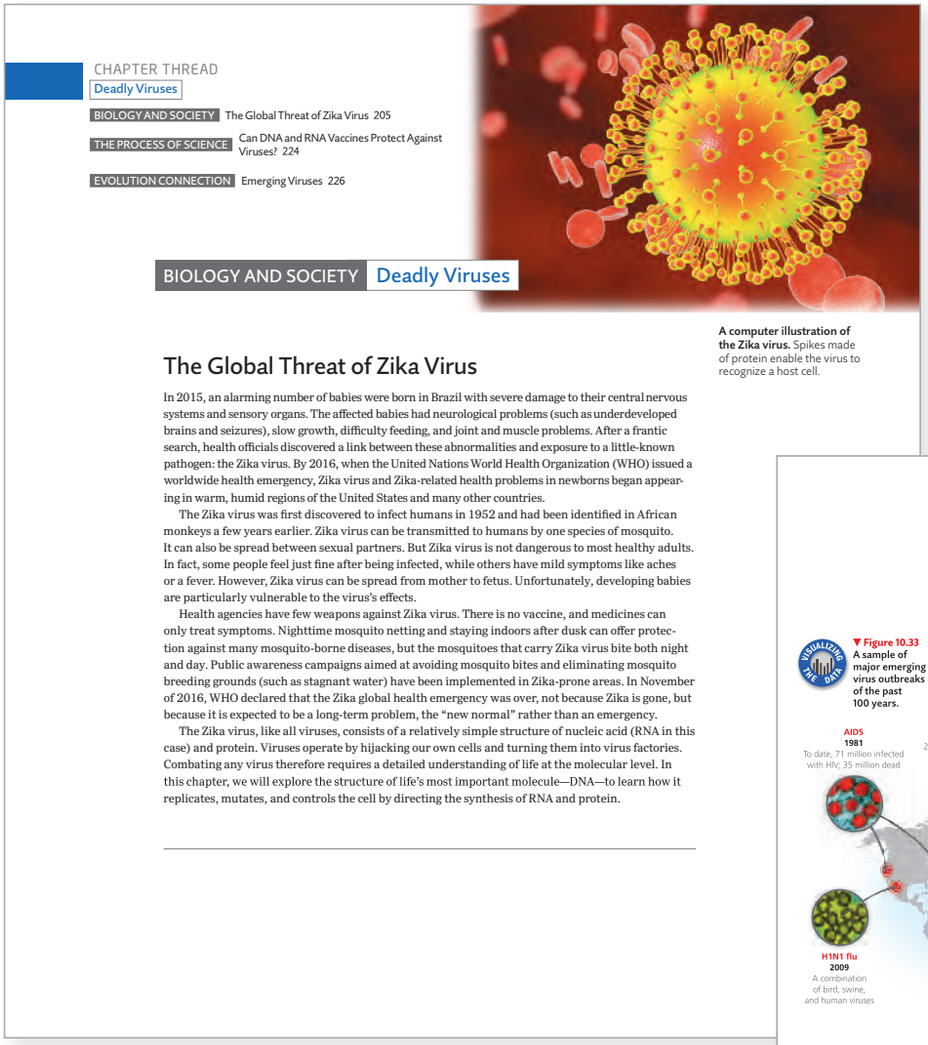
Explore biology with . . .



Why It Matters Photo Collages have been updated to give real-world examples to convey why abstract concepts like cellular respiration or photosynthesis matter.

. . . the most relevant, real-world examples

New and Updated Chapter Threads weave a compelling topic throughout each chapter, highlighted in the Biology and Society, The Process of Science, and Evolution Connection essays.



CHAPTER THREAD
Deadly Viruses

BIOLOGY AND SOCIETY The Global Threat of Zika Virus 205

THE PROCESS OF SCIENCE Can DNA and RNA Vaccines Protect Against Viruses? 224

EVOLUTION CONNECTION Emerging Viruses 226

BIOLOGY AND SOCIETY Deadly Viruses

A computer illustration of the Zika virus. Spikes made of protein enable the virus to recognize a host cell.

The Global Threat of Zika Virus

In 2015, an alarming number of babies were born in Brazil with severe damage to their central nervous systems and sensory organs. The affected babies had neurological problems (such as underdeveloped brains and seizures), slow growth, difficulty feeding, and joint and muscle problems. After a frantic search, health officials discovered a link between these abnormalities and exposure to a little-known pathogen: the Zika virus. By 2016, when the United Nations World Health Organization (WHO) issued a worldwide health emergency, Zika virus and Zika-related health problems in newborns began appearing in warm, humid regions of the United States and many other countries.

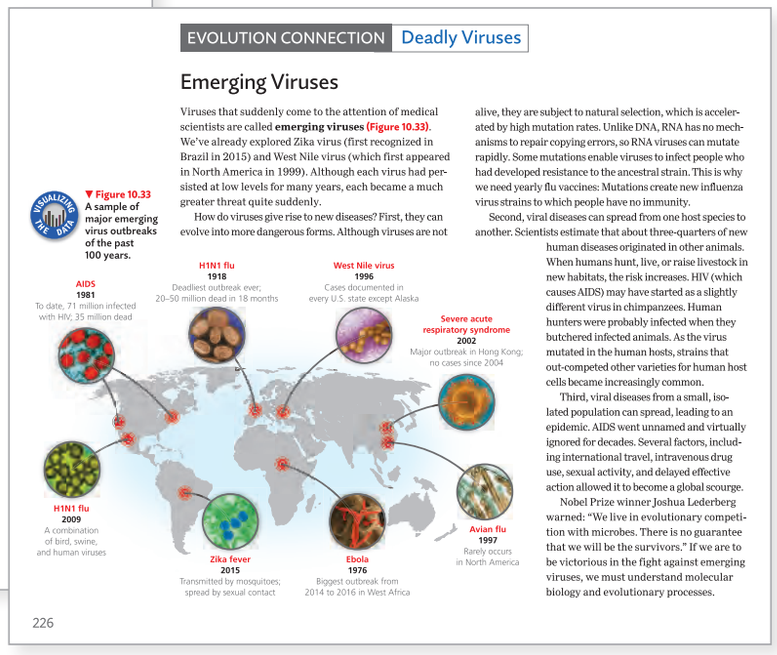
The Zika virus was first discovered to infect humans in 1952 and had been identified in African monkeys a few years earlier. Zika virus can be transmitted to humans by one species of mosquito. It can also be spread between sexual partners. But Zika virus is not dangerous to most healthy adults. In fact, some people feel just fine after being infected, while others have mild symptoms like aches or a fever. However, Zika virus can be spread from mother to fetus. Unfortunately, developing babies are particularly vulnerable to the virus's effects.

Health agencies have few weapons against Zika virus. There is no vaccine, and medicines can only treat symptoms. Nighttime mosquito netting and staying indoors after dusk can offer protection against many mosquito-borne diseases, but the mosquitoes that carry Zika virus bite both night and day. Public awareness campaigns aimed at avoiding mosquito bites and eliminating mosquito breeding grounds (such as stagnant water) have been implemented in Zika-prone areas. In November of 2016, WHO declared that the Zika global health emergency was over, not because Zika is gone, but because it is expected to be a long-term problem, the "new normal" rather than an emergency.

The Zika virus, like all viruses, consists of a relatively simple structure of nucleic acid (RNA in this case) and protein. Viruses operate by hijacking our own cells and turning them into virus factories. Combating any virus therefore requires a detailed understanding of life at the molecular level. In this chapter, we will explore the structure of life's most important molecule—DNA—to learn how it replicates, mutates, and controls the cell by directing the synthesis of RNA and protein.

NEW!
New Chapter Threads include:

- Chapter 1: Swimming with the Turtles
- Chapter 2: Helpful Radiation
- Chapter 7: Solar Energy
- Chapter 13: Evolution in Action
- Chapter 14: Evolution in the Human-Dominated World
- Chapter 20: Importance of Biodiversity



EVOLUTION CONNECTION Deadly Viruses

Emerging Viruses

Viruses that suddenly come to the attention of medical scientists are called **emerging viruses** (Figure 10.33). We've already explored Zika virus (first recognized in Brazil in 2015) and West Nile virus (which first appeared in North America in 1999). Although each virus had persisted at low levels for many years, each became a much greater threat quite suddenly.

How do viruses give rise to new diseases? First, they can evolve into more dangerous forms. Although viruses are not alive, they are subject to natural selection, which is accelerated by high mutation rates. Unlike DNA, RNA has no mechanisms to repair copying errors, so RNA viruses can mutate rapidly. Some mutations enable viruses to infect people who had developed resistance to the ancestral strain. This is why we need yearly flu vaccines: Mutations create new influenza virus strains to which people have no immunity.

Second, viral diseases can spread from one host species to another. Scientists estimate that about three-quarters of new human diseases originated in other animals. When humans hunt, live, or raise livestock in new habitats, the risk increases. HIV (which causes AIDS) may have started as a slightly different virus in chimpanzees. Human hunters were probably infected when they butchered infected animals. As the virus mutated in the human hosts, strains that out-competed other varieties for human host cells became increasingly common.

Third, viral diseases from a small, isolated population can spread, leading to an epidemic. AIDS went unnamed and virtually ignored for decades. Several factors, including international travel, intravenous drug use, sexual activity, and delayed effective action allowed it to become a global scourge.

Nobel Prize winner Joshua Lederberg warned: "We live in evolutionary competition with microbes. There is no guarantee that we will be the survivors." If we are to be victorious in the fight against emerging viruses, we must understand molecular biology and evolutionary processes.

VISUALIZING LIFE DATA

▼ Figure 10.33 A sample of major emerging virus outbreaks of the past 100 years.

AIDS
1981
To date, 71 million infected with HIV; 35 million dead

H1N1 flu
1918
Deadliest outbreak ever; 20–50 million dead in 18 months

West Nile virus
1996
Cases documented in every U.S. state except Alaska

Severe acute respiratory syndrome
2002
Major outbreak in Hong Kong; no cases since 2004

H1N1 flu
2009
A combination of bird, swine, and human viruses

Zika fever
2015
Transmitted by mosquitoes; spread by sexual contact

Ebola
1976
Biggest outbreak from 2014 to 2016 in West Africa

Avian flu
1997
Rarely occurs in North America

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Biology and Society essays

relating biology to everyday life are either new or updated. Some new topics:

- Chapter 7: A Solar Revolution p. 141
- Chapter 10: The Global Threat of Zika Virus p. 205
- Chapter 14: Humanity's Footprint p. 303
- Chapter 17: Evolving Adaptability p. 371

Evolution Connection essays

demonstrate the importance of evolution as a theme throughout biology, by appearing in every chapter.
Some new topics:

- Chapter 1 Turtles in the Tree of Life p. 52
- Chapter 10 Emerging Viruses p. 226
- Chapter 20 Saving the Hot Spots p. 483
- Chapter 27 A Neurotoxin Arms Race p. 633

Complex biological processes are explained . . .

Mastering™ Biology is an online homework, tutorial, and assessment platform that improves results by helping students quickly master concepts.

A wide range of interactive, engaging, and assignable activities, many of them contributed by *Campbell Essential Biology with Physiology* authors, encourage active learning and help with understanding tough course concepts.

NEW! 29 Figure Walkthrough Videos, created and narrated by the authors, give clear, concise explanations of key figures in each chapter. The videos are accessible through QR codes in the print text, and assignable in Mastering Biology.

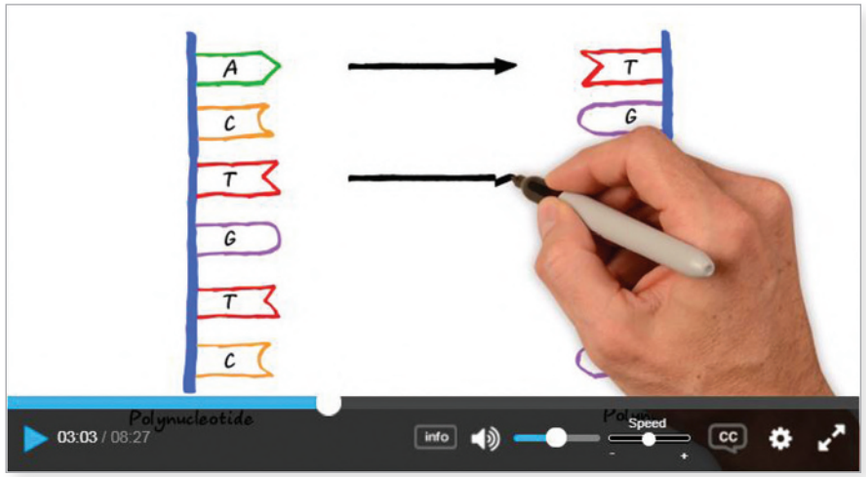
NEW! Visualizing the Data coaching activities bring the infographic figures in the text to life and are assignable in Mastering Biology.

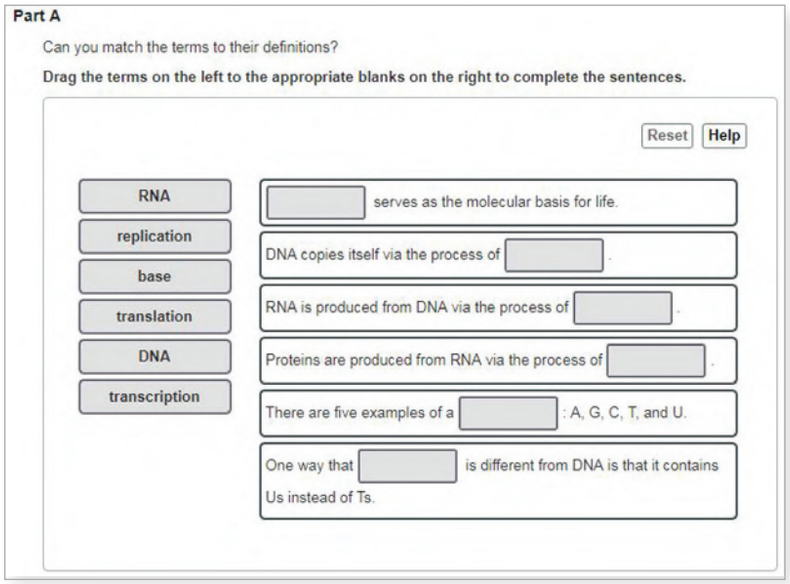
. . . with engaging visuals and narrated examples in Mastering Biology

12 Topic Overview videos, created by the authors, introduce key concepts and vocabulary. These brief, engaging videos introduce topics that will be explored in greater depth in class.

Topics include:

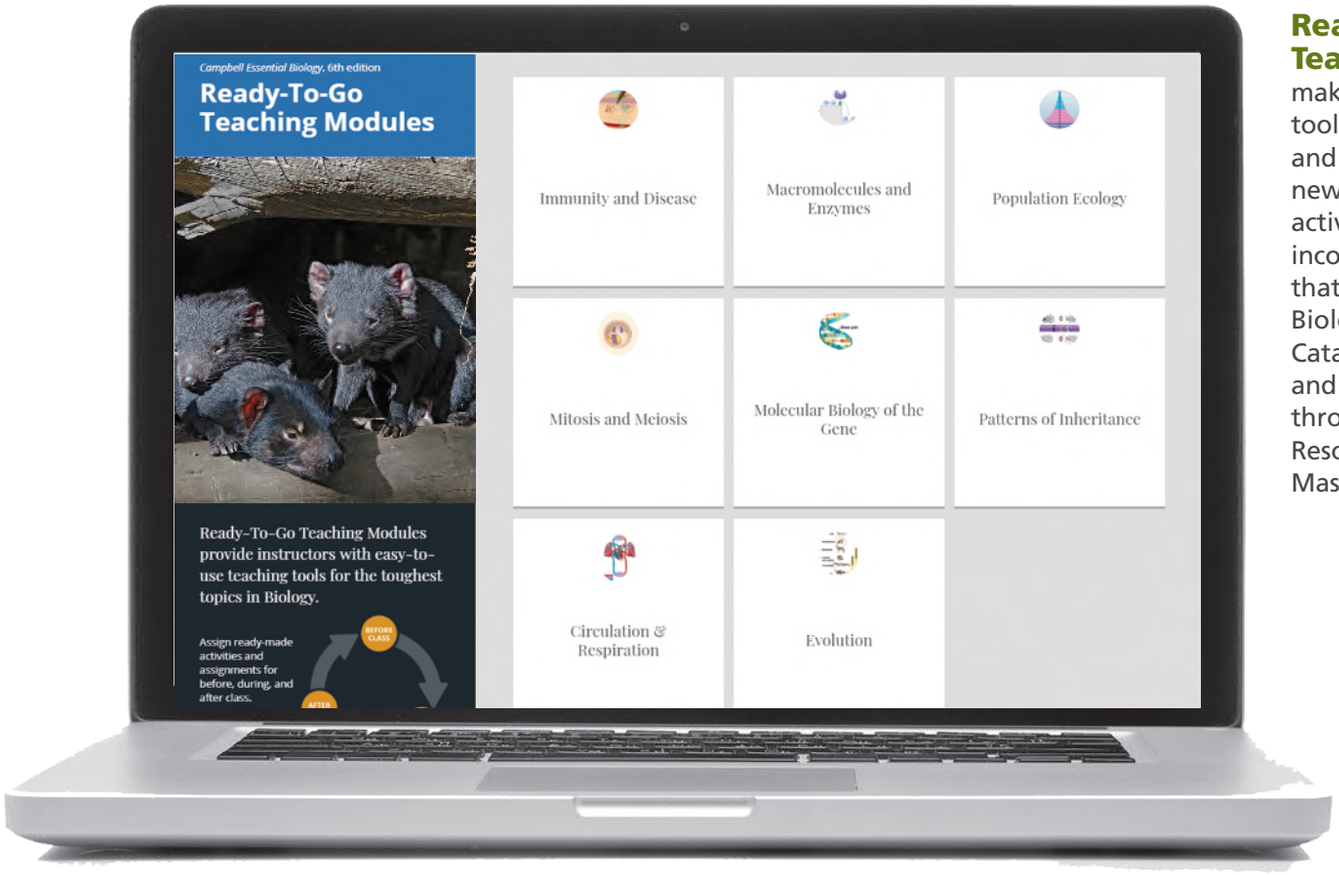
– Macromolecules
– Ecological Organization
– Mechanisms of Evolution
– An Introduction to Structure and Function
– Interactions Between the Respiratory and Circulatory Systems
– DNA Structure and Function
. . . And more!





BioInteractive Short Films from HHMI, Video Tutors, BioFlix® 3D animations, and MP3 Audio Tutors support key concept areas covered in the text and provide coaching by using personalized feedback on common wrong answers.

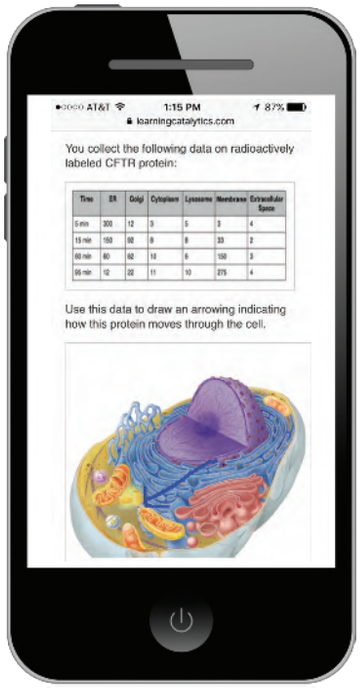
New approaches to teaching and learning . . .



Ready-to-Go Teaching Modules make use of teaching tools for before, during, and after class, including new ideas for in-class activities. These modules incorporate the best that the text, Mastering Biology, and Learning Catalytics have to offer and can be accessed through the Instructor Resources area of Mastering Biology.

Learning Catalytics™ helps generate class discussion, customize lectures, and promote peer-to-peer learning with real-time analytics. Learning Catalytics acts as a student response tool that uses students' smartphones, tablets, or laptops to engage them in more interactive tasks and thinking.

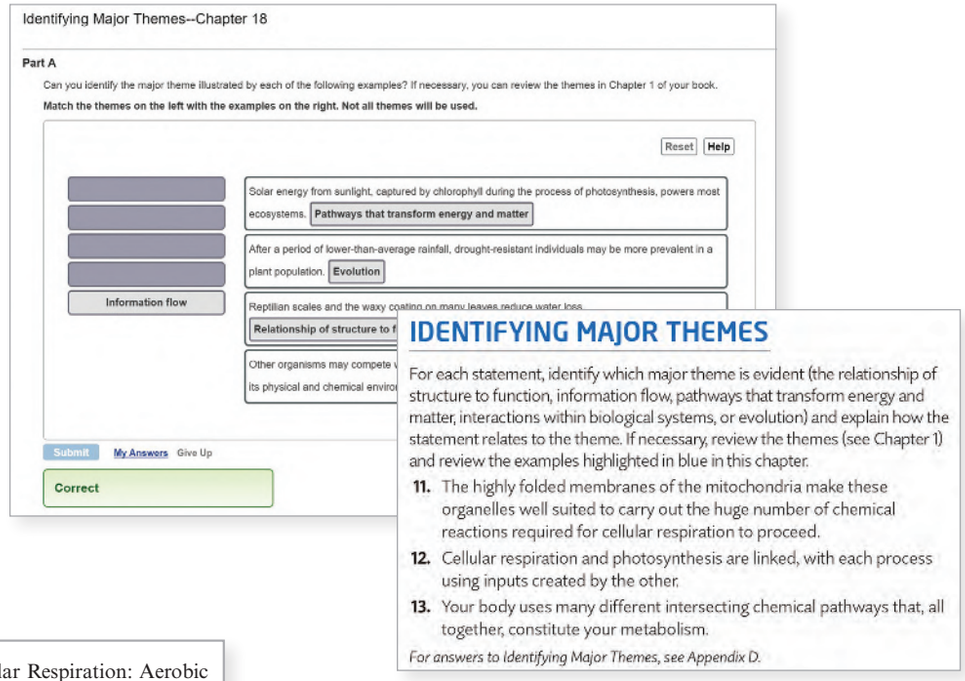
- Help your students develop critical thinking skills
- Monitor responses to find out where your students are struggling
- Rely on real-time data to adjust your teaching strategy



. . . and the resources to accomplish them

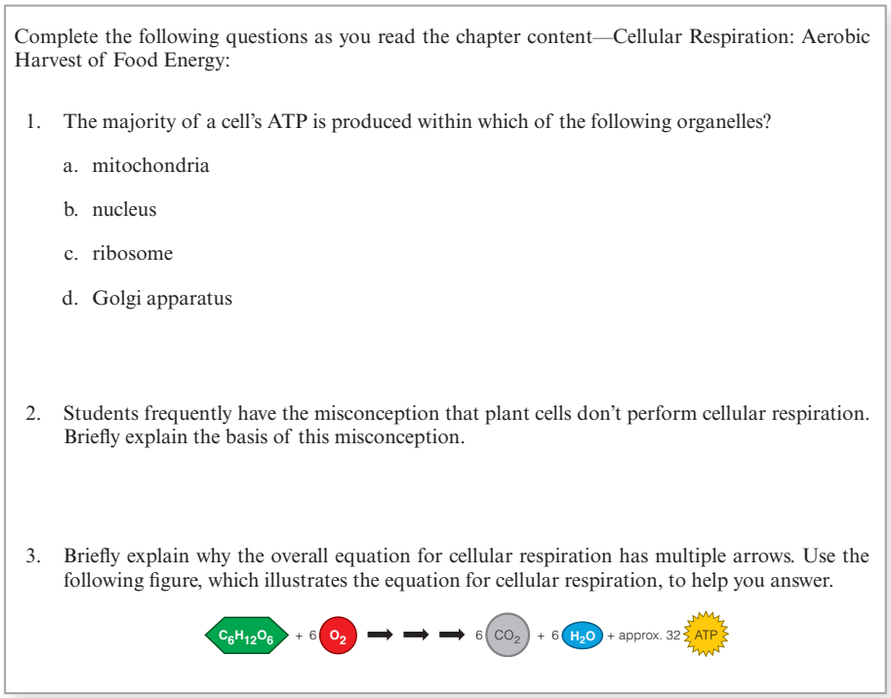
Extensive resources save instructors valuable time both in course preparation and during class. Instructor materials can be accessed and downloaded from the Instructor Resources area of Mastering Biology.
www.pearson.com/mastering/biology

New! Identifying Major Themes end-of-chapter questions in the text and coaching activities in Mastering Biology give instructors resources to integrate Vision and Change biological themes into their course.



Revised Guided Reading Activities

in the Mastering Biology Study Area and Instructor Resources offer a simple resource that encourages students to get the most out of each text chapter. These worksheets accompany each chapter of the text and are downloadable from Mastering Biology.



Complete the following questions as you read the chapter content—Cellular Respiration: Aerobic Harvest of Food Energy:

1. The majority of a cell's ATP is produced within which of the following organelles?
   a. mitochondria
   b. nucleus
   c. ribosome
   d. Golgi apparatus

2. Students frequently have the misconception that plant cells don't perform cellular respiration. Briefly explain the basis of this misconception.

3. Briefly explain why the overall equation for cellular respiration has multiple arrows. Use the following figure, which illustrates the equation for cellular respiration, to help you answer.

$C_6H_{12}O_6$ + 6 O_2 → 6 CO_2 + 6 H_2O + approx. 32 ATP

The **Instructor Exchange** in the Instructor Resources area of Mastering Biology provides successful, class-tested active learning techniques and analogies from biology instructors around the world, offering a springboard for quick ideas to create more compelling lectures. Contributor Kelly Hogan moderates contributions to the exchange.

Engage with biology concepts anytime, anywhere with Pearson eText

New to *Campbell Essential Biology* 7th edition/*Campbell Essential Biology with Physiology* 6th edition, the Pearson eText includes videos, interactives, animations, and audio tutors that bring the text to life and help you understand key concepts. Get all the help you need in one integrated digital experience.

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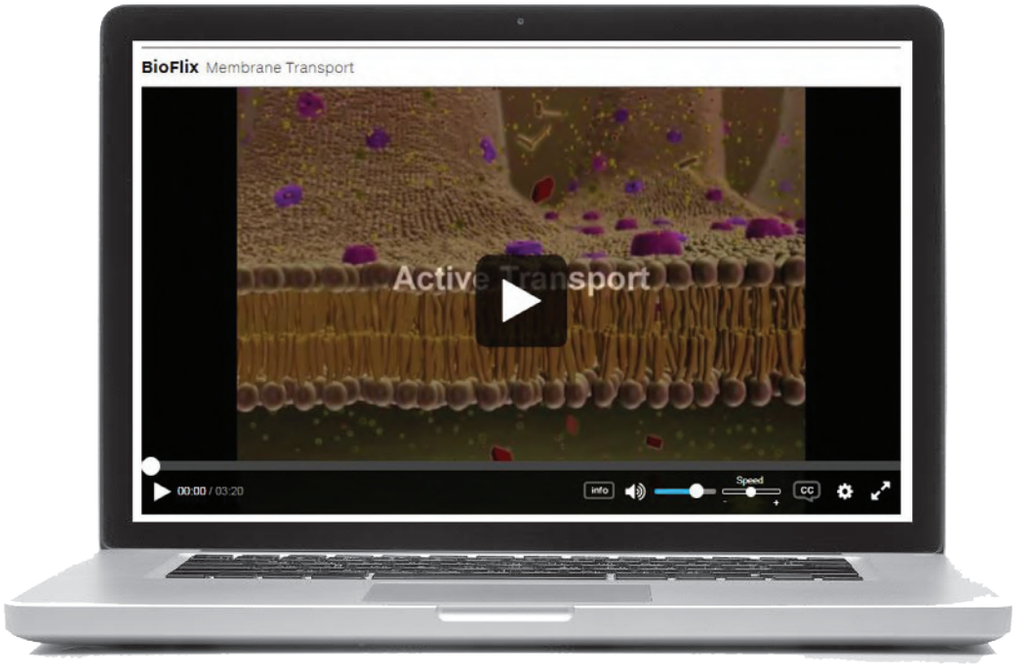

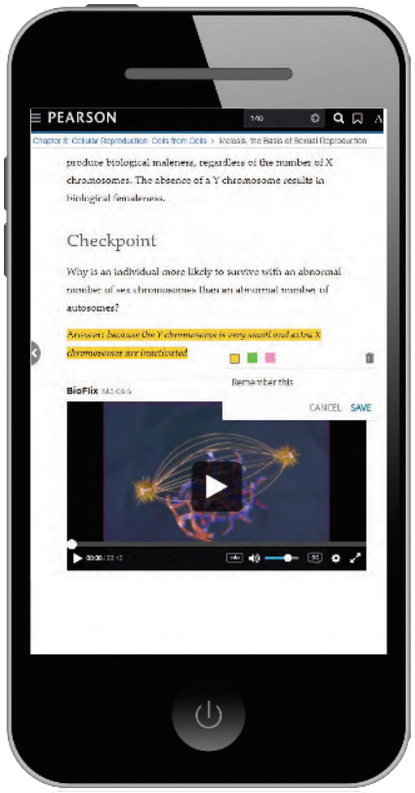

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Acknowledgments

Throughout the process of planning and writing *Campbell Essential Biology with Physiology*, the author team has had the great fortune of collaborating with an extremely talented group of publishing professionals and educators. We are all truly humbled to be part of one of the most experienced and successful publishing teams in biology education. Although the responsibility for any shortcomings lies solely with the authors, the merits of the book and its supplements reflect the contributions of a great many dedicated colleagues.

First and foremost, we must acknowledge our huge debt to Neil Campbell, the founding author of this book and a source of ongoing inspiration for each of us. Although this edition has been carefully and thoroughly revised—to update its science, its connections to students' lives, its pedagogy, and its currency—it remains infused with Neil's original vision and his commitment to share biology with introductory students.

This edition benefited significantly from the efforts of contributor Rebecca S. Burton from Alverno College. Using her years of teaching expertise, Becky made substantial improvements to two chapters, contributed to the development of new and revised Chapter Thread essays, and helped shape the emphasis on the unifying themes throughout the text and in Mastering Biology. We thank Becky for bringing her considerable talents to bear on this edition!

This book could not have been completed without the efforts of the *Campbell Essential Biology with Physiology* team at Pearson Education. Leading the team is courseware portfolio management specialist Alison Rodal, who is tireless in her pursuit of educational excellence and who inspires all of us to constantly seek better ways to help teachers and students. Alison stands at the interface between the book development team and the educational community of professors and students. Her insights and contributions are invaluable. We also thank the Pearson Science executive team for their supportive leadership, in particular, senior vice president of portfolio management Adam Jaworski, director of portfolio management Beth Wilbur, and directors of courseware content development Barbara Yien and Ginnie Simione Jutson.

It is no exaggeration to say that the talents of the best editorial team in the industry are evident on every page of this book. The authors were continuously guided with great patience and skill by courseware senior analyst John Burner and senior developmental editor Susan Teahan. We owe this editorial team—which also includes the wonderfully capable and friendly editorial assistant Alison Candlin—a deep debt of gratitude for their talents and hard work.

Once we formulated our words and images, the production and manufacturing teams transformed them into the final book. Senior content producer Lori Newman oversaw the production process and kept everyone and everything on track. We also thank the managing content producer Mike Early for his careful oversight. Every edition of *Campbell Essential Biology with Physiology* is distinguished by continuously updated and beautiful photography. For that we thank photo researcher Kristin Piljay, who constantly dazzles us with her keen ability to locate memorable images.

For the production and composition of the book, we thank senior project editor Margaret McConnell of Integra Software Services, whose professionalism and commitment to the quality of the finished product is visible throughout. The authors owe much to copyeditor Joanna Dinsmore and proofreader Pete Shanks for their keen eyes and attention to detail. We thank design manager Mark Ong and designer tani hasegawa of TT Eye for the beautiful interior and [U.S.-edition] cover designs; and we are grateful to Rebecca Marshall and Courtney Coffman and the artists at Lachina for rendering clear and compelling illustrations. We also thank rights and permissions project manager Matt Perry at Cenveo and the manager of rights and permissions Ben Ferrini. In the final stages of production, the talents of manufacturing buyer Stacy Weinberger shone.

Most instructors view the textbook as just one piece of the learning puzzle, with the book's supplements and media completing the picture. We are lucky to have a *Campbell Essential Biology with Physiology* supplements team that is fully committed to the core goals of accuracy and readability. Content producer Lori Newman expertly coordinated the supplements, a difficult task given their number and variety. We also thank media project manager Ziki Dekel for his work on the excellent Instructor Resources and eText that accompanies the text. We owe particular gratitude to the supplements authors, especially the indefatigable and eagle-eyed Ed Zalisko of Blackburn College, who wrote the Instructor Guide and the PowerPoint© Lectures; the highly skilled and multitalented Doug Darnowski of Indiana University Southeast, who revised the Quiz Shows and Clicker Questions; and Jean DeSaix of the University of North Carolina at Chapel Hill, Justin Shaffer of the University of California, Irvine, Kristen Miller of the University of Georgia, and Suann Yang of SUNY Geneseo, our collaborative team of Test Bank authors for ensuring excellence in our assessment program. In addition, the authors thank Reading Quiz authors Amaya Garcia Costas of Montana State University and Cindy Klevickis of James Madison University; Reading Quiz accuracy reviewer Veronica Menendez; Practice Test author Chris Romero of Front Range Community College; and Practice Test accuracy reviewer Justin Walgaurnery of the University of Hawaii.

We wish to thank the talented group of publishing professionals who worked on the comprehensive media program that accompanies *Campbell Essential Biology with Physiology*. The team members dedicated to Mastering Biology are true "game changers" in the field of biology education. We thank rich media content producers Ziki Dekel and Tod Regan for coordinating our multimedia plan. Vital contributions were also made by associate Mastering media producer Kaitlin Smith and web developer Barry Offringa. We also thank Sarah Jensen, senior content developer, for her efforts to make our media products the best in the industry.

As educators and writers, we are very lucky to have a crack marketing team. Product marketing manager Christa Pelaez and field marketing manager Kelli Galli seemed to be everywhere at once as they helped us achieve

our authorial goals by keeping us constantly focused on the needs of students and instructors.

We also thank the Pearson Science sales representatives, district and regional managers, and learning technology specialists for representing *Campbell Essential Biology with Physiology* on campuses. These representatives are our lifeline to the greater educational community, telling us what you like (and don't like) about this book and the accompanying supplements and media. Their enthusiasm for helping students makes them not only ideal ambassadors but also our partners in education. We urge all educators to take full advantage of the wonderful resource offered by the Pearson sales team.

Eric Simon would like to thank his colleagues at New England College for their support and for providing a model of excellence in education, in particular, Lori Koziol, Deb Dunlop, Mark Mitch, Bryan Partridge, and Wayne Lesperance. Eric would also like to acknowledge the contributions of Jim Newcomb of New England College for lending his keen eye for accuracy and for always being available to discuss teaching innovations; Jay Withgott for sharing his expertise; Elyse Carter Vosen for providing much-needed social context; Jamey Barone for her sage sensitivity; and Amanda Marsh for her expert eye, sharp attention to detail, tireless commitment, constant support, compassion, and seemingly endless wisdom.

At the end of these acknowledgments, you'll find a list of the many instructors who provided valuable information about their courses, reviewed chapters, and/or conducted class tests of *Campbell Essential Biology with Physiology* with their students. All of our best ideas spring from the classroom, so we thank them for their efforts and support.

Most of all, we thank our families, friends, and colleagues, who continue to tolerate our obsession with doing our best for science education. And finally, we all wish to welcome budding superstar Leo to our *Campbell Essential Biology with Physiology* family.

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Acknowledgments for the Global Edition

Pearson would like to thank the following for contributing to the Global Edition:

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Pearson would like to thank the following for reviewing the Global Edition:

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