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BIOLOGY

CONCEPTS & CONNECTIONS

NINTH EDITION

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BIOLOGY

CONCEPTS & CONNECTIONS

NINTH EDITION

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Text Printer: *Courier/Kendallville*
Cover Photo Credit: *Heather Angel/Natural Visions/ Alamy Stock Photo*

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Library of Congress Cataloging-in-Publication Data
Names: Reece, Jane B. | Taylor, Martha R. | Simon, Eric J. (Eric Jeffrey), 1967- | Dickey, Jean | Hogan, Kelly A.
Title: Campbell biology : concepts & connections / Jane B. Reece, Berkeley, California, Martha R. Taylor, Ithaca, New York, Eric J. Simon, New England College, Jean L. Dickey, Clemson University, Kelly Hogan, University of North Carolina, Chapel Hill.
Other titles: Biology
Description: Ninth edition. | Boston : Pearson Education, [2017]
Identifiers: LCCN 2016019061
Subjects: LCSH: Biology.
Classification: LCC QH308.2 .B56448 2017 | DDC 570—dc23
LC record available at https://lccn.loc.gov/2016019061

1 16

Pearson

ISBN 10: 0-134-29601-X; ISBN 13: 978-0-134-29601-2 (Student Edition)
ISBN 10: 0-134-44277-6; ISBN 13: 978-0-134-44277-8 (Books a la Carte Edition)
ISBN 10: 0-134-65340-8; ISBN 13: 978-0-134-65340-2 (NASTA Edition)

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Brief Contents

About the Authors

Martha R. Taylor has been teaching biology for more than 35 years. She earned her B.A. in biology from Gettysburg College and her M.S. and Ph.D. in science education from Cornell University. At Cornell, Dr. Taylor has served as assistant director of the Office of Instructional Support and has taught introductory biology for both majors and nonmajors. Most recently, she was a lecturer in the Learning Strategies Center, teaching supplemental biology courses. Her experience working with students in classrooms, in laboratories, and with tutorials has increased her commitment to helping students create their own knowledge of and appreciation for biology. She was the author of the *Student Study Guide* for ten editions of *Campbell Biology*.

Eric J. Simon is a professor in the Department of Biology and Health Science at New England College in Henniker, New Hampshire. He teaches introductory biology to science majors and nonscience majors, as well as upper-level courses in tropical marine biology and careers in science. Dr. Simon received a B.A. in biology and computer science and an M.A. in biology from Wesleyan University, and a Ph.D. in biochemistry from Harvard University. His research focuses on innovative ways to use technology to improve teaching and learning in the science classroom. Dr. Simon also leads numerous international student field research trips and is a Scientific Advisor to the Elephant Conservation Center in Sayaboury, Laos. Dr. Simon is the lead author of the introductory nonmajors biology textbooks *Campbell Essential Biology,* Sixth Edition, and *Campbell Essential Biology with Physiology,* Fifth Edition, and the author of the introductory biology textbook *Biology: The Core,* Second Edition.

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 author of *Laboratory Investigations for Biology*, Second Edition, and coauthor of *Campbell Essential Biology*, Sixth Edition, and *Campbell Essential Biology with Physiology*, Fifth Edition.

Kelly Hogan is a faculty member in the Department of Biology at the University of North Carolina at Chapel Hill, teaching introductory biology and genetics. Dr. Hogan teaches hundreds of students at a time, using active-learning methods that incorporate educational technologies both inside and outside of the classroom. She received her B.S. in biology at the College of New Jersey and her Ph.D. in pathology at the University of North Carolina, Chapel Hill. Her research interests focus on how large classes can be more inclusive through evidence-based teaching methods and technology. As the Director of Instructional Innovation at UNC, she encourages experienced faculty to take advantage of new professional development opportunities and inspires the next generation of innovative faculty. Dr. Hogan is the author of *Stem Cells and Cloning,* Second Edition, and co-author on *Campbell Essential Biology with Physiology*, Fifth Edition.

Jane B. Reece has worked in biology publishing since 1978, when she joined the editorial staff of Benjamin Cummings. Her education includes 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. 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). During her 12 years as an editor at Benjamin Cummings, she played a major role in a number of successful textbooks. She is coauthor of *Campbell Biology*, Eleventh Edition, *Campbell Biology in Focus*, Second Edition, *Campbell Essential Biology*, Sixth Edition, and *Campbell Essential Biology with Physiology*, Fifth Edition.

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. While 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.

See Connections

New Features of the ninth edition of ***Campbell Biology: Concepts & Connections*** provide students with a framework for understanding biological concepts and encourage students to see connections between concepts and the world outside of the classroom.

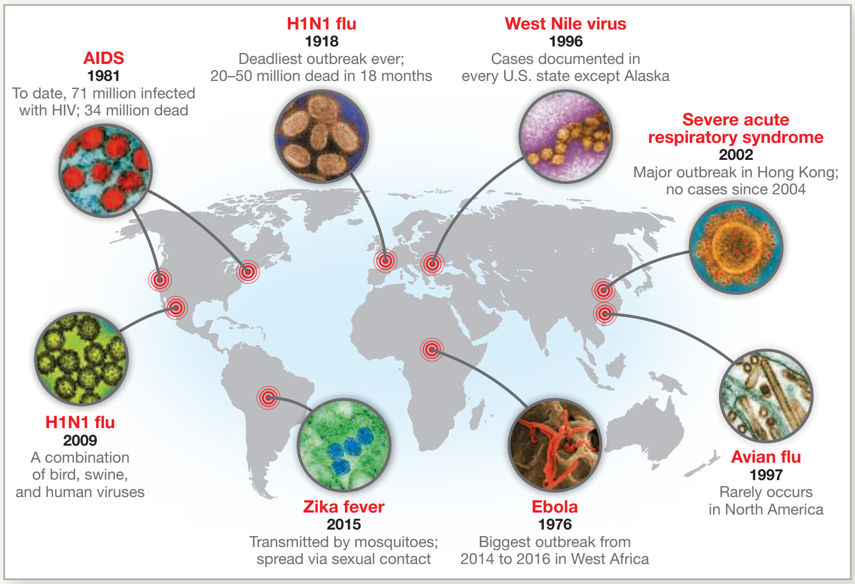
NEW! Unit Openers highlight the relevancy of the course to **careers** in a variety of fields.

Connection and **Evolution Connection Modules** present engaging examples and relate chapter content to evolution.

NEW! A reframed focus on Major Themes in Biology provide students with a framework for understanding and organizing biological concepts. Icons throughout the text call students attention to examples of specific themes within each chapter.

Throughout the Ninth Edition, the five themes introduced in Chapter 1 are highlighted with specific references. Examples from Unit 1 include "Illustrating our theme of ENERGY AND MATTER, we see that matter has been rearranged, with an input of energy provided by sunlight" (Module 2.9); "The flow of genetic instruction that leads to gene expression, summarized as DNA → RNA → protein, illustrates the important biological theme of INFORMATION" (Module 3.15); "The interconnections among these pathways provide a clear example of the theme of INTERACTIONS in producing the emergent property of a balanced metabolism" (Module 6.15); and "The precise arrangements of these membranes and compartments are essential to the process of photosynthesis—a classic example of the theme of STRUCTURE AND FUNCTION" (Module 7.2). The theme of evolution is featured, as it is in every chapter, in an Evolution Connection module, such as Module 4.15, Mitochondria and chloroplasts evolved by endosymbiosis.

Build Science Literacy Skills



NEW! Visualizing the Data Figures are eye-catching infographics designed to provide students with a fresh approach to understanding concepts illustrated by quantitative information.

Scientific Thinking modules explore how scientists use the process of science and discovery. End-of-module questions prompt students to think critically.

24.11 Scientists measure antibody levels to look for waning immunity after HPV vaccination

SCIENTIFIC THINKING

Active adaptive immunity to a specific pathogen can be gained through a natural infection or through vaccination. With human papillomavirus (HPV), infections are common: Approximately 50% of all sexually active adults become infected by the virus. Usually there are no noticeable symptoms, and the immune system clears the HPV infection within two years. The individual now has active immunity to HPV—a second infection with the same viral strain would be cleared rapidly by the secondary immune response. Some individuals, however, have an HPV infection that escapes the immune system for many more years, interfering with the regulation of cell growth in the infected epithelial cells. Cells with a persistent infection can grow uncontrolled for years, increasing the likelihood that mutations will accumulate and result in cervical and anal cancers.

Several vaccines have been developed to promote active immunity before individuals come into contact with cancer-causing strains of HPV. The first two vaccines approved in the United States were Gardasil and Cervarix. Both of these vaccines are made with HPV antigens. To determine the effectiveness of these vaccines, scientists have been conducting controlled studies. In these studies, participants are randomly assigned to one of two groups; those in the experimental group receive an injection of a vaccine, while those in the control group are injected with a placebo. Scientists then follow the participants to see if they develop precancerous lesions. For as many years as they have been studied, both vaccines have been 93–100% effective in preventing precancerous cervical lesions. These results are very good news, but scientists do not know how long this effectiveness lasts. The vaccines have not been in use long enough to provide the decades of data needed to determine the longevity of the immunity they confer.

How long does the protection provided by HPV vaccination last?

Can scientists predict if or when an HPV vaccine's effectiveness will decrease? Not exactly, but they can analyze data about one component of the adaptive immune response: the level of antibodies being produced against HPV at various times after vaccination. If there is a significant decline of antibody levels, another dose of the antigen (vaccine) may be needed. An additional dose of a vaccine that is needed periodically is commonly known as a "booster shot."

Although you learned in Module 24.7 that the effector cells that produce antibodies are short-lived, the production of some antibodies continues for many years after vaccination. Scientists do not yet have a clear understanding of the process by which the immune system produces antibodies against certain antigens for long periods, but this enduring production of antibodies can be measured after some vaccinations.

To measure long-lasting antibody production against HPV, scientists designed and carried out two long-term studies. One study followed individuals for 5 years after vaccination with Gardasil and another followed individuals for 9.4 years after vaccination with Cervarix. Figure 24.11 provides data on the levels of two HPV-specific antibodies—anti-HPV-16 and anti-HPV-18—in the blood of individuals vaccinated with Gardasil (magenta bars) or Cervarix (blue bars). The two antibodies that were measured recognize two strains of HPV that cause cervical and anal cancer; both vaccines provide immunity against these two strains. On the *y* axis, you can see the percentage of individuals whose blood still contained measurable levels of HPV-specific antibodies. A person with no measurable antibodies might be susceptible to HPV infection.

Scientists hypothesize that higher levels of anti-HPV antibodies provide greater protection from HPV-related cancers than lower levels of antibodies, but they don't yet have strong evidence to support this hypothesis. Also unknown is whether there is a minimum antibody level necessary to prevent cancer. So far, the effectiveness of the vaccines remains high even in individuals where antibody levels have decreased, suggesting that long-term memory cells are marching into action when the virus is encountered. To know if booster shots will be necessary, vaccinated individuals will need to be followed for decades to see if there is a correlation between antibody levels and the onset of precancerous lesions. Such studies are ongoing. Stay tuned!

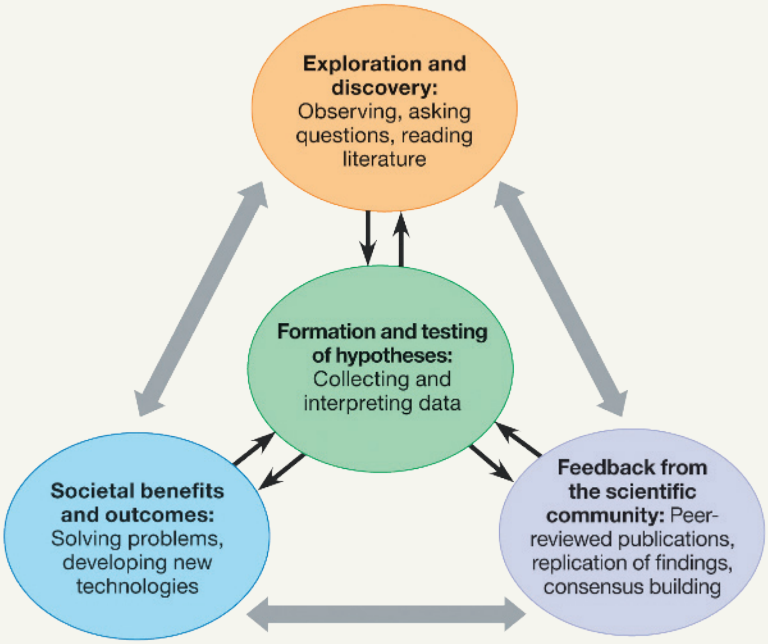
? **Based on the data in the graph, does it seem likely that either vaccine will require a booster in the future?**

Yes, Gardasil may require a booster: after 5 years, the antibody levels protecting against HPV-18 were undetectable in approximately 35% of individuals vaccinated.

Anti-HPV-16 antibodies measured | Anti-HPV-18 antibodies measured
Percentage of vaccinated individuals with measurable antibodies (0–100)
5, 9.4, 5, 9.4
Number of years after vaccination
Key: Gardasil, Cervarix

▲ Figure 24.11 The levels of anti-HPV-16 and anti-HPV-18 in blood after Cervarix and Gardasil vaccination

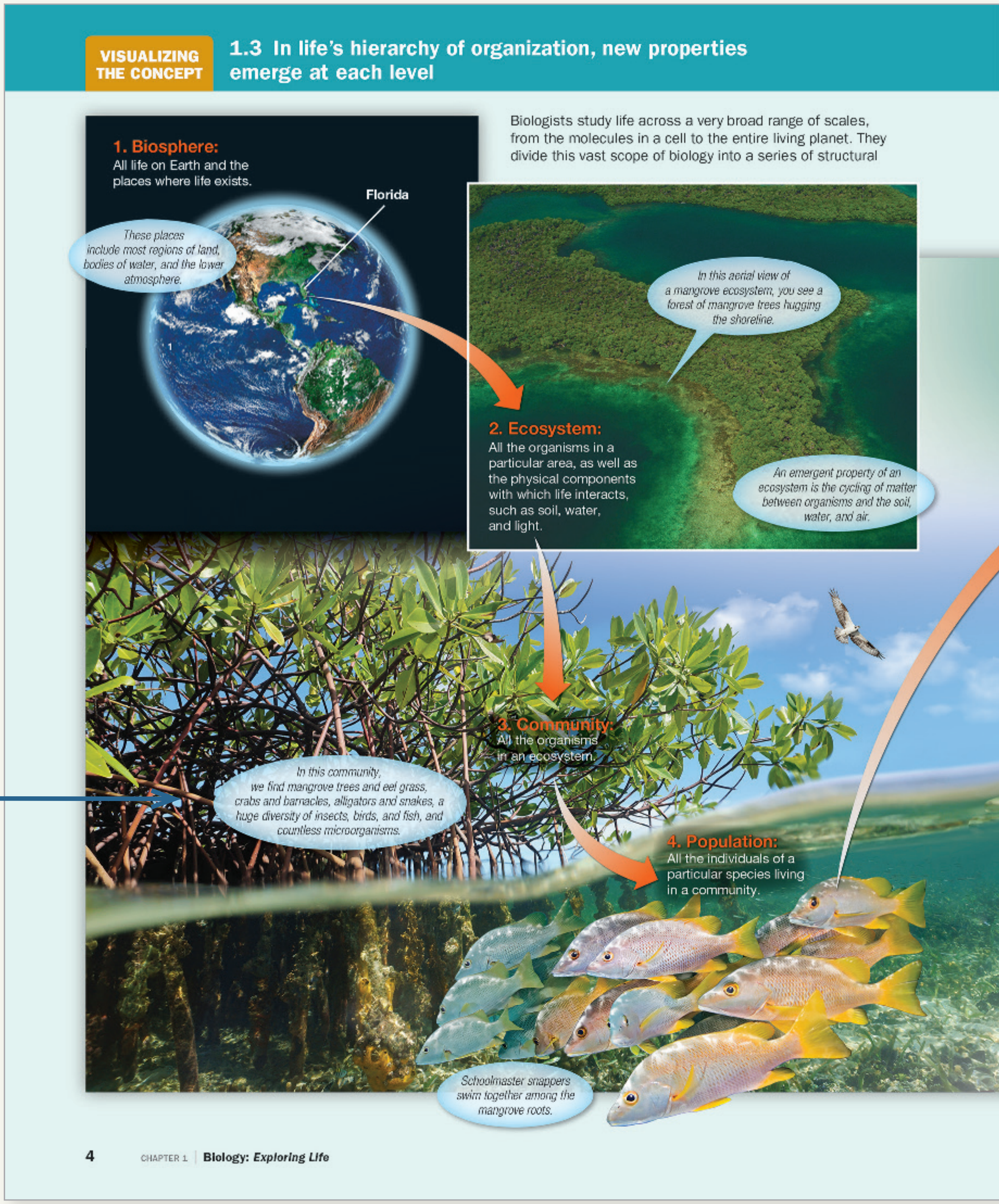
500 CHAPTER 24 | The Immune System



A new presentation of the process of science in chapter 1 demonstrates to students the iterative nature of scientific research.

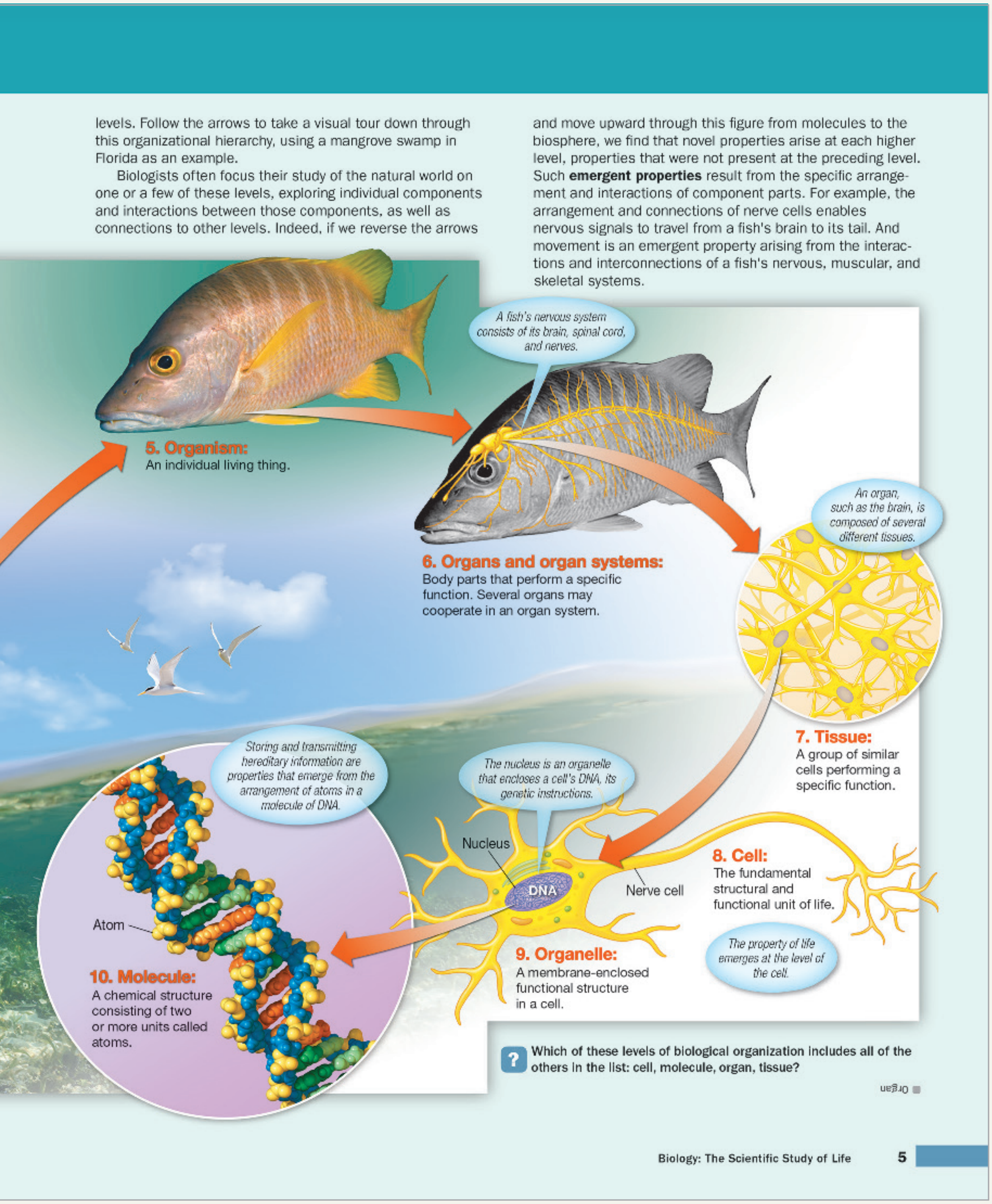
Visualize Tough Topics

EXPANDED! Visualizing the Concept Modules bring dynamic visuals and text together to walk students through tough concepts. The ninth edition features 28 of these immersive modules. Select modules are assignable in MasteringBiology as animated videos.



Embedded text **coaches students** through key points and **help address common misunderstandings.**

and Develop Understanding


levels. Follow the arrows to take a visual tour down through this organizational hierarchy, using a mangrove swamp in Florida as an example.

Biologists often focus their study of the natural world on one or a few of these levels, exploring individual components and interactions between those components, as well as connections to other levels. Indeed, if we reverse the arrows and move upward through this figure from molecules to the biosphere, we find that novel properties arise at each higher level, properties that were not present at the preceding level. Such **emergent properties** result from the specific arrangement and interactions of component parts. For example, the arrangement and connections of nerve cells enables nervous signals to travel from a fish's brain to its tail. And movement is an emergent property arising from the interactions and interconnections of a fish's nervous, muscular, and skeletal systems.

? Which of these levels of biological organization includes all of the others in the list: cell, molecule, organ, tissue?

Organ

Biology: The Scientific Study of Life 5

Streamlined text and illustrations **step students through the concept.**

NEW! Topics in the ninth edition include:

1.3: Hierarchy of Life
6.9: Oxidative Phosphorylation
8.17: Crossing Over
13.14: Natural Selection
25.4: Osmoregulation

Encourage Focus on

Main headings allow students to see the big picture.

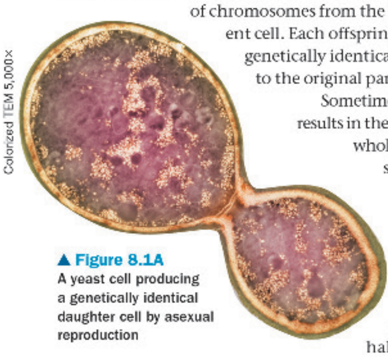
A Central Concept at the start of each module helps students to focus on one concept at a time.

Cell Division and Reproduction

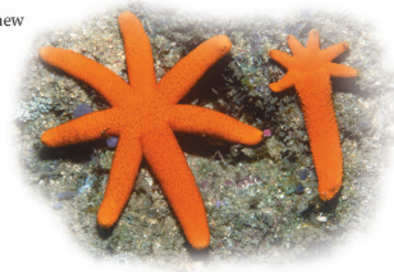
8.1 Cell division plays many important roles in the lives of organisms

The ability to transmit INFORMATION is one of the unifying themes that encompasses all levels of biological study. Such information flow is absolutely necessary for reproduction. Only people can make more people and only maple trees can make more maple trees because each species carries and transmits its own specific genetic information at the cellular level. When a cell undergoes reproduction, or **cell division**, the two "daughter" cells that result are genetically identical to each other and to the original "parent" cell. (Biologists traditionally use the word *daughter* in this context; it does not imply gender.) Before the parent cell splits into two, it duplicates its **chromosomes**, the structures that contain most of the cell's genetic information in the form of DNA. Then, during cell division, one set of chromosomes is distributed to each daughter cell. As a rule, the daughter cells receive identical sets of chromosomes from the lone, original parent cell. Each offspring cell will thus be genetically identical to the other and to the original parent cell.

Sometimes, cell division results in the reproduction of a whole organism. Many single-celled organisms, such as prokaryotes or the eukaryotic yeast cell in Figure 8.1A, reproduce by dividing in half, and the offspring are genetic replicas. This is an example of **asexual reproduction**, the creation of genetically identical offspring ...ent, without the participation of sperm and egg. ... that reproduces asexually gives rise to a **clone**, ...etically identical individuals. Many multicellu... can reproduce asexually to produce clones. For ...e sea star species and many house plants have the ability to grow new individuals from fragmented pieces (Figures 8.1B and 8.1C). In asexual reproduction, there is one simple principle of inheritance: The lone parent and each of its offspring have identical genes.

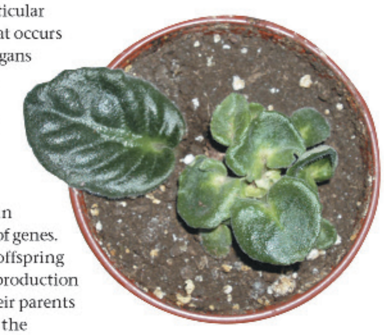


▲ Figure 8.1A A yeast cell producing a genetically identical daughter cell by asexual reproduction



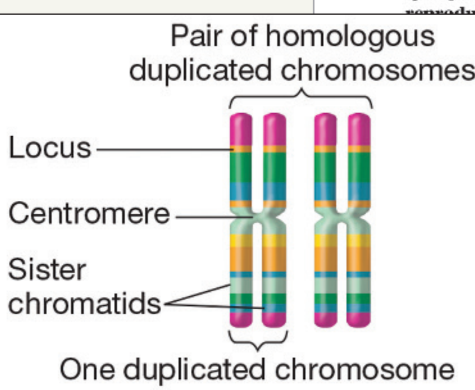
▲ Figure 8.1B A sea star reproducing asexually via fragmentation and regeneration of the body from the fragmented arm

Sexual reproduction is different; it requires the fusion of gametes, egg and sperm. The production of gametes involves a particular type of cell division that occurs only in reproductive organs (testes and ovaries in humans). A gamete has only half as many chromosomes as the parent cell that gave rise to it, and these chromosomes contain unique combinations of genes. In contrast to a clone, offspring produced by sexual reproduction are not identical to their parents or to each other (with the exception of identical twins), although they generally resemble their parents more closely than they resemble unrelated individuals of the same species. They are variations on a common theme of family resemblance, not exact replicas (Figure 8.1D). Each offspring inherits a unique combination of genes from its two parents,



▲ Figure 8.1C An African violet reproducing asexually from a cutting (the large leaf on the left)

◀ Figure 8.1D Sexual reproduction produces offspring with unique combinations of genes

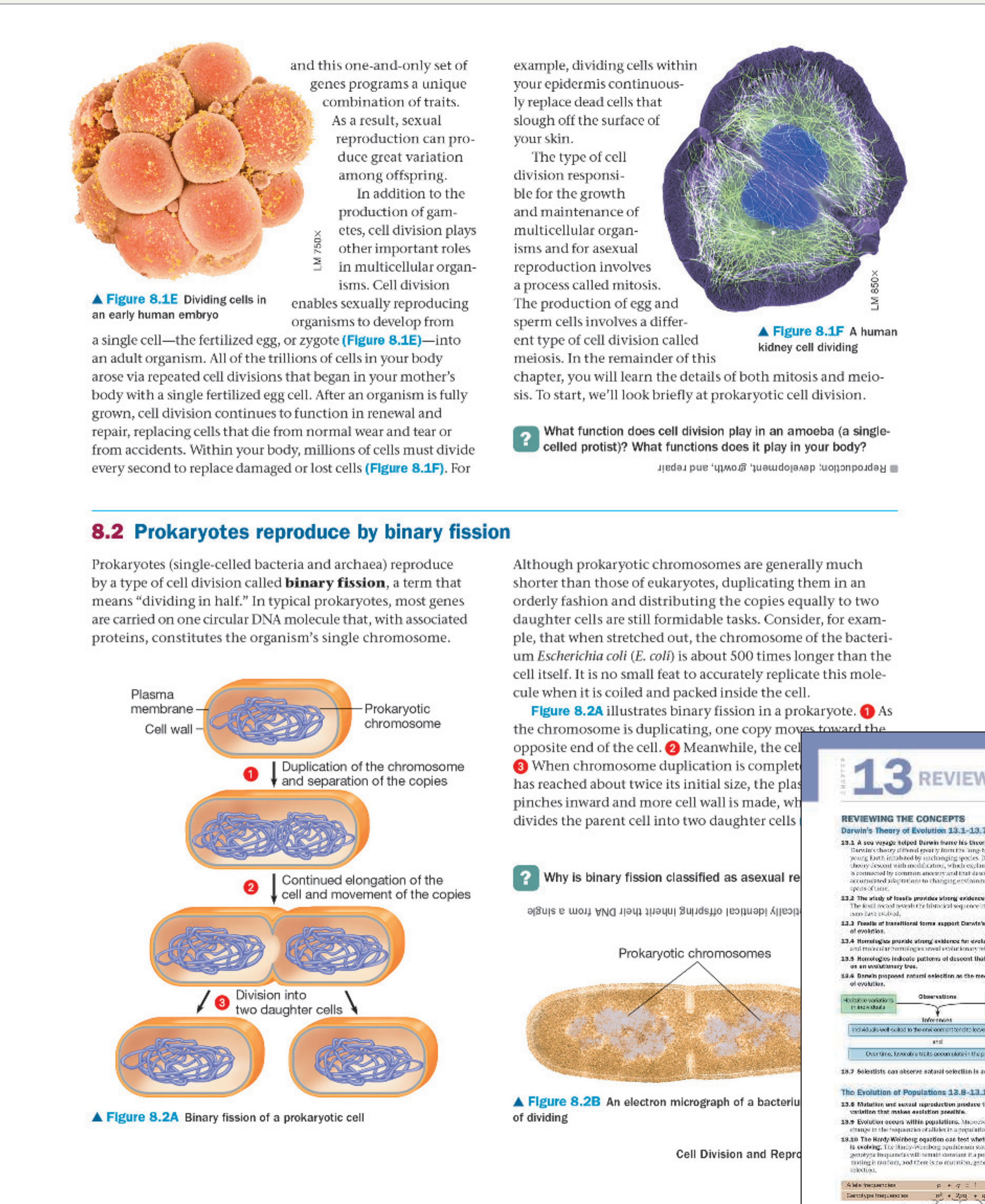


▲ Figure 8.11 A pair of homologous chromosomes

TRY THIS Cover this figure, and on a piece of paper, draw a pair of homologous chromosomes, and label the sister chromatids, the centromere, and one chromosome. Then, uncover this figure and compare it to your drawing.

Try This activities in every chapter encourage students to actively engage with the figures and develop positive study habits.

Key Concepts and Active Learning


and this one-and-only set of genes programs a unique combination of traits. As a result, sexual reproduction can produce great variation among offspring.

In addition to the production of gametes, cell division plays other important roles in multicellular organisms. Cell division enables sexually reproducing organisms to develop from a single cell—the fertilized egg, or zygote (Figure 8.1E)—into an adult organism. All of the trillions of cells in your body arose via repeated cell divisions that began in your mother's body with a single fertilized egg cell. After an organism is fully grown, cell division continues to function in renewal and repair, replacing cells that die from normal wear and tear or from accidents. Within your body, millions of cells must divide every second to replace damaged or lost cells (Figure 8.1F). For example, dividing cells within your epidermis continuously replace dead cells that slough off the surface of your skin.

The type of cell division responsible for the growth and maintenance of multicellular organisms and for asexual reproduction involves a process called mitosis. The production of egg and sperm cells involves a different type of cell division called meiosis. In the remainder of this chapter, you will learn the details of both mitosis and meiosis. To start, we'll look briefly at prokaryotic cell division.

LM 750×

▲ Figure 8.1E Dividing cells in an early human embryo

LM 850×

▲ Figure 8.1F A human kidney cell dividing

? What function does cell division play in an amoeba (a single-celled protist)? What functions does it play in your body?

■ Reproduction; development, growth, and repair

8.2 Prokaryotes reproduce by binary fission

Prokaryotes (single-celled bacteria and archaea) reproduce by a type of cell division called **binary fission**, a term that means "dividing in half." In typical prokaryotes, most genes are carried on one circular DNA molecule that, with associated proteins, constitutes the organism's single chromosome.

Although prokaryotic chromosomes are generally much shorter than those of eukaryotes, duplicating them in an orderly fashion and distributing the copies equally to two daughter cells are still formidable tasks. Consider, for example, that when stretched out, the chromosome of the bacterium *Escherichia coli* (*E. coli*) is about 500 times longer than the cell itself. It is no small feat to accurately replicate this molecule when it is coiled and packed inside the cell.

Figure 8.2A illustrates binary fission in a prokaryote. 1 As the chromosome is duplicating, one copy moves toward the opposite end of the cell. 2 Meanwhile, the cel[...] 3 When chromosome duplication is complet[...] has reached about twice its initial size, the plas[...] pinches inward and more cell wall is made, wh[...] divides the parent cell into two daughter cells [...]

▲ Figure 8.2A Binary fission of a prokaryotic cell

? Why is binary fission classified as asexual re[...]

■ [...]tically identical offspring inherit their DNA from a single

▲ Figure 8.2B An electron micrograph of a bacteriu[...] of dividing

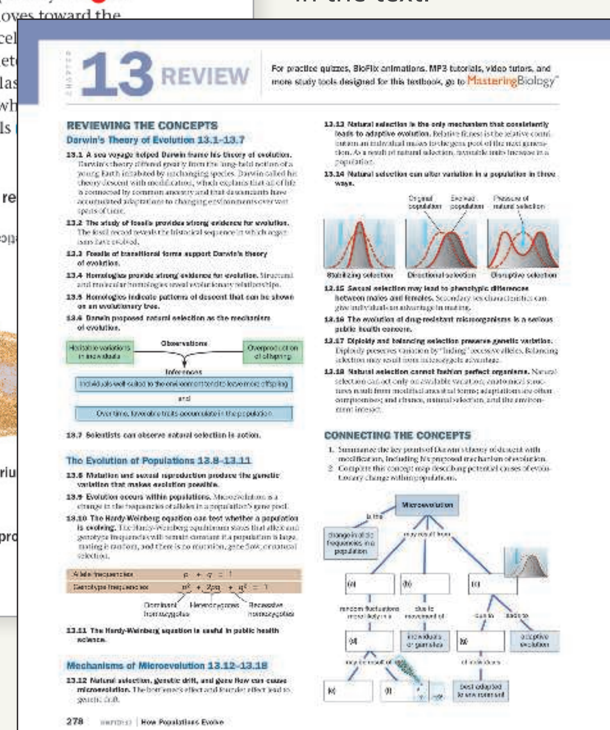
Cell Division and Repr[...]

Checkpoint questions

at the end of every module let students check their understanding right away.

Figures describing a process

take students through a series of numbered steps keyed to explanations in the text.

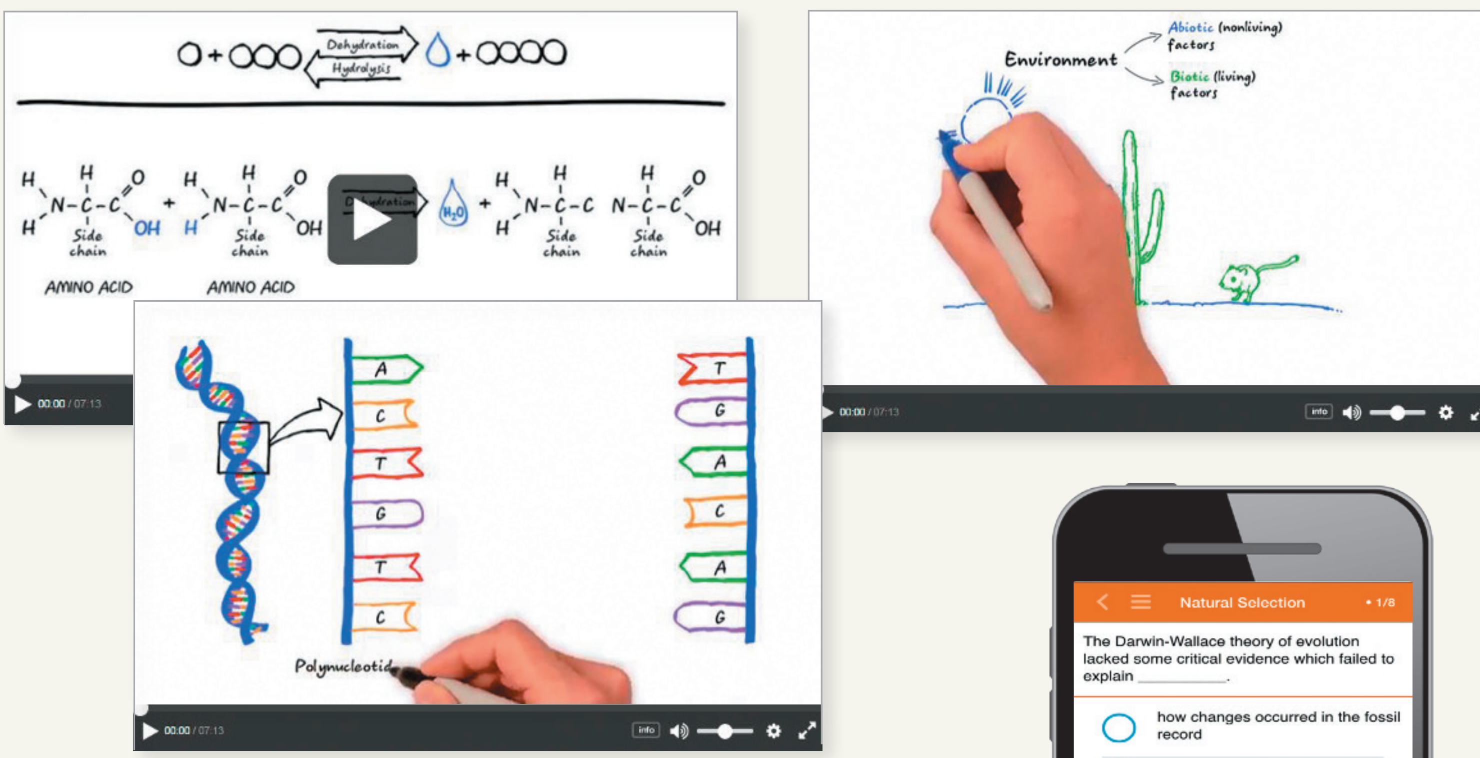


Chapter summaries include figures and text to help students review and check their understanding of the chapter concepts.

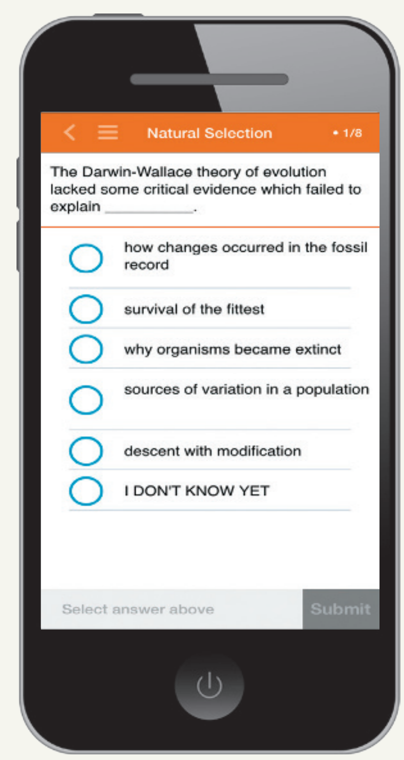
Continuous Learning
Before, During, and After Class

BEFORE CLASS
Interactive assignments introduce students to key concepts

NEW! Key Topic Overview videos introduce students to key concepts and vocabulary and are created by authors Eric Simon, Jean Dickey and Kelly Hogan. All 12 videos are delivered as a whiteboard style mini-lesson and are accompanied by assessment so that students can check their understanding.

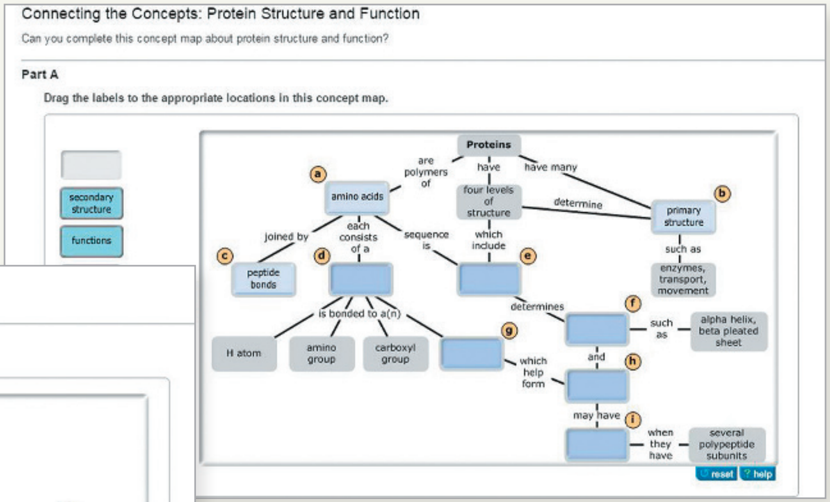


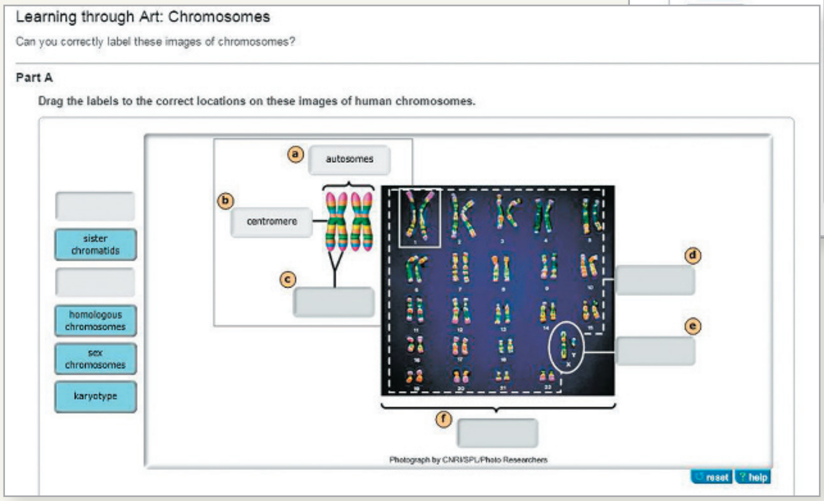
Dynamic Study Modules provide students with multiple sets of questions with extensive feedback so that they can test, learn, and retest until they achieve mastery of the textbook material.



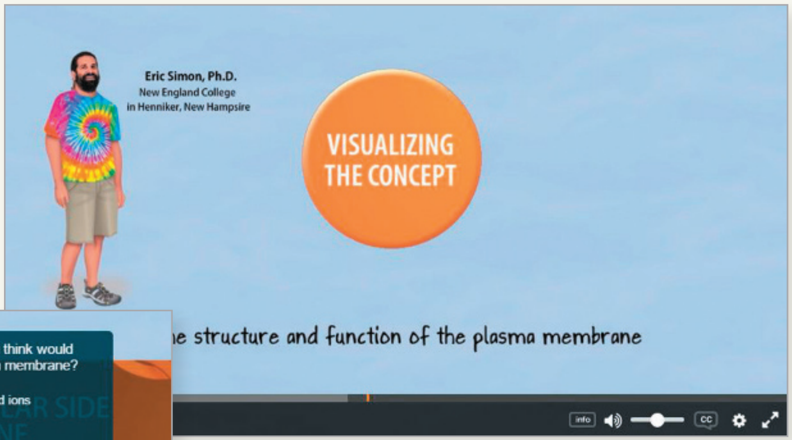
with MasteringBiology

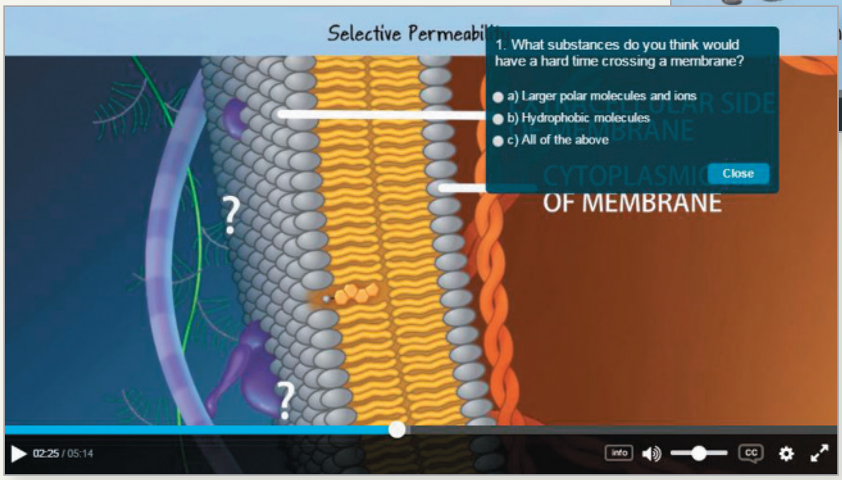
Create pre-lecture assignments with 170 **author created interactive coaching activities**.





EXPANDED! Give students extra practice with **18 assignable Visualizing the Concept videos**, which pair with the select modules in the text.



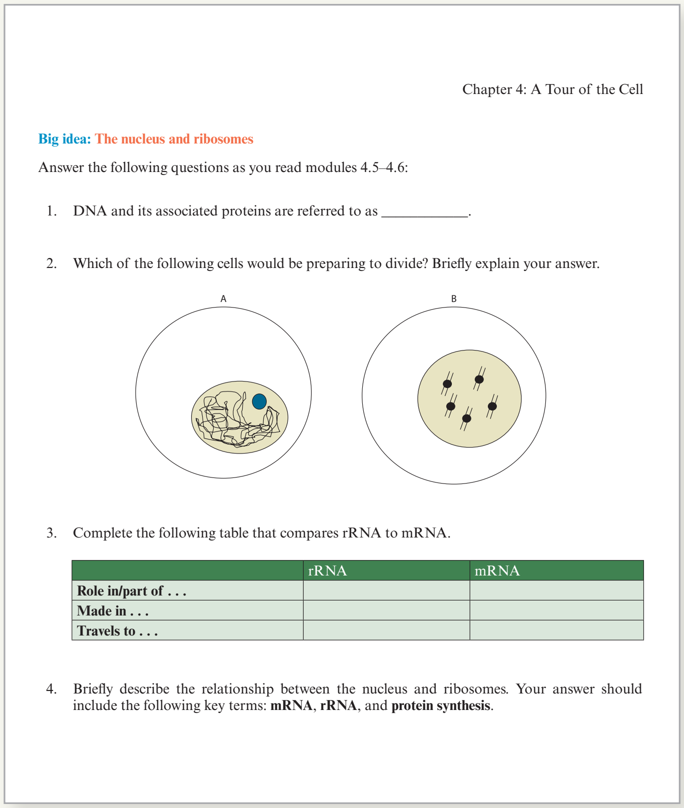


Continuous Learning
Before, During, and After Class

DURING CLASS
Encourage engagement with dynamic videos and resources for in class activities

NEW! HHMI Short Films are documentary-quality movies from the Howard Hughes Medical Institute with explorations from the discovery of the double helix to evolution and include assignable questions.

Guided Reading Activities, in the MasteringBiology study area, accompany all chapters and are designed to help students stay on track and develop active reading skills.


Chapter 4: A Tour of the Cell

Big idea: The nucleus and ribosomes

Answer the following questions as you read modules 4.5–4.6:

1. DNA and its associated proteins are referred to as ___________.
2. Which of the following cells would be preparing to divide? Briefly explain your answer.

A B

3. Complete the following table that compares rRNA to mRNA.

	rRNA	mRNA
Role in/part of . . .		
Made in . . .		
Travels to . . .		

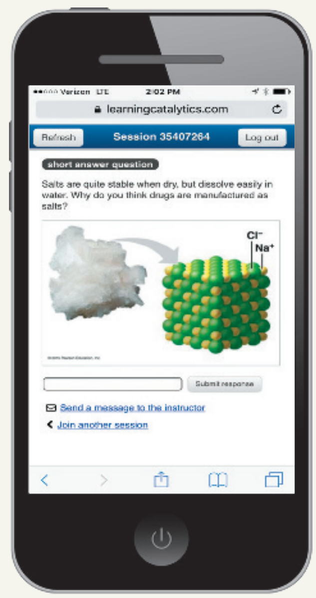
4. Briefly describe the relationship between the nucleus and ribosomes. Your answer should include the following key terms: **mRNA**, **rRNA**, and **protein synthesis**.

Resources to help instructors plan dynamic lectures:

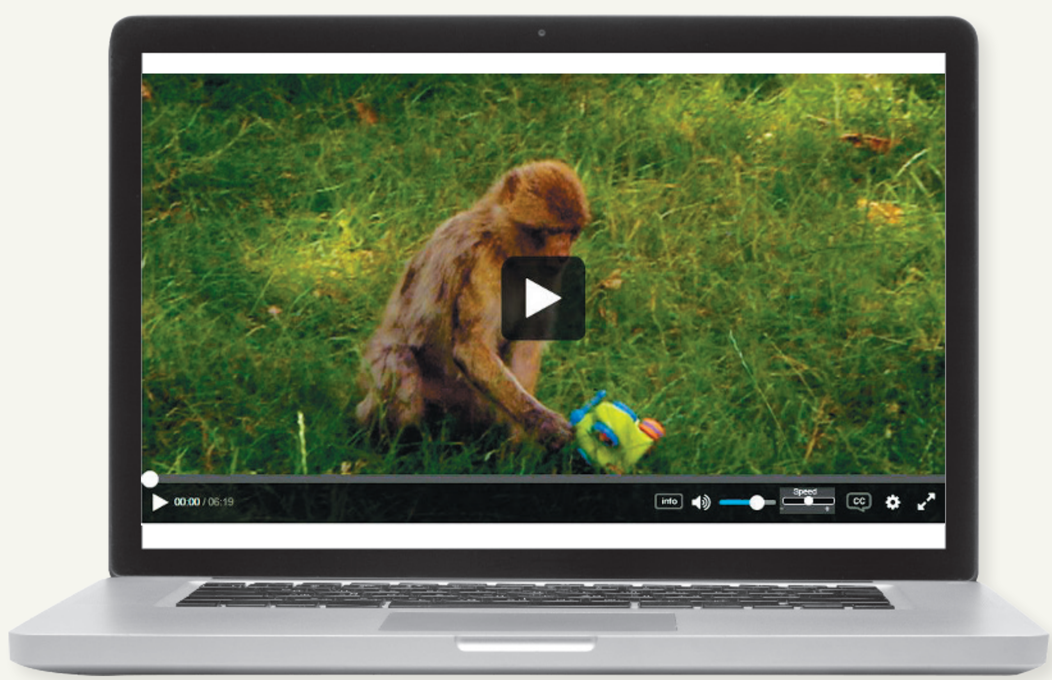
- **NEW! Ready-to-Go Teaching Modules** help instructors efficiently make use of the available teaching tools for the toughest topics.
- The **Instructor Exchange** provides active learning techniques from biology instructors around the nation. Co-author Kelly Hogan moderates the exchange.

with MasteringBiology

Learning Catalytics is a "bring your own device" (laptop, smartphone, or tablet) engagement, assessment, and classroom intelligence system that allows for active learning and discussion.



NEW! Try This questions in Learning Catalytics are easy to assign in-class active learning questions, based on the text "Try This" feature.

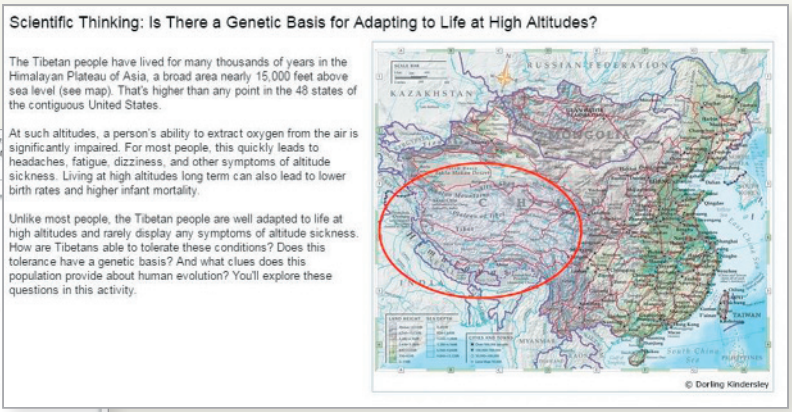


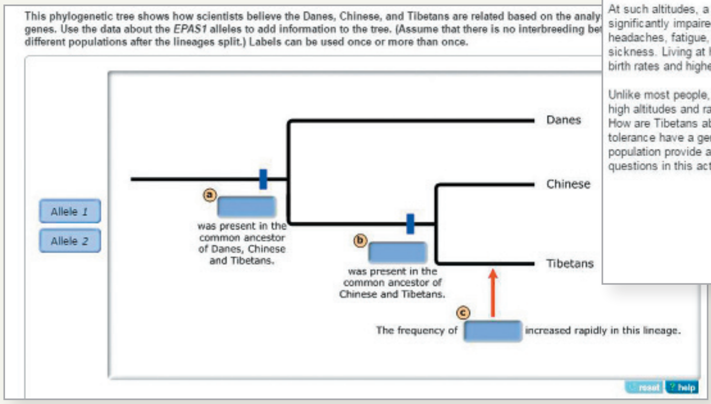
NEW! Everyday Biology Videos briefly explore interesting and relevant biology topics that relate to concepts that students are learning in class. These 20 videos, produced by the BBC, can be assigned in MasteringBiology.

Engage in Biology
anytime, anywhere

AFTER CLASS
Dynamic activities let students put skills into practice

Scientific Thinking Activities
help students develop an understanding of how scientific research is conducted.





Examples of topics include:

- What Is the Role of Peer Review in the Process of Science?
- How Does "Citizen Science" Affect Scientific Data Collection?
- Do the Microorganisms in Our Digestive Tract Play a Role in Obesity?


The New York Times

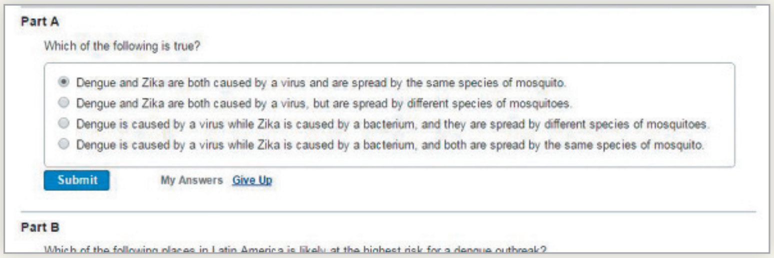
Argentina Battles Major Outbreak of Dengue as Mosquito Population Swells

By JONATHAN GILBERT FEB. 17, 2016

A fumigation squad in Buenos Aires last month. Argentina reported nearly 4,900 cases of dengue in the first five weeks of 2016.
Natacha Pisarenko/Associated Press

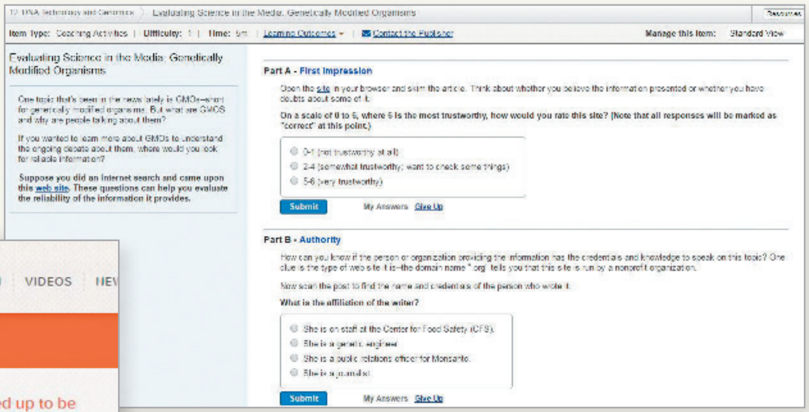
BUENOS AIRES — Argentina is grappling with its worst

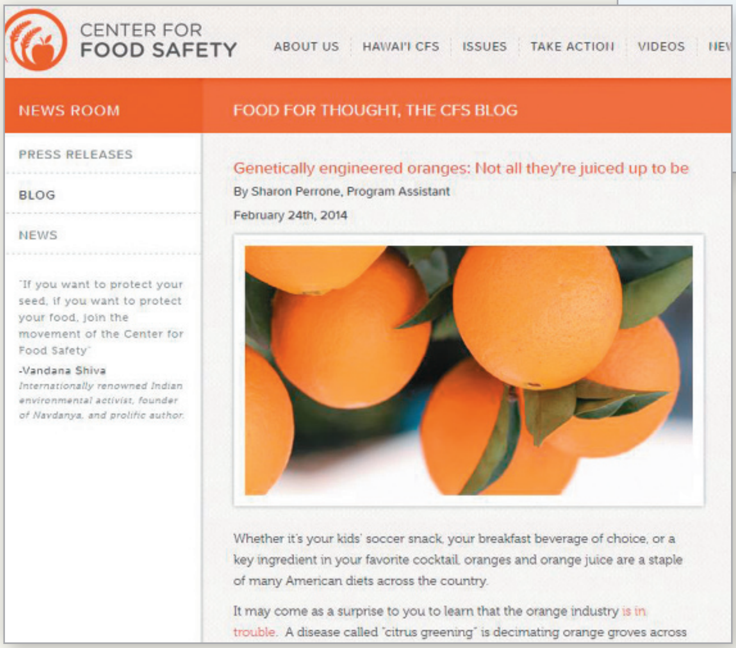
Current Events Activities cover a wide range of biological topics to demonstrate to students how science connects to everyday life.



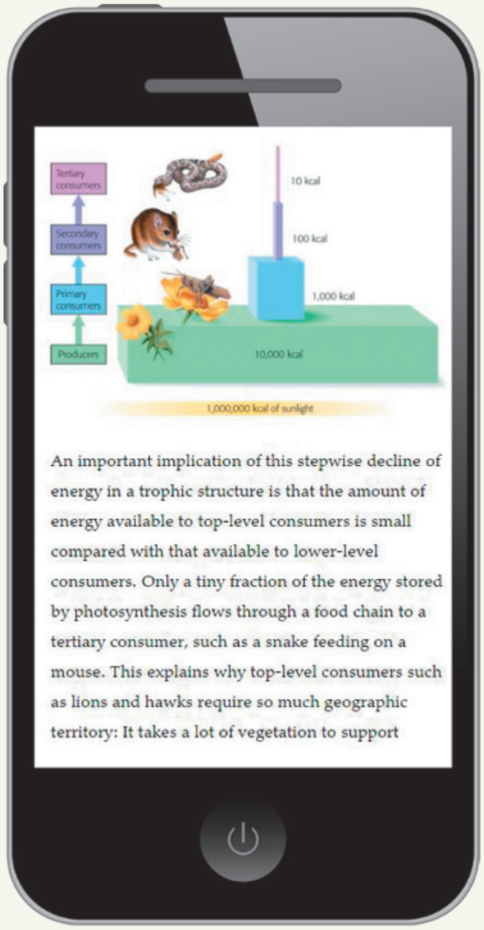
with MasteringBiology

NEW! Evaluating Science in the Media Activities teach students to recognize validity, bias, purpose, and authority in everyday sources of information.





NEW! eText 2.0 is now available on smartphones, tablets and computers, featuring seamlessly integrated videos, and concept check questions. The eText 2.0 mobile app is available for most iOS and Android phones.



Powerful interactive and customization functions include integrated videos and concept check questions, accessible (screen-reader ready), note-taking, highlighting, bookmarking, search, and links to glossary terms.

Preface

Inspired by the thousands of students in our own classes over the years and by enthusiastic feedback from the many instructors who have used or reviewed our book, we are delighted to present this new, Ninth Edition. We authors have worked together closely to ensure that both the book and the supplementary material online reflect the changing needs of today's courses and students, as well as current progress in biology. Titled *Campbell Biology: Concepts & Connections* to honor Neil Campbell's founding role and his many contributions to biology education, this book continues to have a dual purpose: to engage students from a wide variety of majors in the wonders of the living world and to show them how biology relates to their own existence and the world they inhabit. Most of these students will not become biologists themselves, but their lives will be touched by biology every day. Understanding the concepts of biology and their connections to our lives is more important than ever. Whether we're concerned with our own health or the health of our planet, a familiarity with biology is essential. This basic knowledge and an appreciation for how science works have become elements of good citizenship in an era when informed evaluations of health issues, environmental problems, and applications of new technology are critical.

Concepts and Connections

Concepts Biology is a vast subject that gets bigger every year, but an introductory biology course is still only one or two semesters long. This book was the first introductory biology textbook to use concept modules to help students recognize and focus on the main ideas of each chapter. The heading of each module is a carefully crafted statement of a key concept. For example, "Helper T cells stimulate the humoral and cell-mediated immune responses" announces a key concept about the role of helper T cells in adaptive immunity (Module 24.12). Such a concept heading serves as a focal point, and the module's text and illustrations converge on that concept with explanation and, often, analogies. The module text walks the student through the illustrations, just as an instructor might do in class. And in teaching a sequential process, such as the one diagrammed in Figure 24.12A, we number the steps in the text to correspond to numbered steps in the figure. The synergy between a module's narrative and graphic components transforms the concept heading into an idea with meaning to the student. The checkpoint question at the end of each module encourages students to test their understanding as they proceed through a chapter. Finally, in the Chapter Review, all the key concept statements are listed and briefly summarized under the overarching section titles, explicitly reminding students of what they've learned.

Connections Students are more motivated to study biology when they can connect it to their own lives and interests—for example, when they are able to relate science to health issues, economic problems, environmental quality, ethical controversies, and social responsibility. In this edition, purple Connection icons mark the numerous application modules that go beyond the core biological concepts. For example, the new Connection Module 32.6 describes how humans tap into plant transport mechanisms for harvesting such materials as maple syrup and latex. In addition, our Evolution Connection modules, identified by green icons, connect the content of each chapter to the grand unifying theme of evolution, without which the study of life has no coherence. For example, a new Evolution Connection in Chapter 14 uses data from studies by Rosemary and Peter Grant and their students to demonstrate the continuing effects of natural selection on Darwin's finches. Explicit connections are also made between the chapter introduction and either the Evolution Connection module or the Scientific Thinking module in each chapter; high-interest questions introduce each chapter, drawing students into the topic and encouraging a curiosity to explore the question further when it appears again later in the chapter. And, connections are made in every chapter between key concepts and the core concepts of biology.

New to This Edition

New Focus on Five Underlying Themes of Biology

A major goal of this Ninth Edition is to provide students with an explicit framework for understanding and organizing the broad expanse of biological information presented in Concepts and Connections. This framework is based on the five major themes outlined in *Vision and Change in Undergraduate Biology Education: A Call to Action* published by the American Academy for the Advancement of Science. These major themes extend across all areas of biology: evolution, the flow of information, the correlation of structure and function, the exchange of energy and matter, and the interactions and interconnections of biological systems. Chapter 1 introduces each of these themes in a separate module. Specific examples of the themes are then called out in each chapter by green icons: **INFORMATION**, **STRUCTURE AND FUNCTION**, **ENERGY AND MATTER**, **INTERACTIONS**, and **EVOLUTION CONNECTION** (always in module form).

Expanded Coverage of the Process of Science

Chapter 1 also includes an enhanced focus on the nature of science and the process of scientific inquiry, setting the stage for both the content of the text and the process by which our biological knowledge has been built and continues to grow. We continue this emphasis on the process of scientific inquiry through our Scientific Thinking modules in every chapter, which are called out with an orange icon. New concept check questions for these modules focus on aspects of the process of science: the forming and testing of hypotheses; experimental design; variables and controls; the analysis of data; and the evaluation and communication of scientific results.

Additional Visualizing the Concept Modules These modules, which were new to the Eighth Edition, have raised our hallmark art–text integration to a new level. Visualizing the Concept modules take challenging concepts or processes and walk students through them in a highly visual manner, using engaging, attractive art; clear and concise labels; and instructor "hints" called out in light blue bubbles. These short hints emulate the one-on-one coaching an instructor might provide to a student during office hours and help students make key connections within the figure. Examples of the eight new Visualizing the Concept modules include Module 6.9, Most ATP production occurs by oxidative phosphorylation; Module 8.17, Crossing over further increases genetic variability; Module 13.14, Natural selection can alter variation in a population in three ways; Module 28.6, Neurons communicate at synapses, and Module 34.18, The global water cycle connects aquatic and terrestrial biomes.

New Visualizing the Data Figures Also new to this edition are figures that present data in an infographic form, marked by Visualizing the Data icons. These 19 eye-catching figures provide students with a fresh approach to understanding the concepts illustrated by graphs and numerical data. Figure 10.19 maps emergent virus outbreaks, showing that they originate throughout the world. Figure 12.17 summarizes a wealth of bioinformatics data on genome sizes versus the number of genes found in various species. Figure 13.16 illustrates the growing threat of antibiotic resistant bacteria. Figure 21.14 allows students to directly compare caloric intake (via food) with caloric expenditure (via exercise). Figure 30.5B shows changes in bone mass during the human life span. Figure 36.11 offers an illuminating visual comparison of the per capita and national ecological footprints of several countries with world average and "fair share" footprints. Figure 38.3 shows graphic evidence of global warming by tracking annual global temperatures since 1880.

New Unit Openers That Feature Careers Related to the Content of the Unit Expanding our emphasis on the connections of biology to students' lives, each unit opener page now includes photos of individuals whose professions relate to the content of the unit. For instance, Unit I features a brewery owner and a solar energy engineer. Unit IV portrays a hatchery manager and a paleoanthropologist. These examples are intended to help students see how their biology course relates to the world outside the classroom and to their own career paths.

New Design and Improved Art The fresh new design used throughout the chapters and the extensive reconceptualization of many figures make the book even more appealing and accessible to visual learners. Much of the art in Chapter 6, How Cells Harvest Chemical Energy, for example, has been revised to help students work through the complex reactions of cellular respiration. Other examples of improved art are found in Figures 5.15B, 10.11A, and 37.22B.

The Latest Science Biology is a dynamic field of study, and we take pride in our book's currency and scientific accuracy. For this edition, as in previous editions, we have integrated the results of the latest scientific research throughout the book. We have done this carefully and thoughtfully, recognizing that research advances can lead to new ways of looking at biological topics; such changes in perspective can necessitate organizational changes in our textbook to better reflect the current state of a field. For example, Chapter 12 uses both text and art to present the innovative CRISPR-Cas9 system for gene editing. You will find a unit-by-unit account of new content and organizational improvements in the "New Content" section on pages xix–xx following this Preface.

MasteringBiology® MasteringBiology, the most widely used online tutorial and assessment program for biology, continues to accompany *Campbell Biology: Concepts & Connections*. In addition to 170 author-created activities that help students learn vocabulary, extend the book's emphasis on visual learning, demonstrate the connections among key concepts (helping students grasp the big ideas), and coach students on how to interpret data, the Ninth Edition features new assignable videos. These videos bring this text's Visualizing the Concept modules to life, help students learn how to evaluate sources of scientific information for reliability, and include short news videos that engage students in the many ways course concepts connect to the world outside the classroom. MasteringBiology® for *Campbell Biology: Concepts & Connections*, Ninth Edition, will help students to see strong connections through their text, and the additional practice available online allows instructors to capture powerful data on student performance, thereby making the most of class time.

This Book's Flexibility

Although a biology textbook's table of contents is by design linear, biology itself is more like a web of related concepts without a single starting point or prescribed path. Courses can navigate this network by starting with molecules, with ecology, or somewhere in-between, and courses can omit topics. *Campbell Biology: Concepts & Connections* is uniquely suited to offer flexibility and thus serve a variety of courses. The seven units of the book are largely self-contained, and in a number of the units, chapters can be assigned in a different order without much loss of coherence. The use of numbered modules makes it easy to skip topics or reorder the presentation of material.

For many students, introductory biology is the only science course that they will take during their college years. Long after today's students have forgotten most of the specific content of their biology course, they will be left with general impressions and attitudes about science and scientists. We hope that this new edition of *Campbell Biology: Concepts & Connections* helps make those impressions positive and supports instructors' goals for sharing the fun of biology. In our continuing efforts to improve the book and its supporting materials, we benefit tremendously from instructor and student feedback, not only in formal reviews but also via informal communication. Please let us know how we are doing and how we can improve the next edition of the book.

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New Content

Below are some important highlights of new content and organizational improvements in *Campbell Biology: Concepts & Connections*, Ninth Edition.

Chapter 1, Biology: Exploring Life This chapter has been extensively reorganized and revised. Our expanded coverage of the nature of science and scientific inquiry has now moved to the forefront of Chapter 1. The first of the five modules in this section provides a general description of data, hypothesis formation and testing, the centrality of verifiable evidence to science, and an explanation of scientific theories. The module describing how hypotheses can be tested using controlled experiments now includes a subsection on hypothesis testing in humans. A new Scientific Thinking module entitled Hypotheses can be tested using observational data, describes how multiple lines of evidence, including DNA comparisons, have helped resolve the classification of the red panda. Another new module—The process of science is repetitive, nonlinear, and collaborative—presents a more accurate model of the process of science that includes four interacting circles: Exploration and Discovery; Forming and Testing Hypotheses: Analysis and Feedback from the Scientific Community; and Societal Benefits and Outcomes. The chapter concludes with the introduction of five core themes that underlie all of biology: evolution; information; structure and function; energy and matter; and interactions.

Unit I, The Life of the Cell This unit guides students from basic chemistry and the molecules of life through cellular structures to cellular respiration and photosynthesis. Throughout the Ninth Edition, the five themes introduced in Chapter 1 are highlighted with specific references. Examples from Unit 1 include "Illustrating our theme of **ENERGY AND MATTER**, we see that matter has been rearranged, with an input of energy provided by sunlight" (Module 2.9); "The flow of genetic instruction that leads to gene expression, summarized as DNA → RNA → protein, illustrates the important biological theme of **INFORMATION**" (Module 3.15); "The interconnections among these pathways provide a clear example of the theme of **INTERACTIONS** in producing the emergent property of a balanced metabolism" (Module 6.15); and "The precise arrangements of these membranes and compartments are essential to the process of photosynthesis—a classic example of the theme of **STRUCTURE AND FUNCTION**" (Module 7.2). The theme of evolution is featured, as it is in every chapter, in an Evolution Connection module, such as Module 4.15, Mitochondria and chloroplasts evolved by endosymbiosis. Two new Visualizing the Concept modules are Module 2.6, Covalent bonds join atoms into molecules through electron sharing, and Module 6.9, Most ATP production occurs by oxidative phosphorylation. Both use new and highly revised art to guide students through these challenging topics. The Connection Module 2.2, Trace elements are common additives to food and water, uses added information on water fluoridation to emphasize the process of science and societal interactions. Two new Connection modules are Module 3.6, Are we eating too much sugar? (which includes a Visualizing the Data figure on recommended and actual sugar consumption), and Module 7.14, Reducing both fossil fuel use and deforestation may moderate climate change (which includes information on the 2015 Paris climate accord). New orientation diagrams help students follow the various stages of cellular respiration and photosynthesis in Chapters 6 and 7.

Unit II, Cellular Reproduction and Genetics The purpose of this unit is to help students understand the relationship between DNA, chromosomes, and organisms and to help students see that genetics is not purely hypothetical but connects in many important and interesting ways to their lives, human society, and other life on Earth. The content has been reinforced with updated discussions of relevant topics, such as DCIS (also called stage 0 breast cancer), increased use of genetically modified organisms (GMOs), recent examples of DNA profiling, information about the 2015 California measles outbreak, a new infographic that charts emergent virus outbreaks, and new data on the health prospects of clones. This edition includes discussion of many recent advances in the field, such as an updated definition of the gene, and a largely new presentation of DNA technologies and bioinformatics, including extensive discussion in both text and art of the CRISPR-Cas9 system, GenBank, and BLAST searches. In some cases, sections within chapters have been reorganized to present a more logical flow of materials. Examples of new organization include an improved presentation of the genetics underlying cancer, a new Visualizing the Concept module on crossing over, a new circular genetic code chart that should improve student understanding, and a new Visualizing the Data that summarizes relevant information about different types of cancer and their survival rates. Material throughout the unit has been updated to reflect recent data, such as the latest statistics on cancer, cystic fibrosis, and Down syndrome, an improved model of ribosomes, new information about prions, expanded coverage of noncoding small RNAs, new human gene therapy trials, and recent information about Y chromosome inheritance.

Unit III, Concepts of Evolution This unit presents the basic principles of evolution and natural selection, the overwhelming evidence that supports these theories, and their relevance to all of biology—and to the lives of students. For example, a new Visualizing the Data figure (13.16) illustrates the growing threat of antibiotic resistance. Chapter 13 also includes a new Visualizing the Concept module (13.14) on the effects of natural selection that shows experimental data along with hypothetical examples. Chapter 14 contains a new

Evolution Connection module (14.9) featuring the work of Rosemary and Peter Grant on Darwin's finches. Modules 15.14 to 15.19 were revised to improve the flow and clarity of the material on phylogenetics and include updates from genomic studies and new art (for example, Figures 15.17 and 15.19A).

Unit IV, The Evolution of Biological Diversity The diversity unit surveys all life on Earth in less than a hundred pages! Consequently, descriptions and illustrations of the unifying characteristics of each major group of organisms, along with a small sample of its diversity, make up the bulk of the content. Two recurring elements are interwoven with these descriptions: evolutionary history and examples of relevance to our everyday lives and society at large. With the rapid accumulation of molecular evidence, taxonomic revisions are inevitable. These changes are reflected in Chapter 16, Microbial Life, with a new module and figure (16.13) on protist supergroups, and in Chapters 18 and 19, Evolution of Invertebrate Diversity and Evolution of Vertebrate Diversity, with three modules about animal phylogeny (18.10, 18.11, and 19.1). The importance of metagenomics to the study of microorganisms is highlighted in Modules 16.1 and 16.7 (prokaryotes) and 17.14 (fungi). New examples of relevance include valley fever, a fungal disease linked to climate change (Module 17.19), and a Visualizing the Data figure (19.16) on the evolution of human skin color.

Unit V, Animals: Form and Function This unit combines a comparative animal approach with an exploration of human anatomy and physiology. The introduction to Chapter 20, Unifying Concepts of Animal Structure and Function, begins with the question "Does evolution lead to the perfect animal form?" and the question is answered in the Evolution Connection, Module 20.1, in discussion of the lengthy laryngeal nerve in giraffes. By illustrating that a structure in an ancestral organism can become adapted to function in a descendant organism without being "perfected," this example helps to combat a common student misconception about evolution. The main portion of every chapter in this unit is devoted to detailed presentations of human body systems, frequently illuminated by discussion of the health consequences of disorders in those systems. The Chapter 22 opening essay and Scientific Thinking module (22.7) were revised to compare the conclusions from long term studies on the health hazards of cigarette smoking with the very recent research on the effects of e-cigarettes. In Chapter 23, Circulation, the Scientific Thinking module (23.6) discusses the consequences of treating coronary artery disease with medicine or both medicine and stents. Chapter 29, The Senses, incorporates new material on common eye conditions, glaucoma and cataracts. In many areas, content has been updated to reflect newer issues in biology. New modules include 24.9 on the importance of community vaccination, 28.18 on neuronal plasticity, and 29.12 about the contribution of genes in one's perception of the taste of cilantro. New Visualizing the Concept modules on osmoregulation (25.4) and neuronal synapses (28.6) help students better envision big concepts. New Visualizing the Data figures detail data on hypertension in the United States (23.9B), worldwide HIV infection and treatments (24.14B), and changes in bone mass during the human life span (30.5B). Chapter 21, Nutrition and Digestion, includes a new discussion of human microbiome and microbiota as well as presentation of the forthcoming changes to food nutritional labels. Module 22.9, Breathing is automatically controlled, was heavily revised. The equation showing the formation and dissociation of carbonic acid now accompanies the discussion of how the medulla regulates breathing, a process illustrated by new art. Improvements to this unit also include a significant revision to the presentation of the kidney as a water-conserving organ (25.7) and a clearer four-step process by which a sensory stimulus results in a perception (Module 29.1). Chapter 27, Reproduction and Embryonic Development, presents data on the decreased incidence of cervical cancer due to early detection, a new Visualizing the Data (Figure 27.8) that summarizes different methods of contraception, and new information on reproductive technologies.

Unit VI, Plants: Form and Function To help students gain an appreciation of the importance of plants, this unit presents the anatomy and physiology of angiosperms with frequent connections to the importance of plants to society. New Connections modules in this edition include an improved discussion of agriculture via artificial selection on plant parts and via plant cloning in Chapter 31; updated discussions of organic farming, human harvesting of plant transport products (such as maple syrup and rubber), and GMOs in Chapter 32; and a new discussion of caffeine as an evolutionary adaptation that can prevent herbivory in Chapter 33. Throughout the unit, the text has been revised with the goal of making the material more engaging and accessible to students. For example, the discussion of plant nutrients has been entirely reorganized into a large Visualizing the Data in Module 32.7, and the presentation of the potentially confusing topic of the effect of auxin on plant cell elongation benefits from a new visual presentation (Figure 33.3B). All of these changes are meant to make the point that human society is inexorably connected to the health of plants.

Unit VII, Ecology In this unit, students learn the fundamental principles of ecology and how these principles apply to environmental problems. The Ninth Edition features a new Visualizing the Concept module that explains the global water cycle (34.18) and Visualizing the Data figures that compare ecological footprints (36.11), track global temperatures since 1880 (38.3A), and illustrate the results of a study on optimal foraging theory (35.12). Module 35.16 has been updated with new examples of the effects of endocrine-disrupting chemicals on animal behavior and the EPA's progress in evaluating endocrine disruptors in pesticides as potential hazards to human health. Other content updates in this unit include human population data (36.9 and 36.10), species at risk for extinction (38.1), and the new federal law banning the use of microbeads in health and beauty products (38.2). Module 37.13 has been heavily revised to include more examples of invasive species. The unit-wide emphasis on climate change and sustainability continues in this edition. For example, the module on ecological footprints (36.11) has been updated and revised, and Module 37.23 includes a new emphasis on the role of wetlands in mitigating the effects of climate change. Figures 38.3B and 38.4A were updated with the most recent data available, and Module 38.3 was heavily revised.

Acknowledgments

This Ninth Edition of *Campbell Biology: Concepts & Connections* is a result of the combined efforts of many talented and hardworking people, and the authors wish to extend heartfelt thanks to all those who contributed to this and previous editions. Our work on this edition was shaped by input from the biologists acknowledged in the reviewer list on pages xxii–xxiv, who shared with us their experiences teaching introductory biology and provided specific suggestions for improving the book. Feedback from the authors of this edition's supplements and the unsolicited comments and suggestions we received from many biologists and biology students were also extremely helpful. In addition, this book has benefited in countless ways from the stimulating contacts we have had with the coauthors of *Campbell Biology*, Eleventh Edition.

We wish to offer special thanks to the students and faculty at our teaching institutions. Marty Taylor thanks her students at Cornell University for their valuable feedback on the book. Eric Simon thanks his colleagues and friends at New England College, especially within the collegium of Natural Sciences and Mathematics, for their continued support and assistance. Jean Dickey thanks her colleagues at Clemson University for their expertise and support. And Kelly Hogan thanks her students for their enthusiasm and colleagues at the University of North Carolina, Chapel Hill, for their continued support.

We thank Paul Corey, managing director of Higher Education Learning Services. In addition, the superb publishing team for this edition was headed up by courseware portfolio management specialist Alison Rodal, with the invaluable support of courseware portfolio management director Beth Wilbur. We cannot thank them enough for their unstinting efforts on behalf of the book and for their commitment to excellence in biology education. We are fortunate to have had once again the contributions of courseware director of content development Ginnie Simione Jutson. We are similarly grateful to the members of the editorial development team—Debbie Hardin, Evelyn Dahlgren, Julia Osborne, Susan Teahan, and Mary Catherine Hager—for their steadfast commitment to quality. We thank them for their thoroughness, hard work, and good humor; the book is far better than it would have been without their efforts. Thanks also to supplements project editor Melissa O'Conner on her oversight of the supplements program and to editorial coordinator Alison Cagle for the efficient and enthusiastic support she provided.

This book and all the other components of the teaching package are both attractive and pedagogically effective in large part because of the hard work and creativity of the production professionals on our team. We wish to thank managing producer Mike Early and content producers Mae Lum and Courtney Towson. We also acknowledge copy editor Jon Preimesberger, proofreaders Pete Shanks and Joanna Dinsmore, and indexer Tim Engman. We again thank photo researcher Kristin Piljay for her contributions, as well as text permissions manager K. Ganesh and photo permissions manager Eric Shrader. Integra was responsible for composition, headed by production project manager Alverne Ball, and the art house Lachina, headed by project manager Whitney Philipp, who was responsible for overseeing the rendering of new and revised illustrations. We also thank manufacturing overseer Stacey Weinberger.

We thank Elise Lansdon for creating a beautiful and functional interior design and a stunning cover, and we are again indebted to design manager Mark Ong for his oversight and design leadership.

The value of *Campbell Biology: Concepts & Connections* as a learning tool is greatly enhanced by the hard work and creativity of the authors of the supplements that accompany this book: Ed Zalisko (*Instructor's Guide* and *PowerPoint® Lecture Presentations*); Jean DeSaix, Kristen Miller, Justin Shaffer, and Suann Yang (*Test Bank*); Dana Kurpius (*Active Reading Guide*); Bob Iwan and Sukanya Subramanian (*Reading Quizzes*); Cheri LaRue (media correlator), and Brenda Hunzinger (*Clicker Questions* and *Quiz Shows*). In addition to supplements project editor Melissa O'Conner, the editorial and production staff for the supplements program included supplements production project manager Alverne Ball (Integra), Marsha Hall (PPS), and Jennifer Hastings (PPS). And the superlative MasteringBiology® program for this book would not exist without Lauren Fogel, Stacy Treco, Katie Foley, Sarah Jensen, Chloé Veylit, Jim Hufford, Charles Hall, Caroline Power, and David Kokorowski and his team. And a special thanks to Arl Nadel and Sarah Young-Dualan for their thoughtful work on the Visualizing the Concepts interactive videos.

For their important roles in marketing the book, we are very grateful to marketing manager Christa Pelaez and vice president of marketing Christy Lesko. The members of the Pearson Science sales team have continued to help us connect with biology instructors and their teaching needs, and we thank them.

Finally, we are deeply grateful to our families and friends for their support, encouragement, and patience throughout this project. Our special thanks to Paul, Dan, Maria, Armelle, and Sean (J.B.R.); Josie, Jason, Marnie, Alice, Jack, David, Paul, Ava, and Daniel (M.R.T.); Amanda, Reed, Forest, and dear friends Jamey, Nick, Jim, and Bethany (E.J.S.); Jessie and Katherine (J.L.D.); and Tracey, Vivian, Carolyn, Brian, Jake, and Lexi (K.H.)

Jane Reece, Martha Taylor, Eric Simon, Jean Dickey, and Kelly Hogan

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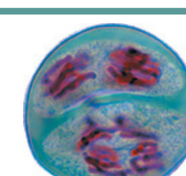

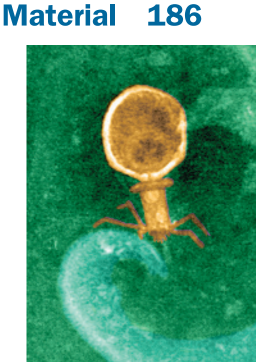

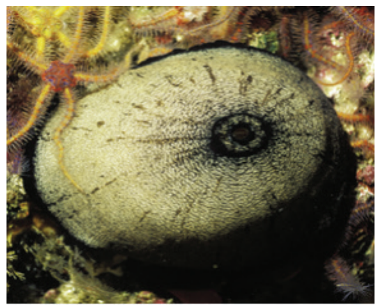

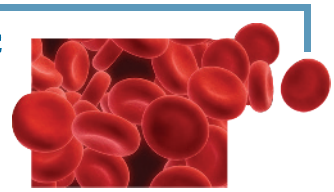

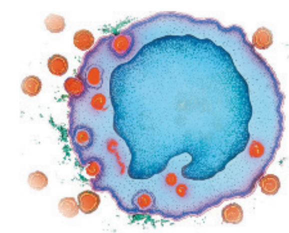

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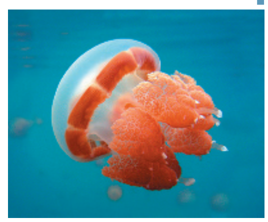

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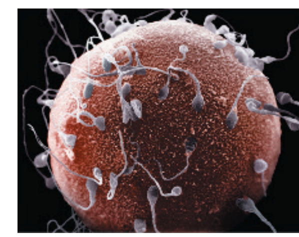

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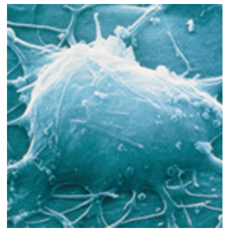

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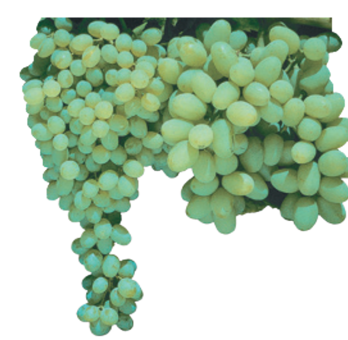


UNIT VII

Ecology 681

Biology: *Exploring Life*

CHAPTER 1

Red pandas (*Ailurus fulgens*), such as the one on the cover of this textbook and the one pictured to the right, have a characteristic kitten-like face and grow to be about the size of a large house cat. These captivating creatures are well adapted for life in the mountainous forests of Asia. Their cinnamon red and white coat camouflages them with the red mosses and white lichens of their environment, while their dark underbelly helps hide them from predators looking up from below. Their long bushy tail helps them balance in the trees and, when wrapped around their bodies, provides warmth during the winter. And a bony projection in their wrist helps them grasp one of their favorite foods, bamboo.

Who are a red panda's closest relatives?

You might think of the much larger, black and white pandas when you think about bamboo-eaters. Giant pandas live in similar regions in Asia. Are they closely related to red pandas? Scientists once thought so but have since reclassified red pandas into their own family. Later in the chapter we'll explore how scientists have traced the family tree of red pandas.

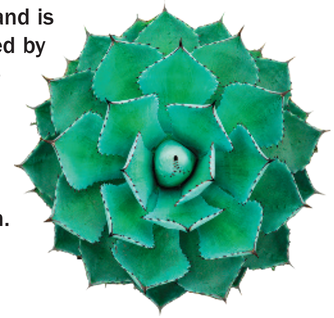
Despite their distinct lineages, the red panda and the giant panda do have something in common—they are both at risk of going extinct in the wild. Scientists don't have an accurate count of the red panda's numbers or know exactly where they live. The most recent counts estimate there are about 10,000 red pandas left in the world, a number that is likely to fall below 9,000 over the next 30 years. Finding and counting these shy, solitary animals in their remote habitats is difficult—just one example of the challenges and adventures encountered in biology, the scientific study of life.

We will begin this chapter by defining biology. Next we'll consider the nature and process of science. And we'll end the chapter with an exploration of five unifying themes that you will find woven throughout your study of biology.

BIG IDEAS

Biology: The Scientific Study of Life (1.1–1.3)

Life can be defined by a group of properties common to all living organisms and is characterized by both a huge diversity of organisms and a hierarchy of organization.



The Process of Science (1.4–1.8)

Science is based on verifiable evidence. In studying nature, scientists make observations, form hypotheses, and test predictions.

Five Unifying Themes in Biology (1.9–1.14)

Themes that run through all of biology are evolution, information, structure and function, energy and matter, and interactions.

Biology: The Scientific Study of Life

1.1 What is life?

Defining **biology** as the scientific study of life raises the obvious question: What is *life*? Even a small child realizes that an ant or a plant is alive, whereas a rock or a car is not. But the phenomenon we call life defies a one-sentence definition. We recognize life mainly by what living things do. **Figure 1.1** explores some of the properties and processes we associate with life.

All organisms, from ants to plants to people, are composed of **cells**—the structural and functional units of life. The phenomenon we call life emerges at the level of a cell: A cell can regulate its internal environment, take in and use energy, and respond to its environment. The ability of cells to give rise to new cells is the basis for all reproduction and for the growth and repair of multicellular organisms. A cell may be part of a complex plant or animal, or it may be an organism in its own right. Indeed, single-celled bacteria and other unicellular organisms far outnumber multicellular organisms on Earth.

Figure 1.1 also illustrates that the living world is wondrously varied. In the next module we see how biologists attempt to organize the remarkable diversity of life.

? **How would you define life?**

■ Life can be characterized by its properties and processes, such as those depicted in Figure 1.1.

▲ **Figure 1.1** Some properties of life

1.2 Biologists arrange the diversity of life into three domains

Diversity is a hallmark of life. One way in which biologists make sense of the vast array of organisms existing now and over the long history of life on Earth is to organize life's diversity into groups. Each unique form of life is called a species and is given a two-part, italicized, scientific name. The name identifies the genus and the particular species within that genus. For instance, the name for our species is *Homo sapiens*, meaning "wise man." Biologists have so far identified and named about 1.8 million species. Estimates of the total number of species range from 10 million to more than 100 million.

There seems to be a human tendency to group things, such as snakes or butterflies, although we recognize that each group includes many different species. And we often cluster groups into broader categories, such as reptiles (which include snakes) and insects (which include butterflies). Taxonomy, the branch of biology that names and classifies species, arranges species into a hierarchy of broader and broader groups, from genus, family, order, class, and phylum, to kingdom. A goal of this classification system is to reflect the evolutionary history and relationships of organisms.

Historically, biologists divided all of life into five kingdoms. But new methods for assessing evolutionary relationships, such as comparisons of DNA sequences, have led to an ongoing reevaluation of the number and boundaries of kingdoms. Although the debate continues on such divisions, there is consensus among biologists that life can be organized into three higher levels called **domains**. **Figure 1.2** shows representatives of domains Bacteria, Archaea, and Eukarya.

Domains Bacteria and Archaea both consist of microscopic organisms with relatively simple cells. You are probably most familiar with bacteria, a very diverse and widespread group. Many members of domain Archaea live in Earth's extreme environments, such as salty lakes and boiling hot springs. Each rod-shaped or round structure in the photos of bacteria and archaea in Figure 1.2 is a single cell. These photos were made with an electron microscope, and the number along the side indicates the magnification of the image.

All the organisms with more complex cells are called eukaryotes and are grouped in domain Eukarya. Protists are a diverse collection of mostly single-celled organisms. Figure 1.2 shows an assortment of protists in a drop of pond water. Biologists continue to assess how to group the protists to reflect their evolutionary relationships.

The three remaining groups within Eukarya are distinguished partly by their modes of nutrition. Kingdom Plantae consists of plants, which produce their own food by photosynthesis. The plant pictured in Figure 1.2 is a tropical bromeliad, a plant native to the Americas.

▲ **Figure 1.2** **The three domains of life**

Kingdom Fungi, represented by the mushrooms in Figure 1.2, is a diverse group whose members mostly decompose organic wastes and absorb the nutrients into their cells.

Animals, which are grouped in Kingdom Animalia, obtain food by eating other organisms. The butterfly in Figure 1.2 is drinking nectar from a thistle flower.

Another way in which biologists make sense of the diversity and complexity of life is to organize it into a hierarchy of structural levels, extending from the microscopic level of cells to the global scale of the entire Earth. In the next module we take a visual journey through these levels.

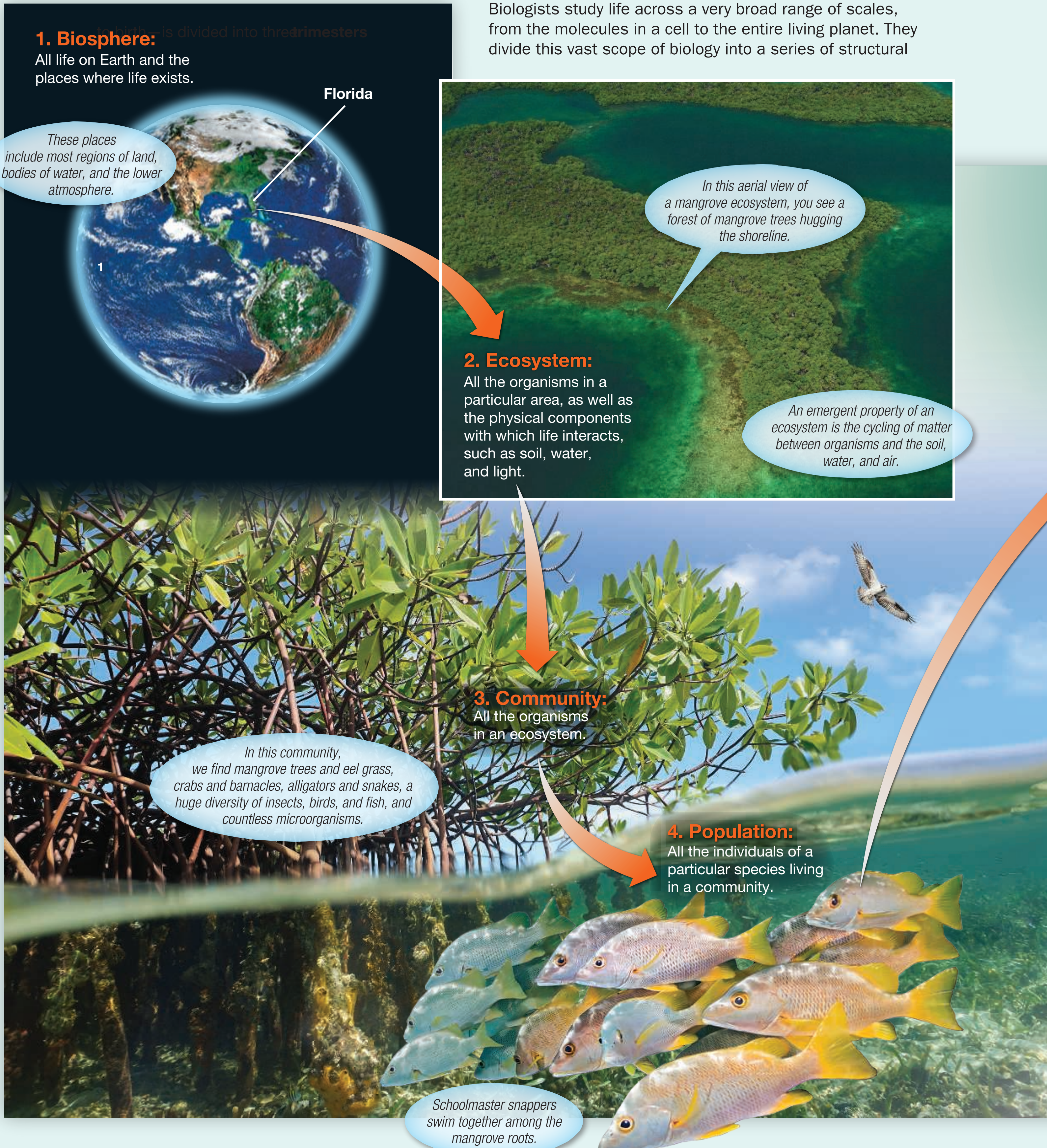
? **To which of the three domains of life do we belong?**

Eukarya

VISUALIZING THE CONCEPT

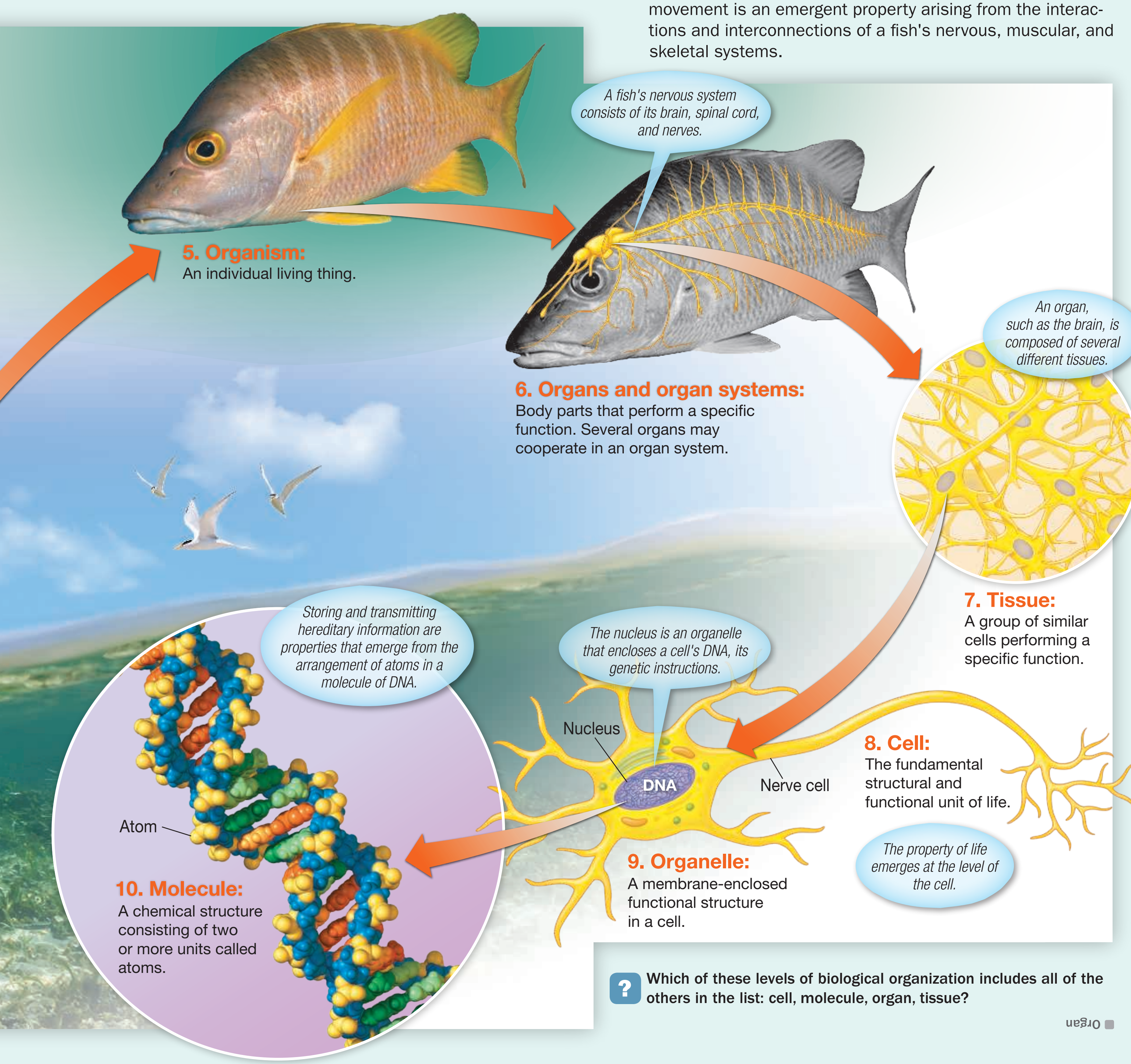
1.3 In life's hierarchy of organization, new properties emerge at each level

Biologists study life across a very broad range of scales, from the molecules in a cell to the entire living planet. They divide this vast scope of biology into a series of structural



levels. Follow the arrows to take a visual tour down through this organizational hierarchy, using a mangrove swamp in Florida as an example.

Biologists often focus their study of the natural world on one or a few of these levels, exploring individual components and interactions between those components, as well as connections to other levels. Indeed, if we reverse the arrows and move upward through this figure from molecules to the biosphere, we find that novel properties arise at each higher level, properties that were not present at the preceding level. Such **emergent properties** result from the specific arrangement and interactions of component parts. For example, the arrangement and connections of nerve cells enables nervous signals to travel from a fish's brain to its tail. And movement is an emergent property arising from the interactions and interconnections of a fish's nervous, muscular, and skeletal systems.



? **Which of these levels of biological organization includes all of the others in the list: cell, molecule, organ, tissue?**

■ Organ

The Process of Science

1.4 What is science?

Science is a way of knowing—an approach to understanding the natural world. It stems from our curiosity about ourselves and the world around us. At the heart of science is inquiry, a search for information and explanations of natural phenomena.

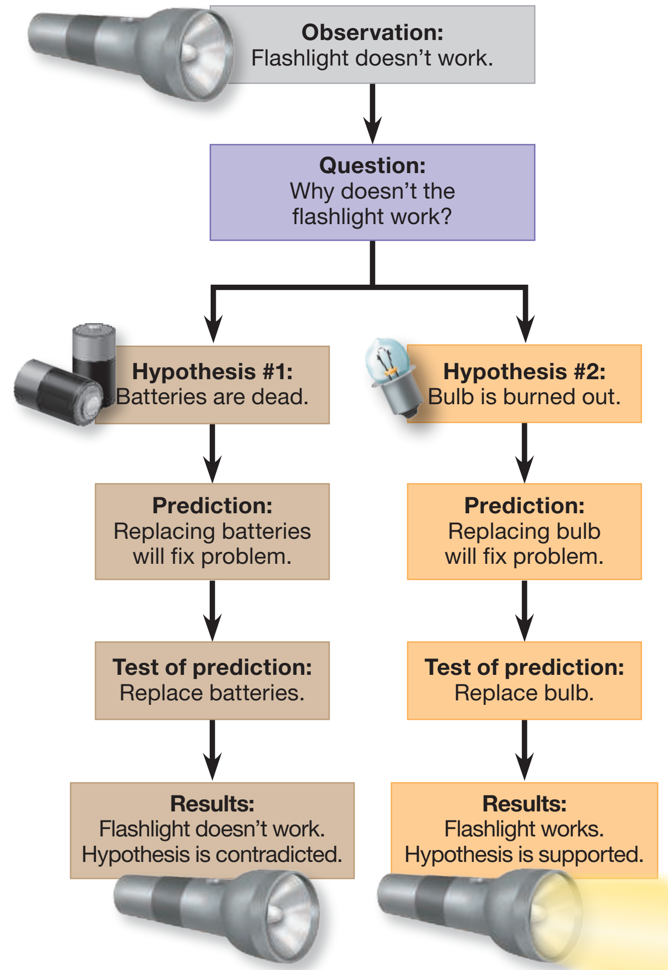
Biology, like other sciences, begins with careful observation. In gathering information, biologists often use tools such as microscopes to extend their senses and precision instruments to facilitate careful measurement. Recorded observations are called **data**—the evidence on which scientific inquiry is based. Some data are *qualitative*, often in the form of recorded descriptions. For example, Jane Goodall spent decades recording her observations of chimpanzee behavior during field research in Tanzania (see Module 35.22). She also recorded volumes of *quantitative* data, such as the frequency and duration of specific behaviors. Quantitative data are generally numerical measurements, which may be organized into tables and graphs and analyzed with a type of mathematics called statistics.

Observations often prompt us to ask questions and then seek answers by forming and testing hypotheses. A **hypothesis** is a proposed explanation for a set of observations, and it leads to predictions that can be tested by making additional observations or by performing experiments. An **experiment** is a scientific test, often carried out under controlled conditions.

We all use hypotheses and predictions in solving everyday problems. Let's say you are preparing for a big storm that is approaching your area and find that your flashlight isn't working. That your flashlight isn't working is an observation, and the question is obvious: Why doesn't it work? **Figure 1.4** presents two hypotheses, each of which leads to predictions you can test. Predictions are the results we should expect if the hypothesis is correct, and they often take an "*if* . . . *then*" form. For example, *if* the dead-battery hypothesis is correct, *then* replacing the batteries with new ones will fix the problem.

An important point about scientific inquiry is that we can never *prove* that a hypothesis is true. As shown in Figure 1.4, the burned-out bulb hypothesis is the more likely explanation in our hypothetical scenario. But perhaps the old bulb was simply loose and the new bulb was inserted correctly. We could test this hypothesis by carefully reinstalling the original bulb. If the flashlight doesn't work, the burned-out bulb hypothesis is supported by another line of evidence. Testing a hypothesis in various ways provides additional support and increases our confidence in the hypothesis. Indeed, multiple rounds of hypothesis testing may lead to a scientific consensus—the shared conclusion of many scientists that a particular hypothesis explains the known data well and stands up to experimental testing.

How is a theory different from a hypothesis? A scientific **theory** is much broader in scope and is supported by a large and usually growing body of evidence. For example, the theory of evolution by natural selection explains a great diversity of observations, is supported by a vast quantity of evidence, and has not been contradicted by any scientific data.



▲ **Figure 1.4** **An everyday example of forming and testing hypotheses**

How is science different from other ways of describing and explaining nature, such as philosophy or religion? Those endeavors also seek to make sense of the world around us, and they often play an important role in society. But the scientific view of the world is based on hypothesis testing and verifiable evidence. Indeed, one of the distinguishing characteristics of science is the willingness to follow the evidence—and to correct itself when new evidence is found.

To help you better understand what science is, we include a Scientific Thinking module in each chapter. These modules encompass several broad activities that scientists engage in: observing nature; forming hypotheses and testing them using various research methods; analyzing data; using tools and technologies to build scientific knowledge; communicating the results of scientific research; and evaluating the implications of such studies for society as a whole.

? **What is the main requirement for a scientific hypothesis?**

■ It must generate predictions that can be tested by experiments or gathering further observations.

1.5 Hypotheses can be tested using controlled experiments

Many animals match their environment: toads the color of dead leaves, green cabbage worms on green leaves, or white snowy owls in their arctic habitat. From these observations, one might hypothesize that such color patterns have evolved as adaptations that protect animals from predation. Can scientists test this hypothesis?

▲ **Figure 1.5** Beach mouse and inland mouse with their native habitat

Controlled Experiments In an experimental test of a hypothesis, a researcher often manipulates one component in a system and observes the effects of this change. Variables are factors that *vary* in an experiment. The factor that is manipulated by the researchers is called the **independent variable**. The measure used to judge the outcome of the experiment is called the **dependent variable**. This variable *depends* on, or is affected by, the manipulated variable. A **controlled experiment** is one in which an experimental group is compared with a control group. These groups ideally differ only in the one variable the experiment is designed to test.

Let's consider an example of a controlled experiment involving two populations of mice that belong to the same species (*Peromyscus polionotus*) but live in different environments. The beach mouse lives along the Florida seashore; the inland mouse lives on darker soil farther inland. As you can see in **Figure 1.5**, there is a striking match between mouse coloration and habitat. In 2010, biologist Hopi Hoekstra of Harvard University and a group of her students headed to Florida to test the camouflage hypothesis. They predicted that if camouflage coloration protects mice from predators, then mice that matched their environment would be preyed on less frequently than mice with coloration that did not match their habitat.

This experiment is an example of a field study, one not done in a laboratory but out in nature, using the natural habitat of the mice and their predators. The researchers built 250 plastic models of mice and painted them to resemble either beach or inland mice. Equal numbers of models were placed randomly in both habitats. The models resembling the native mice in each habitat were the control group. The mice with the non-native coloration were the experimental group. Signs of predation were recorded for three days.

As you can see by the results in **Table 1.5**, the noncamouflaged models had a much higher percentage of predation attacks in both habitats. The data thus support the camouflage hypothesis: Coloration that matches the environment protects animals from predation.

TABLE 1.5 Results from Camouflage Experiment

	Number of Attacks		
Habitat	**On Camouflaged Models**	**On Noncamouflaged Models**	**% Attacks on Noncamouflaged Models**
Beach (light habitat)	2	5	71%
Inland (dark habitat)	5	16	76%

Data from S. N. Vignieri et al., The selective advantage of crypsis in mice, *Evolution* 64: 2153–8 (2010).

TRY THIS Identify the independent and dependent variables in this experiment.

Testing Hypotheses in Humans Controlled experiments involving humans, such as tests of new medications, are called clinical trials or clinical studies. Subjects are usually randomly assigned to control and experimental groups. The control group participants are often given a placebo, a treatment (such as a sugar pill) that doesn't contain the substance being studied. In a double-blind trial, neither the researchers nor the subjects know who is in which group. Clinical trials must be cut short if preliminary results show that the treatment is either significantly harmful or significantly beneficial to the participants, because it would be unethical to knowingly harm participants or withhold effective treatment.

Observational studies are often used to test hypotheses in humans. In a retrospective study, researchers may interview people, use medical records, or examine death certificates in the attempt to identify factors that led to a specific outcome. In a prospective study, researchers enter the picture at the beginning, enrolling a group of participants, called a cohort, and then collecting data from them over a period of time. Observational studies have their limitations. A correlation between a factor and an outcome does not necessarily mean that the factor caused the outcome. Large cohort studies, however, have contributed a great deal to our understanding of the effects of many health-related factors, including diet, smoking, exercise, and environmental conditions.

? In some studies, researchers try to match the sex, age, and general health of subjects in the control and experimental groups. What is this experimental design trying to do?

■ Ensure that the two groups differ only in the one variable the experiment is designed to test

1.6 Hypotheses can be tested using observational data

SCIENTIFIC THINKING

Controlled experiments are not the only way to test hypotheses. Scientists often use data from observations to form and test hypotheses. Let's consider an example of how scientists have answered the question of how to classify the red panda. As you will see, the red panda story provides an excellent example of observations leading to hypotheses and the willingness of scientists to revise hypotheses to incorporate new evidence.

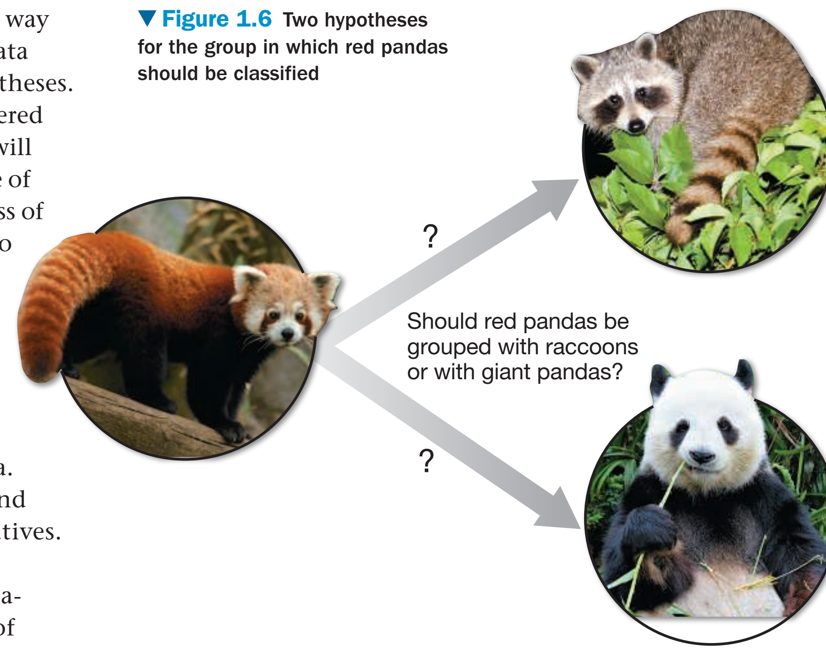
Who are the red panda's closest relatives?

From its antics in YouTube videos, the red panda might remind you of a house cat. Indeed, its scientific name, *Ailurus fulgens*, means "shining cat." But it also looks like a raccoon, and it eats bamboo and has a false thumb like a giant panda. Common names such as lesser panda, red cat-bear, and firefox reflect the confusion over the red panda's relatives. How have scientists classified this animal?

To develop hypotheses about the evolutionary relationships among species, scientists use many kinds of evidence, including comparisons of both fossils and living organisms. Based on observations of physical similarities, scientists initially hypothesized that the red panda was most closely related to raccoons, and therefore classified the two species in the same biological family **(Figure 1.6)**. Other scientists, observing that the diet and habitat of red pandas were similar to those of giant pandas, placed the two pandas together in their own family. As evidence accumulated that giant pandas are members of the bear family, it was proposed that the red panda also belonged in that family.

In recent years, scientists have increasingly used molecular evidence based on comparisons of DNA sequences to test hypotheses about evolutionary relationships. The underlying assumption is that the more closely the DNA sequences of two species match, the more closely they are related. A number of recently published molecular studies strongly support the hypothesis that red pandas are not part of either the bear or the raccoon family. As a result of this new evidence of differences in the DNA sequences of these groups, scientists now classify red pandas as the sole living species of their own family.

▼ **Figure 1.6** Two hypotheses for the group in which red pandas should be classified



? **Explain why comparisons of DNA sequences are considered observational and not experimental data.**

■ Scientists are not manipulating DNA sequences in any type of experiment but are simply recording and comparing the differences in sequences that they observe.

1.7 The process of science is repetitive, nonlinear, and collaborative

As discussed in Module 1.4, scientists use a process of inquiry that includes making observations, asking questions, forming hypotheses, and testing them. Very few scientific inquiries, however, adhere rigidly to the sequence of steps that are typically used to describe "the scientific method."

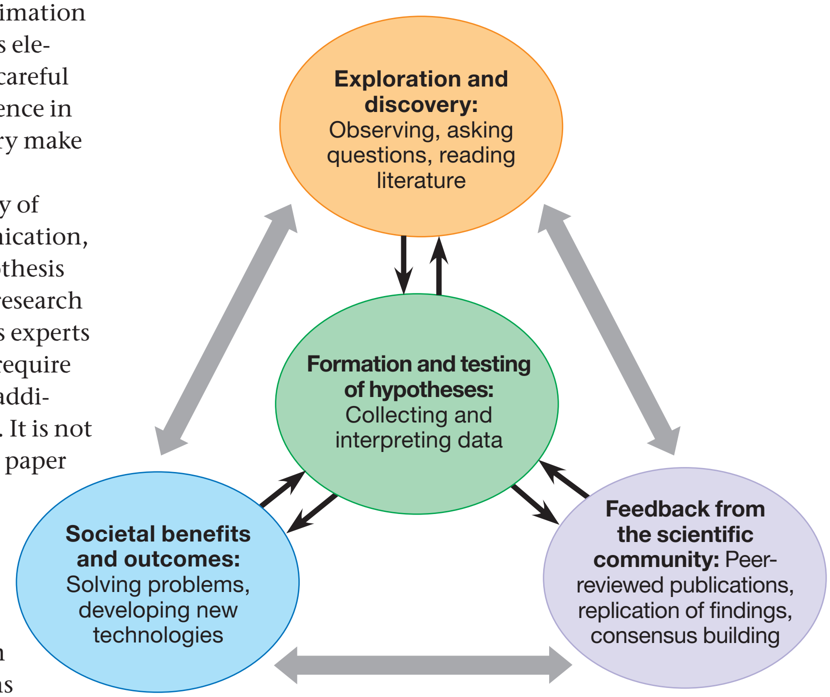
Figure 1.7, on the facing page, presents a more inclusive model of the scientific process. You can see that forming and testing hypotheses are at the center of science. This core set of activities is the reason that science does so well in explaining natural phenomena. These activities, however, are shaped by exploration and discovery (the upper circle in Figure 1.7) and influenced by interactions with other scientists and with society more generally (lower circles). The arrows pointing between the circles illustrate that the components of the scientific process interact and interconnect.

The process of science is typically repetitive and nonlinear. For example, scientists often work through several iterations of making observations and asking questions, with each round informing the next, before settling on hypotheses that they wish to test. In fine-tuning their questions, biologists rely heavily on scientific literature, the published contributions of fellow scientists—their peers. By reading about and understanding past studies, scientists can build on the foundation of existing knowledge.

Scientists rarely work alone in testing their ideas: they may learn methods from each other and share advice on experimental design and data analysis. An experimental design may need to be adjusted after initial data are collected. And results may lead to a revision of the original hypothesis or the formation of alternate ones, thus leading to further testing. In this way, scientists circle closer and closer to their best estimation of how nature works. As in all quests, science includes elements of challenge, adventure, and luck, along with careful planning, reasoning, creativity, patience, and persistence in overcoming setbacks. Such diverse elements of inquiry make science far less structured than most people realize.

Scientists share information with their community of peers through seminars, meetings, personal communication, and scientific publications. Before the results of hypothesis testing are published in a peer-reviewed journal, the research is evaluated by qualified, impartial, often anonymous experts who were not involved in the study. Reviewers often require authors to make revisions to their claims or perform additional experiments to provide more lines of evidence. It is not uncommon for a journal to "reject," or not publish, a paper if it doesn't meet the rigorous standards set by fellow scientists. When a study is published, scientists often check each other's claims by attempting to confirm observations or repeat experiments.

As indicated by the lower left circle in Figure 1.7, science is interwoven with the fabric of society. Much of scientific research is focused on particular problems that are of human concern, such as the push to cure cancer or to understand and slow the process of climate change. Societal needs often determine which research projects are funded and how extensively the results are discussed. To emphasize the connection between biology and society, each chapter of this text includes at least one Connection module. These modules also highlight the connections between biology and your own life.



▲ **Figure 1.7** A more realistic model of the process of science. This illustration in based on a model (How Science Works) from the website Understanding Science (www.understandingscience.org).

? Why is hypothesis testing at the center of the process of science?

■ Hypothesis testing is central because a core component of science is testable explanations of nature.

1.8 Biology, technology, and society are connected in important ways

CONNECTION

Many of the current issues facing society are related to biology, and they often involve our expanding technology. What are the differences between science and technology? The goal of science is to understand natural phenomena. In contrast, the goal of **technology** is to apply scientific knowledge for some specific purpose. Scientists usually speak of "discoveries," whereas engineers more often speak of "inventions." These two fields, however, are interdependent. Scientists use new technology in their research, and scientific discoveries often lead to the development of new technologies.

The potent combination of science and technology can have dramatic effects on society. For example, the discovery of the structure of DNA by Watson and Crick more than 60 years ago was aided by the technology of X-ray crystallography. Subsequent advances in DNA science have led to the technologies of DNA manipulation that today are transforming applied fields such as medicine, agriculture, and forensics.

Technology has improved our standard of living in many ways, but not without consequences. Technology has helped Earth's population to grow tenfold in the past three centuries and to more than double in just the past 40 years. There are now more than 7.3 billion people on Earth. Climate change, toxic wastes, deforestation, and increasing rates of extinction are just some of the repercussions of more and more people wielding more and more technology. Science can help identify problems and provide insight into how to slow down or prevent further damage. But solutions to these problems have as much to do with politics, economics, and cultural values as with science and technology. Every citizen has a responsibility to develop a reasonable amount of scientific literacy to be able to participate in the debates regarding science, technology, and society.

The process of science we have just explored results in new biological discoveries every day. In the next section, we introduce broad themes that you will encounter throughout your study of life.

? How do science and technology interact?

■ New scientific discoveries may lead to new technologies; new technologies may increase the ability of scientists to discover new knowledge.