CAMPBELL

essential biology with physiology

5TH EDITION

Simon Dickey Hogan Reece

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Brief Contents

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essential biology with physiology

5TH EDITION

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To Muriel, my wonderful mother, who always supported my efforts with love, compassion, great empathy, and an unwavering belief in me

JEAN L. DICKEY

is Professor Emerita of Biological Sciences at Clemson University (Clemson, South Carolina). After receiving her B.S. in biology from Kent State University, she went on to earn a Ph.D. in ecology and evolution from Purdue University. In 1984, Dr. Dickey joined the faculty at Clemson, where she devoted her career to teaching biology to nonscience majors in a variety of courses. In addition to creating content-based instructional materials, she developed many activities to engage lecture and laboratory students in discussion, critical thinking, and writing, and implemented an investigative laboratory curriculum in general biology. Dr. Dickey is the author of *Laboratory Investigations for Biology*, 2nd Edition, and is a coauthor of *Campbell Biology: Concepts & Connections*, 8th Edition.

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

KELLY A. HOGAN

is a faculty member in the Department of Biology and the Director of Instructional Innovation at the University of North Carolina at Chapel Hill, teaching introductory biology and introductory genetics to science majors. Dr. Hogan teaches hundreds of students at a time, using active-learning methods that incorporate technology such as cell phones as clickers, online homework, and peer evaluation tools. Dr. Hogan 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 relate to how large classes can be more inclusive through evidence-based teaching methods and technology. She provides faculty development to other instructors through peer coaching, workshops, and mentoring. Dr. Hogan is the author of *Stem Cells and Cloning,* 2nd Edition, and is lead moderator of the *Instructor Exchange*, a site within MasteringBiology® for instructors to exchange classroom materials and ideas. She is also a coauthor of *Campbell Biology: Concepts & Connections*, 8th Edition.

To the good-looking boy I met in my introductory biology course many moons ago—and to our two children, Jake and Lexi, who are everyday reminders of what matters most in life

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 (where she was initially a philosophy major), an M.S. in microbiology from Rutgers University, and a Ph.D. in bacteriology from the University of California, Berkeley. At UC Berkeley, and later as a postdoctoral fellow in genetics at Stanford University, her research focused on genetic recombination in bacteria. Dr. Reece taught biology at Middlesex County College (New Jersey) and Queensborough Community College (New York). During her 12 years as an editor at Benjamin Cummings, she played a major role in a number of successful textbooks. She is the lead author of *Campbell Biology*, 10th Edition, and *Campbell Biology: Concepts & Connections*, 8th Edition.

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

NEIL A. CAMPBELL

(1946–2004) combined the inquiring nature of a research scientist with the soul of a caring teacher. Over his 30 years of teaching introductory biology to both science majors and nonscience majors, many thousands of students had the opportunity to learn from him and be stimulated by his enthusiasm for the study of life. 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.

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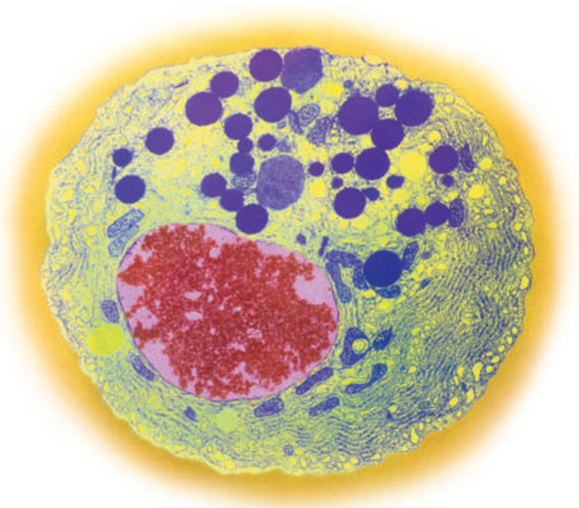

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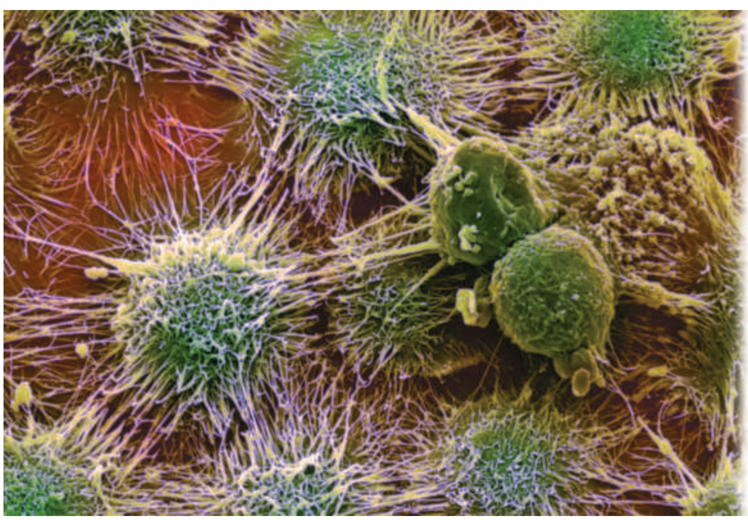


EVIDENCE BAG

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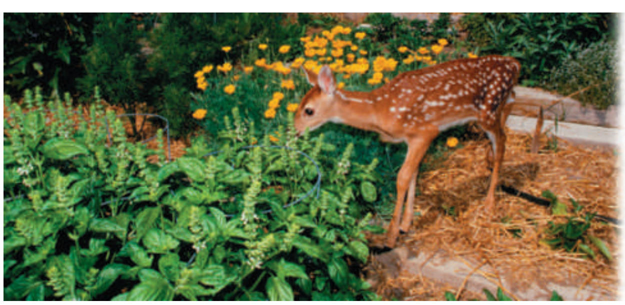

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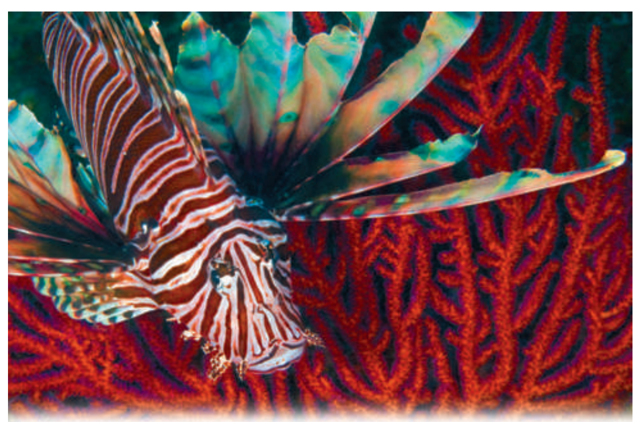

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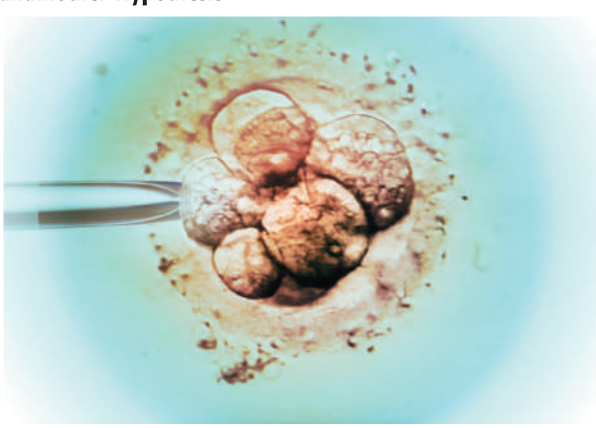

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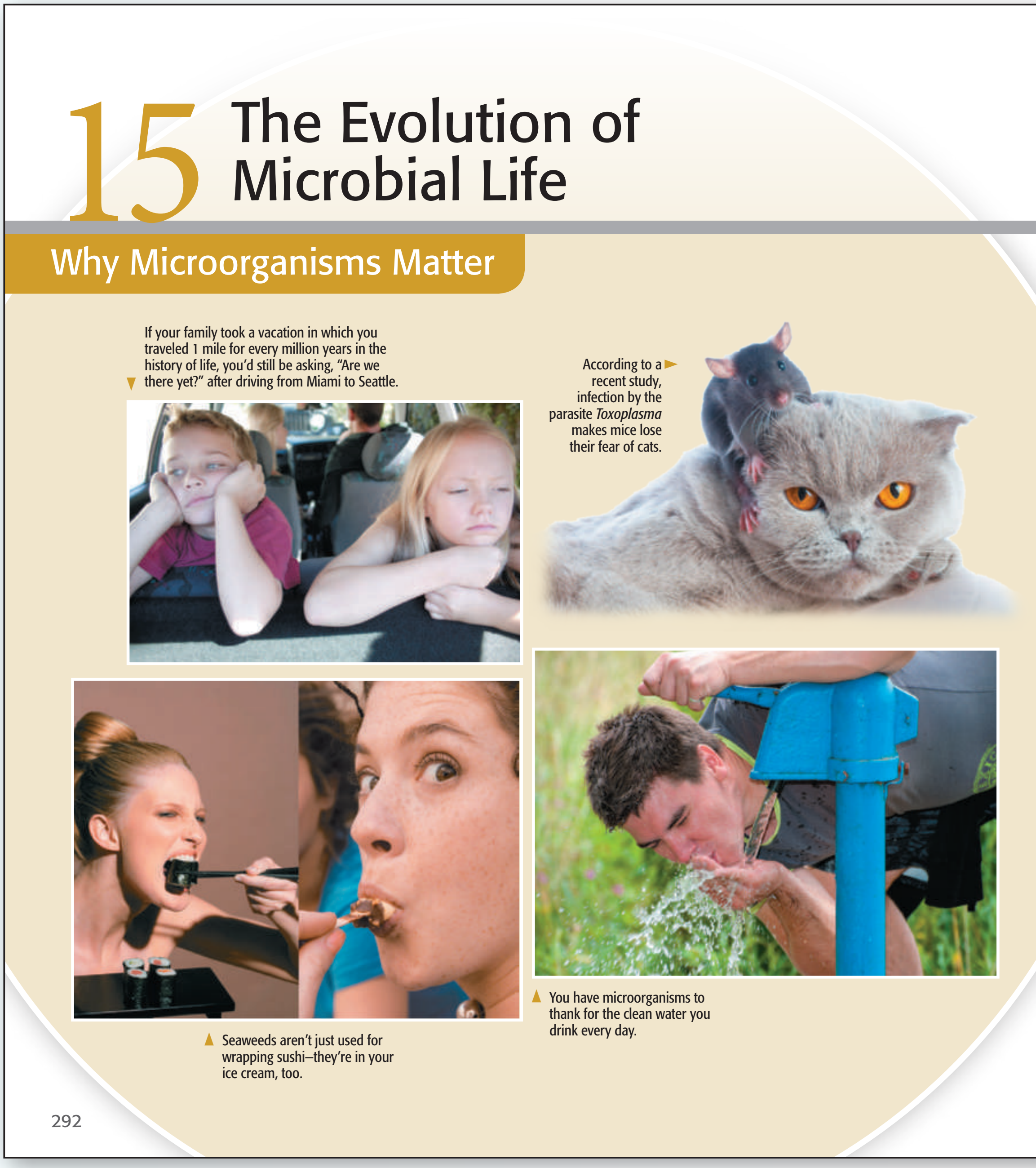
Discover Why Biology *Matters*

Campbell Essential Biology highlights how the concepts that you learn in your biology class are relevant to your everyday life.

- **NEW! Why Biology Matters Photo Essays** use dynamic photographs and intriguing scientific observations to introduce each chapter. Each scientific tidbit is revisited in the chapter.



15 The Evolution of Microbial Life

Why Microorganisms Matter

If your family took a vacation in which you traveled 1 mile for every million years in the history of life, you'd still be asking, "Are we there yet?" after driving from Miami to Seattle.

According to a recent study, infection by the parasite *Toxoplasma* makes mice lose their fear of cats.

Seaweeds aren't just used for wrapping sushi—they're in your ice cream, too.

You have microorganisms to thank for the clean water you drink every day.

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MasteringBiology®

NEW! Everyday Biology Videos briefly explore interesting and relevant biology topics that relate to concepts that students are learning in class. These 20 videos can be assigned in MasteringBiology with assessment questions.

- **UPDATED! Chapter Threads** weave a single compelling topic throughout the chapter. In Chapter 15, human microbiota are explored.

Human Microbiota BIOLOGY AND SOCIETY

Our Invisible Inhabitants

You probably know that your body contains trillions of individual cells, but did you know that they aren't all "you"? In fact, microorganisms residing in and on your body outnumber your own cells by 10 to 1. That means 100 trillion bacteria, archaea, and protists call your body home. Your skin, mouth, and nasal passages and your digestive and urogenital tracts are prime real estate for these microorganisms. Although each individual is so tiny that it would have to be magnified hundreds of times for you to see it, the weight of your microbial residents totals two to five pounds.

We acquire our microbial communities during the first two years of life, and they remain fairly stable thereafter. However, modern life is taking a toll on that stability. We alter the balance of these communities by taking antibiotics, purifying our water, sterilizing our food, attempting to germproof our surroundings, and scrubbing our skin and teeth. Scientists hypothesize that disrupting our microbial communities may increase our susceptibility to infectious diseases, predispose us to certain cancers, and contribute to conditions such as asthma and other allergies, irritable bowel syndrome, Crohn's disease, and autism. Researchers are even investigating whether having the wrong microbial community could make us fat. In addition, scientists are studying how our microbial communities have evolved over the course of human history. As you'll discover in the Evolution Connection section at the end of this chapter, for example, dietary changes invited decay-causing bacteria to make themselves at home on our teeth.

Colorized scanning electron micrograph of bacteria on a human tongue (14,500×).

Throughout this chapter, you will learn about the benefits and drawbacks of human-microbe interactions. You will also sample a bit of the remarkable diversity of prokaryotes and protists. This chapter is the first of three that explore the magnificent diversity of life. And so it is fitting that we begin with the prokaryotes, Earth's first life-form, and the protists, the bridge between unicellular eukaryotes and multicellular plants, fungi, and animals.

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Human Microbiota BIOLOGY AND SOCIETY

Biology and Society essays relate biology to your life and interests. This example discusses the microorganisms that live in your own body.

Human Microbiota THE PROCESS OF SCIENCE

Process of Science explorations give you real-world examples of how the scientific method is applied. Chapter 15 explores a recent investigation into the possible role of microbiota in obesity.

Human Microbiota EVOLUTION CONNECTION

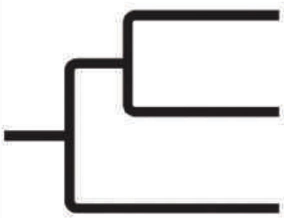
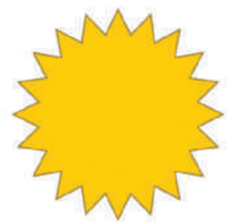
Evolution Connection essays conclude each chapter by demonstrating how the theme of evolution runs throughout all of biology. The example in Chapter 15 discusses how changes in the typical human diet over generations is linked to bacteria that cause tooth decay.

- **Additional updated Chapter Threads and essays** include radioactivity in Chapter 2, muscle performance in Chapter 6, and theft of used cooking oil for biofuel recycling in Chapter 7.

Identify "Big Picture" Themes

Examples of major themes in biology are highlighted throughout the text to help you see how overarching biology concepts are interconnected.

- **NEW! Important Themes in Biology** are introduced in Chapter 1 to underscore unifying principles that run throughout biology.

MAJOR THEMES IN BIOLOGY				
Evolution	Structure/Function	Information Flow	Energy Transformations	Interconnections within Systems
				
Evolution by natural selection is biology's core unifying theme and can be seen at every level in the hierarchy of life.	The structure of an object, such as a molecule or a body part, provides insight into its function, and vice versa.	Within biological systems, information stored in DNA is transmitted and expressed.	All biological systems depend on obtaining, converting, and releasing energy and matter.	All biological systems, from molecules to ecosystems, depend on interactions between components.

- These themes—Evolution, Structure/Function, Information Flow, Energy Transformations, and Interconnections within Systems—are **signaled with icons** throughout the text to help you notice the reoccurring examples of the major themes.

Evolution

Structure/ Function

Information Flow

Energy Transformations

Interconnections within Systems

Human Microbiota EVOLUTION CONNECTION

- The role of evolution throughout all of biology is further explored in depth at the end of each chapter in **Evolution Connection** discussions.

Recognize Analogies and Applications

Analogies and applications to everyday life make unfamiliar biology concepts easier to visualize and understand.

► **Figure 15.1 Some major episodes in the history of life.** On this 4,600-mile metaphorical road trip, each mile equals 1 million years in Earth's history.

If your family took a vacation in which you traveled 1 mile for every million years in the history of life, you'd still be asking, "Are we there yet?" after driving from Miami to Seattle.

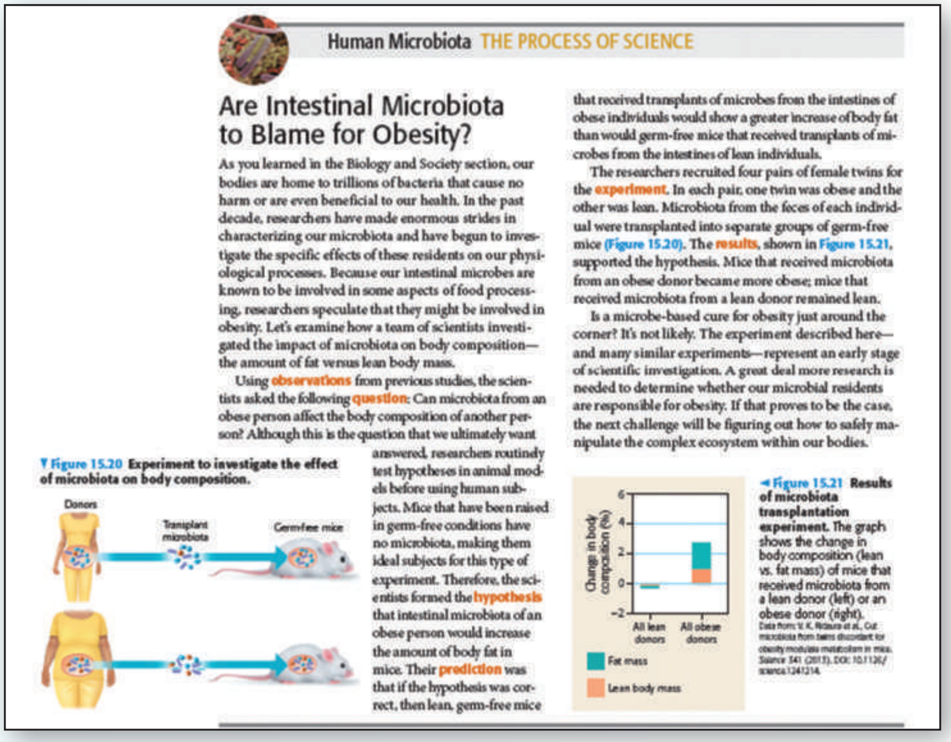
- **NEW analogies and applications** have been added throughout the prose and the illustrations, making it easier to learn and remember key concepts for the first time. Examples include:
  - comparing the significant differences between prokaryotic and eukaryotic cells to the differences between a bicycle and an SUV (Chapter 4)
  - comparing the process of DNA winding into chromosomes with the act of winding yarn into a skein (Chapter 10)
  - comparing a 4,600-mile road trip that describes the scale of biological evolution on Earth (Chapter 15)
  - comparing signal transduction to email communication (Chapter 27*)
  - comparing how dominoes relate to an action potential moving along an axon (Chapter 27*)

* Chapters 21–29 are included in the expanded version of the text that includes coverage of animal and plant anatomy and physiology.

Boost Your Scientific Literacy

A wide variety of exercises and assignments can help you move beyond memorization and think like a scientist.

- **UPDATED! Process of Science essays** appear in every chapter and walk through each step of the scientific method as it applies to a specific research question.



Human Microbiota THE PROCESS OF SCIENCE

Are Intestinal Microbiota to Blame for Obesity?

As you learned in the Biology and Society section, our bodies are home to trillions of bacteria that cause no harm or are even beneficial to our health. In the past decade, researchers have made enormous strides in characterizing our microbiota and have begun to investigate the specific effects of these residents on our physiological processes. Because our intestinal microbes are known to be involved in some aspects of food processing, researchers speculate that they might be involved in obesity. Let's examine how a team of scientists investigated the impact of microbiota on body composition—the amount of fat versus lean body mass.

Using **observations** from previous studies, the scientists asked the following **question**: Can microbiota from an obese person affect the body composition of another person? Although this is the question that we ultimately want answered, researchers routinely test hypotheses in animal models before using human subjects. Mice that have been raised in germ-free conditions have no microbiota, making them ideal subjects for this type of experiment. Therefore, the scientists formed the **hypothesis** that intestinal microbiota of an obese person would increase the amount of body fat in mice. Their **prediction** was that if the hypothesis was correct, then lean, germ-free mice that received transplants of microbes from the intestines of obese individuals would show a greater increase of body fat than would germ-free mice that received transplants of microbes from the intestines of lean individuals.

The researchers recruited four pairs of female twins for the **experiment**. In each pair, one twin was obese and the other was lean. Microbiota from the feces of each individual were transplanted into separate groups of germ-free mice (Figure 15.20). The **results**, shown in Figure 15.21, supported the hypothesis. Mice that received microbiota from an obese donor became more obese; mice that received microbiota from a lean donor remained lean.

Is a microbe-based cure for obesity just around the corner? It's not likely. The experiment described here—and many similar experiments—represent an early stage of scientific investigation. A great deal more research is needed to determine whether our microbial residents are responsible for obesity. If that proves to be the case, the next challenge will be figuring out how to safely manipulate the complex ecosystem within our bodies.

▼ **Figure 15.20 Experiment to investigate the effect of microbiota on body composition.**

◄ **Figure 15.21 Results of microbiota transplantation experiment.** The graph shows the change in body composition (lean vs. fat mass) of mice that received microbiota from a lean donor (left) or an obese donor (right).

Data from: V. K. Ridaura et al., Gut microbiota from twins discordant for obesity modulate metabolism in mice. Science 341 (2013). DOI: 10.1126/science.1241214.

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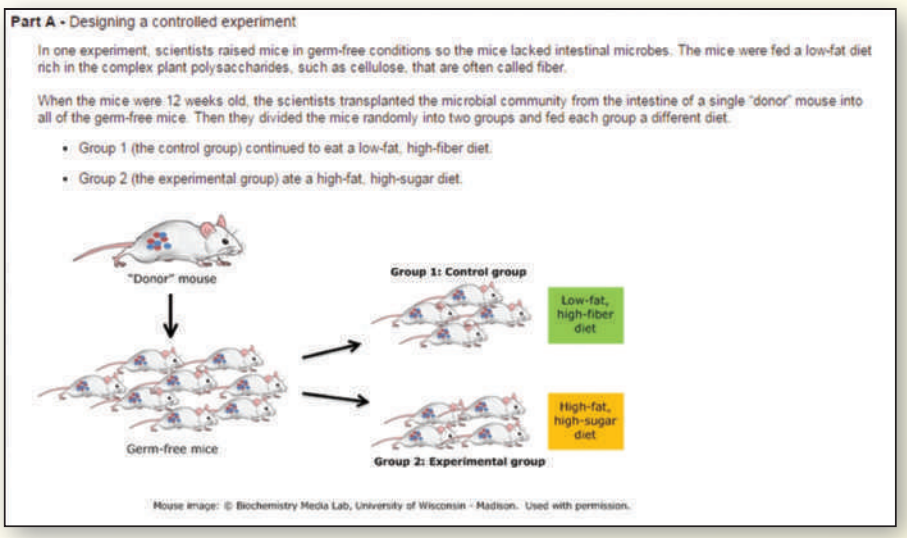


Part A - Designing a controlled experiment

In one experiment, scientists raised mice in germ-free conditions so the mice lacked intestinal microbes. The mice were fed a low-fat diet rich in the complex plant polysaccharides, such as cellulose, that are often called fiber.

When the mice were 12 weeks old, the scientists transplanted the microbial community from the intestine of a single "donor" mouse into all of the germ-free mice. Then they divided the mice randomly into two groups and fed each group a different diet.

- Group 1 (the control group) continued to eat a low-fat, high-fiber diet.
- Group 2 (the experimental group) ate a high-fat, high-sugar diet.

Mouse image: © Biochemistry Media Lab, University of Wisconsin - Madison. Used with permission.

- **NEW! Scientific Thinking Activities** are designed to help you develop an understanding of how scientific research is conducted.

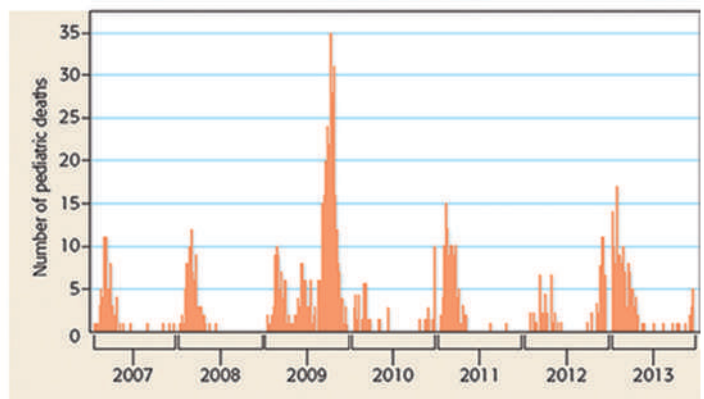
- **NEW! Evaluating Science in the Media Activities** challenge you to recognize validity, bias, purpose, and authority in everyday sources of information.

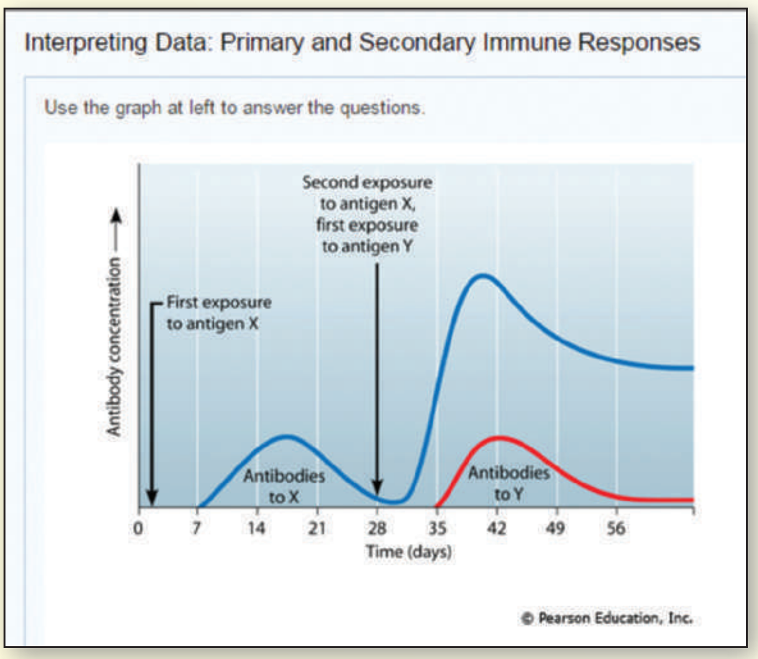
Learn to Interpret Data

Data interpretation is important for understanding biology and for making many important decisions in everyday life. Exercises in the text and online will help you develop this important skill.

- **NEW! Interpreting Data end-of-chapter questions** help you learn to use quantitative material by analyzing graphs and data. This example from Chapter 10 invites you to examine historical data of flu mortality. Other examples include:
  - Chapter 13: Learn how markings on snail shells affect predation rates in an environment
  - Chapter 15: Calculate how quickly bacteria can multiply on unrefrigerated food

14. Interpreting Data The graph below summarizes the number of children who died of all strains of flu from 2007 until 2013. Each bar represents the number of child deaths occurring in one week. Why does the graph have the shape it does, with a series of peaks and valleys? Looking over the Biology and Society section at the start of the chapter, why does the graph reach its highest points near the middle? Based on these data, when does flu season begin and end in a typical year?





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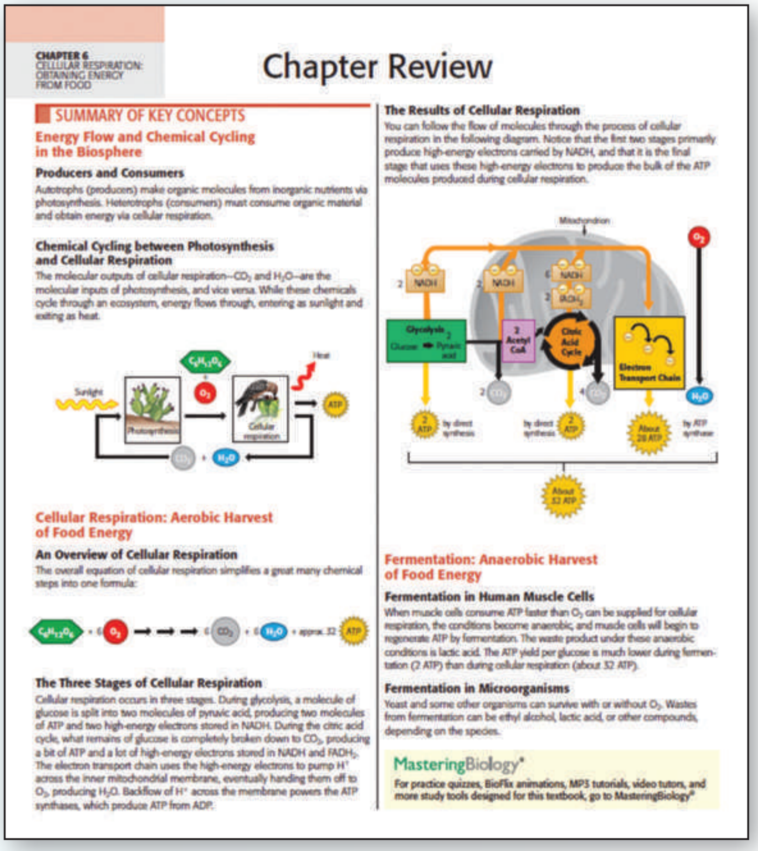
NEW! Interpreting Data Activities help you build and practice data analysis skills.

Maximize Your Study Time

Campbell Essential Biology and the **MasteringBiology** homework, tutorial, and assessment program work hand-in-hand to help students succeed in introductory biology.

- **The Chapter Review** offers a built-in study guide that combines words with images to help you organize the key concepts. The unique figures in the Chapter Review synthesize information from the corresponding chapter, which helps you study more efficiently.



CHAPTER 6
CELLULAR RESPIRATION: OBTAINING ENERGY FROM FOOD

Chapter Review

SUMMARY OF KEY CONCEPTS

Energy Flow and Chemical Cycling in the Biosphere

Producers and Consumers

Autotrophs (producers) make organic molecules from inorganic nutrients via photosynthesis. Heterotrophs (consumers) must consume organic material and obtain energy via cellular respiration.

Chemical Cycling between Photosynthesis and Cellular Respiration

The molecular outputs of cellular respiration—CO_2 and H_2O—are the molecular inputs of photosynthesis, and vice versa. While these chemicals cycle through an ecosystem, energy flows through, entering as sunlight and exiting as heat.

Cellular Respiration: Aerobic Harvest of Food Energy

An Overview of Cellular Respiration

The overall equation of cellular respiration simplifies a great many chemical steps into one formula:

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

The Three Stages of Cellular Respiration

Cellular respiration occurs in three stages. During glycolysis, a molecule of glucose is split into two molecules of pyruvic acid, producing two molecules of ATP and two high-energy electrons stored in NADH. During the citric acid cycle, what remains of glucose is completely broken down to CO_2, producing a bit of ATP and a lot of high-energy electrons stored in NADH and $FADH_2$. The electron transport chain uses the high-energy electrons to pump H^+ across the inner mitochondrial membrane, eventually handing them off to O_2, producing H_2O. Backflow of H^+ across the membrane powers the ATP synthases, which produce ATP from ADP.

The Results of Cellular Respiration

You can follow the flow of molecules through the process of cellular respiration in the following diagram. Notice that the first two stages primarily produce high-energy electrons carried by NADH, and that it is the final stage that uses these high-energy electrons to produce the bulk of the ATP molecules produced during cellular respiration.

Fermentation: Anaerobic Harvest of Food Energy

Fermentation in Human Muscle Cells

When muscle cells consume ATP faster than O_2 can be supplied for cellular respiration, the conditions become anaerobic, and muscle cells will begin to regenerate ATP by fermentation. The waste product under these anaerobic conditions is lactic acid. The ATP yield per glucose is much lower during fermentation (2 ATP) than during cellular respiration (about 32 ATP).

Fermentation in Microorganisms

Yeast and some other organisms can survive with or without O_2. Wastes from fermentation can be ethyl alcohol, lactic acid, or other compounds, depending on the species.

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For practice quizzes, BioFlix animations, MP3 tutorials, video tutors, and more study tools designed for this textbook, go to MasteringBiology®

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MasteringBiology provides a wide range of activities and study tools to match your learning style, including BioFlix animations, MP3 audio tutorials, interactive practice quizzes, and more. Your instructor can assign activities for extra practice to monitor your progress in the course.

NEW! Essential Biology videos introduce you to key concepts and vocabulary, and are narrated by authors Eric Simon and Kelly Hogan. Topics include the **Scientific Method**, **Molecules of Life**, **DNA Replication**, **Mechanisms of Evolution**, **Ecological Principles**, and more.

Learn Before, During, and After Class

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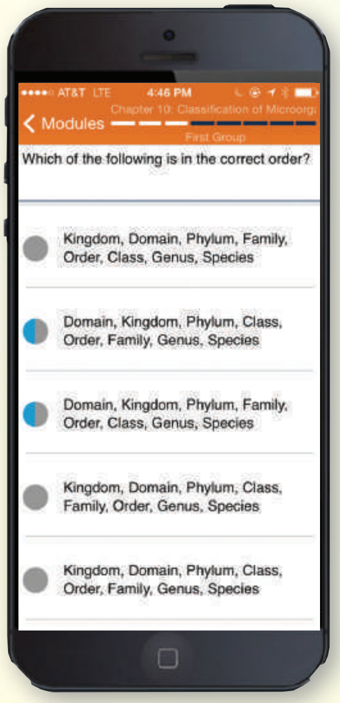


BEFORE CLASS

NEW! Dynamic Study Modules help you acquire, retain, and recall information faster and more efficiently than ever before. The convenient practice questions and detailed review explanations can be accessed on the go using a smartphone, tablet, or computer.

DURING CLASS

NEW! Learning Catalytics is a "bring your own device" assessment and classroom activity system that expands the possibilities for student engagement. Using Learning Catalytics, instructors can deliver a wide range of auto-gradable or open-ended questions that test content knowledge and build critical thinking skills using eighteen different answer types.

AFTER CLASS

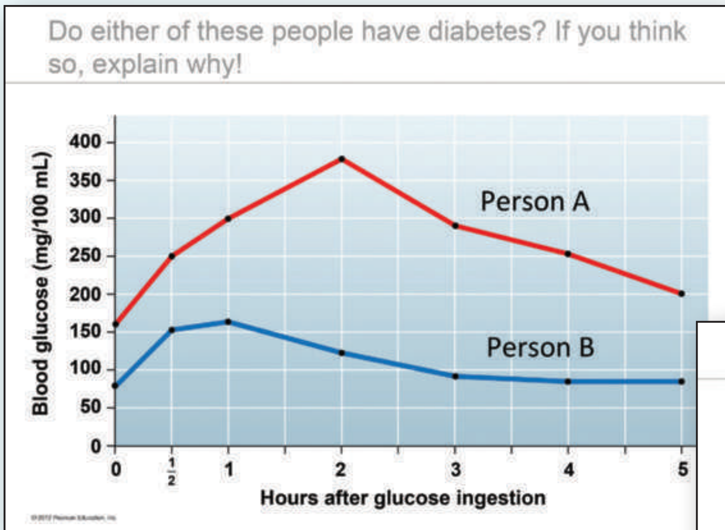
- **Over 100 Coaching Activities** are created by the textbook author team and help you focus on learning key concepts and building your biology vocabulary.
- **NEW! Everyday Biology videos** briefly explore interesting and relevant biology topics that relate to concepts in the course.

Instructors: Extensive Resources for You

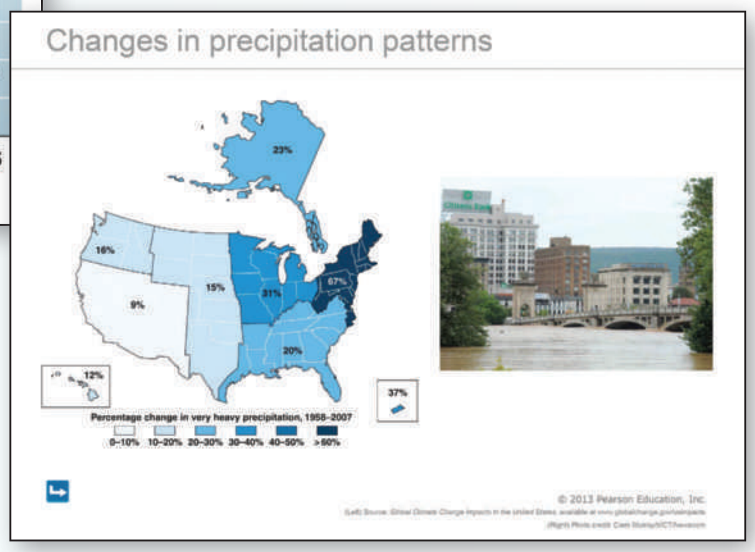
Extensive resources save valuable time both in course prep and during class.

- **The Instructor's Resource DVD for Campbell Essential Biology (with Physiology chapters)** organizes all instructor media resources by chapter into one convenient and easy-to-use package, including PowerPoint® slides, animations, lecture presentations, lecture questions to stimulate class discussions, quiz games, digital transparencies, and more (ISBN 0133950956 / 9780133950953).

- The **Test Bank** provides a variety of test questions, many art- or scenario-based, in both TestGen® and Microsoft® Word.



EXPANDED! Current Topic PowerPoint® presentations include new topics such as DNA Profiling, Stem Cells and Cloning, Diabetes, Biodiversity, and more. Each Powerpoint Presentation includes instructor teaching tips and active learning strategies to help you easily create a high-interest, active lecture.



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Selected materials from the Instructor Resources DVD can be accessed and downloaded from the Instructor Resources area of MasteringBiology.

The **Instructor Exchange** provides successful, class-tested active learning techniques and analogies from biology instructors around the nation, offering a springboard for quick ideas to create more compelling lectures. Co-author Kelly Hogan moderates contributions to the exchange.

Preface

This is a wonderful time to teach and learn biology. Opportunities to marvel at the natural world and the life within it abound. It's difficult to view a news website without finding stories that touch on biology and its intersection with society. In addition, the world of pop culture is rich with books, movies, TV shows, comic strips, and video games that feature biological wonders and challenge us to think about important biological concepts and their implications. Although some people *say* that they don't like biology (or, more often, science in general), nearly everyone will admit to an inborn biophilia. After all, most of us keep pets, tend a garden, enjoy zoos and aquariums, or appreciate time spent outdoors. Furthermore, nearly everyone realizes that the subject of biology has a significant impact on his or her own life through its connections to medicine, biotechnology, agriculture, environmental issues, forensics, and myriad other areas. But despite the inborn affinity that nearly everyone has for biology, it can be a struggle for nonscientists to delve into the subject. Our primary goal in writing *Campbell Essential Biology with Physiology* is to help teachers motivate and educate the next generation of citizens by tapping into the inherent curiosity about life that we all share.

Goals of the Book

Although our world is rich with "teachable moments" and learning opportunities, the explosion of knowledge we have already witnessed in the 21st century threatens to bury a curious person under an avalanche of information. "So much biology, so little time" is the universal lament of biology educators. Neil Campbell conceived of *Campbell Essential Biology with Physiology* as a tool to help teachers and students focus on the most important areas of biology. To that end, the book is organized into six core areas: cells, genes, evolution, ecology, animals, and plants. Dr. Campbell's vision, which we carry on and extend in this edition, has enabled us to keep *Campbell Essential Biology with Physiology* manageable in size and thoughtful in the development of the concepts that are most fundamental to understanding life. We've aligned this new edition with today's "less is more" approach in biology education for nonscience majors—where the emphasis is on fewer topics and more focused explanations—and we never allow the content we do include to be diluted. Toward that end, in this new edition we removed some of the most technical details and terminology, which we hope will help nonscience major students to focus on the key topics in biology.

We formulated our approach after countless conversations with teachers and students in which we noticed some important trends in how biology is taught. In particular, many teachers identify three goals: (1) to engage students by relating the core content to their lives and the greater society; (2) to clarify the process of science by showing how it is applied in the real world and to give students practice in applying scientific and critical thinking skills themselves; and (3) to demonstrate how evolution serves as biology's unifying theme. To help achieve these goals, every chapter of this book includes three important features. First, a chapter-opening essay called Biology and Society highlights a connection between the chapter's core content and students' lives. Second, an essay called The Process of Science (found in the body of the chapter) describes how the scientific process has illuminated the topic at hand, using a classic or modern experiment as an example. Third, a chapter-closing Evolution Connection essay relates the chapter to biology's unifying theme of evolution. To maintain a cohesive narrative throughout each chapter, the content is tied together with a unifying chapter thread, a relevant high-interest topic that is woven throughout the three chapter essays and is touched on several additional times in the chapter. Thus, this unifying chapter thread ties together the three pedagogical goals of the course using a topic that is compelling and relevant to students.

New to This Edition

We hope that this latest edition of *Campbell Essential Biology with Physiology* goes even further in helping students relate the material to their lives, understand the process of science, and appreciate how evolution is the unifying theme of biology. To this end, we've added significant new features and content to this edition:

- **Clarifying the importance of biology to students' lives.** Every student taking an introductory biology course should be made keenly aware of the myriad ways that biology affects his or her own life. To help put such issues front and center, and to "prime the learning pump" before diving into the content, we have included a new feature at the start of each chapter called Why It Matters. Every chapter begins with a series of attention-grabbing facts in conjunction with compelling photographs that illustrate the importance of that chapter's topic to students' lives. These high-interest facts appear again in the chapter narrative, typeset in a design meant to capture students' attention and placed adjacent to the science discussion that explains the fact. Examples include: Why Macromolecules Matter ("A long-distance runner who carbo-loads the night before a race is banking glycogen to be used the next day"), Why Ecology Matters ("Producing the beef for a hamburger requires eight times as much land as producing the soybeans for a soyburger") and Why Hormones Matter ("Strike a pose before a job interview and you just might decrease the hormone that triggers stress").
- **Major themes in biology incorporated throughout the book.** In 2009, the American Association for the

Advancement of Science published a document that served as a call to action in undergraduate biology education. The principles of this document, which is titled "Vision and Change," are becoming widely accepted throughout the biology education community. "Vision and Change" presents five core concepts that serve as the foundation of undergraduate biology. In this edition of *Campbell Essential Biology with Physiology*, we repeatedly and explicitly link book content to each of the five themes. For example, the first theme, the relationship of structure to function, is illustrated in Chapter 2 in the discussion of how the unique chemistry of water accounts for its biological properties. The second theme, information flow, is explored in Chapter 10 in the discussion on how genes control traits. The third theme, interconnections within systems, is illustrated in Chapter 18 in the discussion on the global water cycle. The fourth theme, evolution, is called out in Chapter 17 in the discussion on the phylogeny of animals. The fifth theme, energy transformations, is explored in Chapter 6 in the discussion on the flow of energy through ecosystems. Readers will find at least one major theme called out per chapter, which will help students see the connections between these major themes and the course content, and instructors will have myriad easy-to-reference examples to help underscore these five themes.

- **New unifying chapter threads.** As discussed earlier, every chapter in *Campbell Essential Biology with Physiology* has a unique unifying chapter thread—a high-interest topic that helps to demonstrate the relevance of the chapter content. The chapter thread is incorporated into the three main essays of each chapter (Biology and Society, The Process of Science, and Evolution Connection) and appears throughout the chapter text. This fifth edition features many new chapter threads and essays, each of which highlights a current topic that applies biology to students' lives and to the greater society. For example, Chapter 2 presents a new thread on radioactivity, including discussions of its use in health care and as a tool to test evolutionary hypotheses. Chapter 15 features a new thread on human microbiota, including a recent investigation into the possible role of microbiota in obesity and an exploration of how the change from a hunter-gatherer lifestyle to a diet heavy in processed starch and sugar selected for oral bacteria that cause tooth decay. Chapter 24 offers a new thread on vaccines, introducing the importance of vaccinating an entire community and the reason why a new influenza vaccine is required each year.
- **Developing data literacy.** Many nonscience-major students express anxiety when faced with numerical data, yet the ability to interpret data can help with many important decisions we all face. To help foster critical thinking skills, we have incorporated a new feature called Interpreting Data into the end-of-chapter assessments. These questions, one per chapter, offer students the opportunity to practice their science literacy skills. For example, in Chapter 10, students are asked to examine historical data of flu mortality; in Chapter 15, students are tasked with calculating how quickly bacteria can multiply on unrefrigerated food; and in Chapter 24, students are presented with a graph illustrating the prevalence of food allergies in children and asked to determine what conclusions can be drawn from the data. We hope that practice examining these simple yet relevant data sets will help students be more comfortable when they must confront numerical data in their own lives.
- **Updated content and figures.** As we do in every edition, we have made many significant updates to the content presented in the book. Examples of new or updated material include new discussions on epigenetics, metagenomics, and RNA interference; an examination of new genomic information on Neanderthals; updated climate change statistics; a discussion of advances in fetal genetic testing; and an updated discussion of new threats to biodiversity. We have also included nearly a dozen new examples of DNA profiling and a cutting-edge exploration of genetically modified foods. We also strive with each new edition to update our photos and illustrations. New figures include examples that show how a prion protein can cause brain damage (Figure 3.20), how a breast cancer drug inhibits cancer cells (Figure 25.15), how angioplasty can repair diseased arteries (Figure 23.15), and how real data from DNA profiling can exonerate wrongly accused individuals (Figure 12.16).
- **New analogies.** As part of our continuing effort to help students visualize and relate to biology concepts, we have included numerous new analogies in this edition. For example, in Chapter 4, we compare the significant differences between prokaryotic and eukaryotic cells to the differences between a bicycle and an SUV. In Chapter 8, we compare the process of DNA winding into chromosomes with the act of winding yarn into a skein. In Chapter 27, we analogize humans seeing an array of colors with only three types of photoreceptor cones to how a printer can print an array of colors from only three colors included in a toner cartridge. We also have included new analogies in visual format, such as how dominoes relate to an action potential moving along an axon (Figure 27.4). Additional examples, both narrative and visual, bring biological scale into focus, such as a 4,600-mile road trip that is used to help students imagine the scale of biological evolution on Earth (Figure 15.1).

- **MasteringBiology updates.** New whiteboard-style animated videos provide students with an introduction to key biological concepts so students can arrive to class better prepared to explore applications or dive into any topic more deeply. New Everyday Biology videos, produced by the BBC, promote connections between concepts and biology in everyday life, and Evaluating Science in the Media activities teach students how to be wise consumers of scientific information and coach them through critically evaluating the validity of scientific information on the Internet. New Scientific Thinking activities encourage students to develop scientific reasoning skills as they explore a current area of research and allows instructors to easily assess student mastery of these skills.
- **Teaching the Issues.** Because many instructors, including the authors, prefer to use current topics to demonstrate the relevance of biology to students' lives, we've expanded our series of Current Topic Instructor PowerPoints© with this edition. New topics include DNA Profiling, Stem Cells and Cloning, Diabetes, Biodiversity, and more. Each PowerPoint© Presentation includes instructor teaching tips and active learning strategies to easily create a high-interest, active lecture.

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

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Most instructors view the textbook as just one piece of the learning puzzle, with the book's supplements and media completing the picture. We are lucky to have a *Campbell Essential Biology with Physiology* supplements team that is fully committed to the core goals of accuracy and readability. Project Manager Libby Reiser expertly coordinated the supplements, a difficult task given their number and variety. We thank media project manager Eddie Lee for his work on the excellent Instructor Resources DVD that accompanies the text. We owe particular gratitude to the supplements authors, especially the indefatigable and eagle-eyed Ed Zalisko of Blackburn College, who wrote the Instructor Guide and the PowerPoint© Lectures; the highly skilled and multitalented Hilary Engebretson, of Whatcom Community College, who revised the Quiz Shows and Clicker questions; and Jean DeSaix (University of North Carolina at Chapel Hill), Justin Shaffer (University of California, Irvine), Kristen Miller (University of Georgia), and Suann Yang (Presbyterian College), our collaborative team of test bank authors for ensuring excellence in our assessment program. The authors also thank Justin Shaffer (University of California, Irvine), Suzanne Wakim (Butte Community College), and Eden Effert (Eastern Illinois University) for their fine work on the issues-based presentation Campbell Current Topics PowerPoint© Presentations. In addition, the authors thank Reading Quiz authors Amaya Garcia Costas, Montana State University, and Cindy Klevickis, James Madison University; Reading Quiz accuracy reviewer Veronica Menendez; Practice Test author Chris Romero, Front Range Community College; and Practice Test accuracy reviewer Justin Walgaurnery, University of Hawaii.

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Furman University
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College of the Siskiyous
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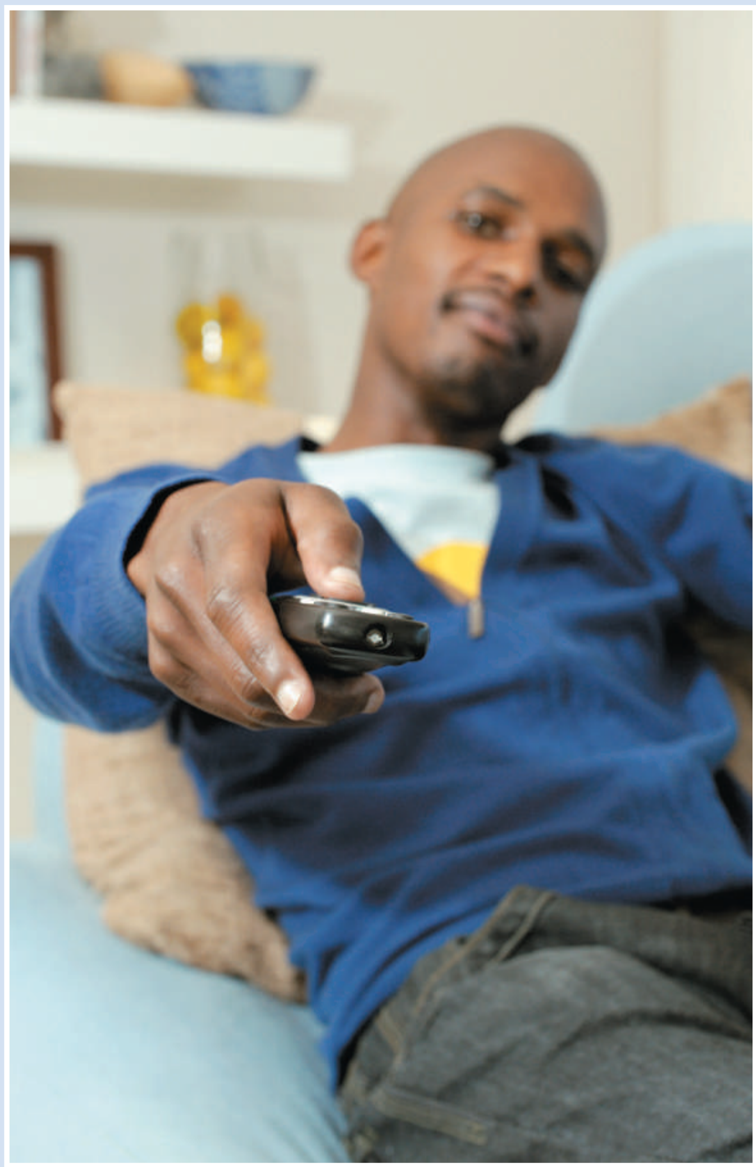
1 Introduction: Biology Today

Why Biology Matters

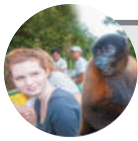
If you've ever wondered what an unusual or especially beautiful animal is called, you're curious about taxonomy.

Although you may not realize it, you use the scientific method every day.



One of the primary missions of the Mars rover is to search for signs of life.

CHAPTER CONTENTS



Biology All Around Us BIOLOGY AND SOCIETY

An Innate Passion for Life

Do you like biology? Wait, let's put this question another way: Do you have a pet? Are you concerned with fitness or healthy eating? Have you ever visited a zoo or an aquarium for fun, taken a nature hike, or gathered shells on the beach? Do you like watching TV shows about sharks or dinosaurs? If you answered yes to any of these questions—well, then, it turns out that you do like biology!

Most of us have an inherent interest in life, an inborn curiosity about the natural world that leads us to study animals and plants and their habitats. We wrote *Essential Biology* to help you—a student with little or no college-level science experience—harness your innate enthusiasm for life. We'll use this passion to help you develop an understanding of the discipline of biology, one that you can apply to your own life and to the society in which you live. We believe that such a biological perspective is essential for any educated person, which is why we named our book *Essential Biology*. So, whatever your reasons for taking this course—even if only to fulfill your school's science requirement—you'll soon discover that exploring life is relevant and important to you, no matter your background or goals.

An inborn curiosity about nature. This student is interacting with a woolly monkey (*Lagothrix lagotricha*) during a school trip to the Amazon River in Peru.

To reinforce the fact that biology affects your everyday life in many ways, every chapter of *Essential Biology* opens with an essay—called Biology and Society—that will help you see the relevance of that chapter's material. Topics as varied as medical uses of radiation (Chapter 2), the importance of a flu shot (Chapter 10), and the community of microscopic organisms that live in and on your body (Chapter 15) help to illustrate biology's scope and show how the subject of biology is woven into the fabric of society. Throughout *Essential Biology*, we'll continuously emphasize these connections, pointing out many examples of how each topic can be applied to your life and the lives of those you care about.

CHAPTER 1
INTRODUCTION:
BIOLOGY TODAY

The Scientific Study of Life

Now that we've established our goal—to examine how biology affects your life—a good place to start is with a basic definition: **Biology** is the scientific study of life. But have you ever looked up a word in the dictionary only to find that you need to look up some of the words within that definition to make sense of the original word? The definition of biology, although seemingly simple, raises more questions: What is a scientific study? And what does it mean to be alive? To help you get started with your investigation of biology, this first chapter of *Essential Biology* expands on important concepts within the definition of biology. First, we'll place the study of life in the broader context of science. Next, we'll investigate the nature of life by surveying the properties and scope of life. Finally, we'll introduce a series of broad themes you will encounter throughout your investigation of life, themes that serve as organizing principles for the information you will learn. Most important, throughout this chapter (and, indeed, throughout all of *Essential Biology*), we'll continue to provide examples of how biology affects *your* life, highlighting the relevance of this subject to society and everyone in it. ☑

☑ CHECKPOINT

Define biology.

Answer: Biology is the scientific study of life.

The Process of Science

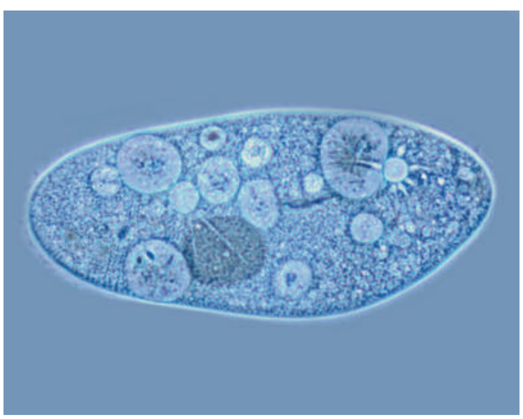
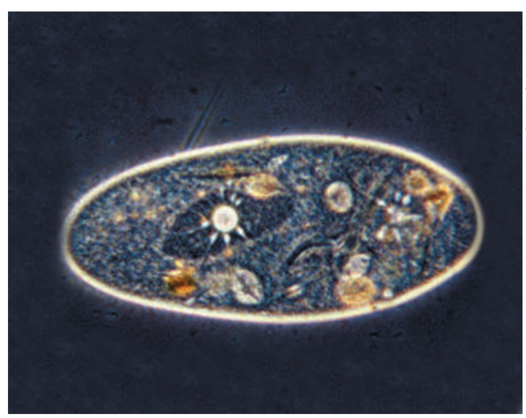
Recall the definition at the heart of this chapter: Biology is the scientific study of life. This leads to an obvious first question: What is a scientific study? Notice that biology is not defined as the "study of life" because there are many nonscientific ways that life can be studied. For example, extended meditation is a valid way of studying the nature of life—this approach might be well suited to a philosophy class, for example—but it does not qualify as biology because it is not a *scientific* means of studying life. How, then, do we tell the difference between science and other ways of trying to make sense of nature?

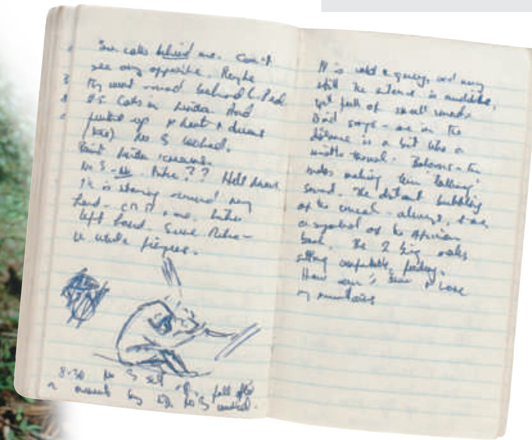
Science is an approach to understanding the natural world that is based on inquiry—a search for information, explanations, and answers to specific questions. This basic human drive to understand our natural world is manifest in two main scientific approaches: discovery science, which is mostly about *describing* nature, and hypothesis-driven science, which is mostly about *explaining* nature. Most scientists practice a combination of these two forms of inquiry.

Discovery Science

Scientists seek natural causes for natural phenomena. This limits the scope of science to the study of structures and processes that we can verifiably observe and measure, either directly or indirectly with the help of tools and technology, such as microscopes **(Figure 1.1)**. Recorded observations are called **data**, and data are the items of information on which scientific inquiry is based. This dependence on verifiable data demystifies nature and distinguishes science from supernatural beliefs. Science can neither prove nor disprove that ghosts, deities, or spirits cause storms, eclipses, or illnesses,

▼ Figure 1.1 The protist *Paramecium* viewed with three different types of microscopes. Photographs taken with microscopes are called micrographs. Throughout this textbook, micrographs will have size notations along the side. For example, "LM 300×" indicates that the micrograph was taken with a light microscope and the objects are magnified to 300 times their original size.

TYPES OF MICROGRAPHS		
Light Micrograph (LM) (for viewing living cells)	**Scanning Electron Micrograph (SEM)** (for viewing surface features)	**Transmission Electron Micrograph (TEM)** (for viewing internal structures)
 LM 300×	 Colorized SEM 300×	 Colorized TEM 300×
Light micrograph of a protist, *Paramecium*	Scanning electron micrograph of *Paramecium*	Transmission electron micrograph of *Paramecium*



◄ **Figure 1.2 Careful observation and measurement: the raw data for discovery science.** Dr. Jane Goodall spent decades recording her observations of chimpanzee behavior during field research in the jungles of Tanzania.

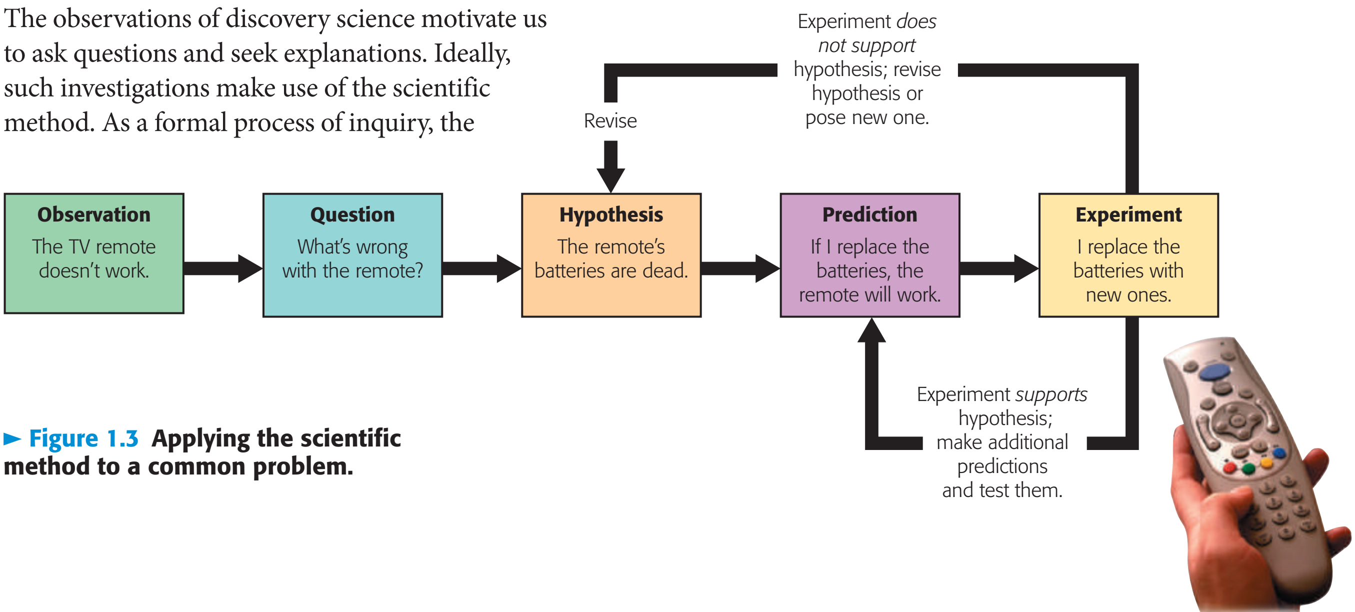
because such explanations are not measurable and are therefore outside the bounds of science.

Verifiable observations and measurements are the data of **discovery science**. In our quest to describe nature accurately, we discover its structure. Charles Darwin's careful description of the diverse plants and animals he observed in South America is an example of discovery science (as you'll learn in Chapter 13). More recently, Jane Goodall spent decades observing and recording the behavior of chimpanzees living in the jungles of Tanzania **(Figure 1.2)**. And even more recently, molecular biologists have sequenced and analyzed huge amounts of DNA (an effort discussed in Chapter 12), gathering data that shed light on the genetic basis of life.

Hypothesis-Driven Science

The observations of discovery science motivate us to ask questions and seek explanations. Ideally, such investigations make use of the scientific method. As a formal process of inquiry, the **scientific method** consists of a series of steps **(Figure 1.3)**. These steps provide a loose guideline for scientific investigations. There is no single formula for successfully discovering something new; instead, the scientific method suggests a broad outline for how discovery might proceed. The scientific method is a bit like an incomplete recipe: A basic outline of steps to be followed is presented, but the details of the dish are left to the cook. Similarly, working scientists do not typically follow the steps of the scientific method rigidly; different scientists proceed through the scientific method in different ways.

Most modern scientific investigations can be described as hypothesis-driven science. A **hypothesis** is a tentative answer to a question—a proposed explanation for a set of observations. A good hypothesis immediately leads to predictions that can be tested by experiments. Although



► **Figure 1.3 Applying the scientific method to a common problem.**

we don't think of it in those terms, we all use hypotheses in solving everyday problems. Imagine that you've completed your homework for the day and are going to reward yourself with some time in front of the TV. You press the power button on your TV remote, but the TV fails to turn on. That the TV does not turn on is an observation. The question that arises is obvious: Why didn't the remote turn on the TV? You could imagine a dozen possible explanations, but you can't possibly investigate them all simultaneously. Instead, you would focus on just one explanation (perhaps the most likely one based on past experience) and test it. That initial explanation is your hypothesis. For example, in this case, a reasonable hypothesis is that the batteries in the remote are dead.

Although you may not realize it, you use the scientific method every day.

Once a hypothesis is formed, an investigator can make predictions about what results are expected if that hypothesis is correct. We then test the hypothesis by performing an experiment to see whether or not the results are as predicted. This logical testing takes the form of "If . . . then" logic:

Observation: The TV remote doesn't work.

Question: What's wrong with the remote?

Hypothesis: The TV remote doesn't work because its batteries are dead.

Prediction: If I replace the batteries, then the remote will work.

Experiment: I replace the batteries with new ones.

Let's say that after you replace the batteries the remote still doesn't work. You would then formulate a second hypothesis and test it. Perhaps, for example, the TV is unplugged. Or you put in the new batteries incorrectly. You could continue to conduct additional experiments and formulate additional hypotheses until you reach a satisfactory conclusion to your initial question. As you do this, you are following the scientific method, and you are acting as a scientist.

Let's back up and examine what you would probably *not* do in this scenario: You most likely would not blame the malfunctioning remote on supernatural spirits, nor are you likely to meditate on the cause of the observed phenomenon. Your natural instinct is to formulate a hypothesis and then test it; the scientific method is probably your "go-to" method for solving problems. In fact, the scientific method is so deeply embedded in our society and in the way we think that most of us use it automatically (although we don't use the terminology presented here). The scientific method is therefore just a formalization of how you already think and act.

In every chapter of *Essential Biology*, we include examples of how the scientific method was used to learn about the material under discussion. In each of these sections (titled The Process of Science), we will, as a reminder, highlight the steps in the scientific method. The questions we will address include: Does lactose intolerance have a genetic basis (Chapter 3)? Why do dog coats come in so many varieties (Chapter 9)? Do the organisms living in your intestine affect your weight (Chapter 15)? As you become increasingly scientifically literate, you will arm yourself with the tools you need to evaluate claims that you hear. We are all bombarded by information every day—via commercials, websites, magazine articles, and so on—and it can be hard to filter out the bogus from the truly worthwhile. Having a firm grasp of science as a process of inquiry can therefore help you in many ways outside the classroom.

It is important to note that scientific investigations are not the only way of knowing nature. A comparative religion course would be a good way to learn about the diverse stories that focus on a supernatural creation of Earth and its life. Science and religion are two very different ways of trying to make sense of nature. Art is yet another way to make sense of the world around us. A broad education should include exposure to all these different ways of viewing the world. Each of us synthesizes our worldview by integrating our life experiences and multidisciplinary education. As a science textbook and part of that multidisciplinary education, *Essential Biology* showcases life in a purely scientific context. ☑

☑ CHECKPOINT

1. If you observe the squirrels on your campus and collect data on their dietary habits, what kind of science are you performing? If you come up with a tentative explanation for their dietary behavior and then test your idea, what kind of science are you performing?
2. Place these steps of the scientific method in their proper order: experiment, hypothesis, observation, prediction, results, question, revise/repeat.

Answers: **1.** *discovery science; hypothesis-driven science* **2.** *observation, question, hypothesis, prediction, experiment, results, revise/repeat*

▼ Figure 1.4 Some properties of life. An object is considered alive if and only if it displays all of these properties simultaneously.

(a) Order **(b) Regulation** **(c) Growth and development** **(d) Energy processing**

Theories in Science

Many people associate facts with science, but accumulating facts is not the primary goal of science. A telephone book is an impressive catalog of factual information, but it has little to do with science. It is true that facts, in the form of verifiable observations and repeatable experimental results, are the prerequisites of science. What really advances science, however, are new theories that tie together a number of observations that previously seemed unrelated. The cornerstones of science are the explanations that apply to the greatest variety of phenomena. People like Isaac Newton, Charles Darwin, and Albert Einstein stand out in the history of science not because they discovered a great many facts but because their theories had such broad explanatory power.

What is a scientific theory, and how is it different from a hypothesis? A scientific **theory** is much broader in scope than a hypothesis. A theory is a comprehensive explanation supported by abundant evidence, and it is general enough to spin off many new testable hypotheses. This is a hypothesis: "White fur is an adaptation that helps polar bears survive in an Arctic habitat." And this is another, seemingly unrelated hypothesis: "The unusual bone structure in a hummingbird's wings is an evolutionary adaptation that provides an advantage in gathering nectar from flowers." In contrast, the following theory ties together those seemingly unrelated hypotheses: "Adaptations to the local environment evolve by natural selection." This particular theory is one that we will describe later in this chapter.

Theories only become widely accepted by scientists if they are supported by an accumulation of extensive and varied evidence and if they have not been contradicted by any scientific data. The use of the term *theory* by scientists contrasts with our everyday usage, which implies untested speculation ("It's just a theory!"). In fact, we use the word "theory" in our everyday speech the way that a scientist uses the word "hypothesis." As you will soon learn, natural selection qualifies as a scientific theory because of its broad application and because it has been validated by a large number of observations and experiments. It is therefore not proper to say that natural selection is "just" a theory to imply that it is untested or lacking in evidence. In fact, any scientific theory is backed up by a wealth of supporting evidence, or else it wouldn't be referred to as a theory. ☑

☑ CHECKPOINT

You arrange to meet a friend for dinner at 6 P.M., but when the appointed hour comes, she is not there. You wonder why. Another friend says, "My theory is that she forgot." If your friend were speaking like a scientist, what would she have said?

Answer: *"My hypothesis is that she forgot."*

The Nature of Life

Recall once again our basic definition: Biology is the scientific study of life. Now that we have an understanding of what constitutes a scientific study, we can turn to the next question raised by this definition: What is life? Or, to put it another way, what distinguishes living things from nonliving things? The phenomenon of **life** seems to defy a simple, one-sentence definition. Yet even a small child instinctively knows that a dog or a bug or a plant is alive but a rock is not.

If I placed an object in front of you and asked you whether it was alive, what would you do? Would you poke it to see if it reacts? Would you watch it closely to see if it moves or breathes? Would you dissect it to look at its parts? Each of these ideas is closely related to how biologists actually define life: We recognize life mainly by what living things do. To start our investigation of biology, let's look at some properties that are shared by all living things.

The Properties of Life

Figure 1.4 highlights seven of the properties and processes associated with life. An object is generally considered to be alive if it displays all of these properties simultaneously. (a) *Order*. All living things exhibit

(e) Response to the environment

(f) Reproduction

(g) Evolution

complex but ordered organization, as seen in the structure of a pinecone. (b) *Regulation*. The environment outside an organism may change drastically, but the organism can adjust its internal environment, keeping it within appropriate limits. When it senses its body temperature dropping, a lizard can bask on a rock to absorb heat. (c) *Growth and development*. Information carried by DNA controls the pattern of growth and development in all organisms, including the crocodile. (d) *Energy processing*. Organisms take in energy and use it to perform all of life's activities; they emit energy as heat. A cheetah obtains energy by eating its kill, uses this energy to power running and other work, and continuously emits body heat into the environment. (e) *Response to the environment*. All organisms respond to environmental stimuli. A carnivorous Venus flytrap closes its leaves rapidly in response to the environmental stimulus of an insect touching the plant's sensory hairs. (f) *Reproduction*. Organisms reproduce their own kind. Thus, monkeys reproduce only monkeys—never lizards or cheetahs. (g) *Evolution*. Reproduction underlies the capacity of populations to change (evolve) over time. For example, the giant leaf insect (*Phyllium giganteum*) has evolved in a way that provides camouflage in its environment. Evolutionary change is a central, unifying phenomenon of all life.

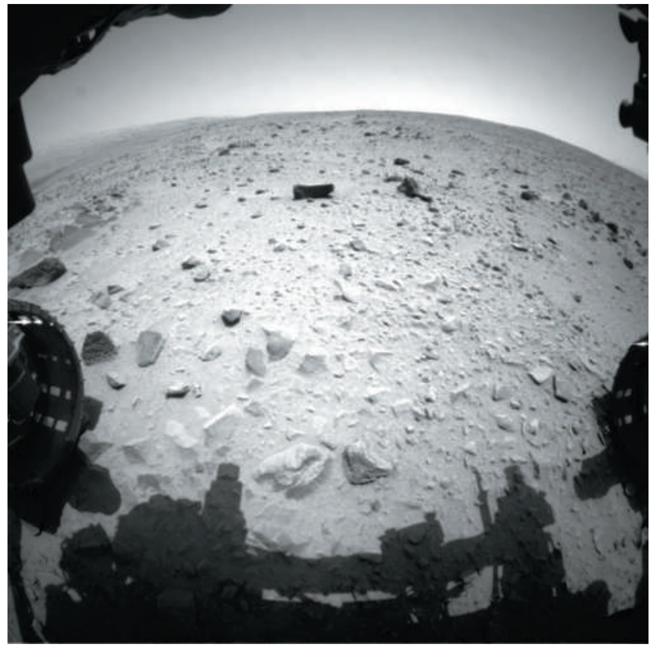
☑ CHECKPOINT

Which properties of life apply to a car? Which do not?

Answer: A car demonstrates order, regulation, energy utilization, and response to the environment. But a car does not grow, reproduce, or evolve.

Although we have no proof that life has ever existed anywhere other than Earth, biologists speculate that extraterrestrial life, if it exists, could be recognized by the same properties listed in Figure 1.4. The Mars rover *Curiosity* **(Figure 1.5)**, which has been exploring the surface of the red planet since 2012, contains several instruments designed to identify biosignatures, substances that provide evidence of past or present life. For example, *Curiosity* is using a suite of onboard instruments to detect chemicals that could provide evidence of energy processing by microscopic organisms. As of yet, no definitive signs of the properties of life have been detected, and the search continues. ☑

One of the primary missions of the Mars rover is to search for signs of life.



▲ **Figure 1.5 A view from the Mars rover *Curiosity* searching for signs of life.**

Life in Its Diverse Forms

The tarsier shown in **Figure 1.6** is just one of about 1.8 million identified species on Earth that displays all of the properties outlined in Figure 1.4. The diversity of known life—all the species that have been identified and named—includes at least 290,000 plants, 52,000 vertebrates (animals with backbones), and 1 million insects (more than half of all known forms of life). Biologists add thousands of newly identified species to the list each year. Estimates of the total number of species range from 10 million to more than 100 million.

Whatever the actual number turns out to

◄ **Figure 1.6 A small sample of biological diversity.** A primate called a tarsier sits in a tree in a rainforest within the Philippines. The scientific name for this species is *Tarsius syrichta.*

▲ **Figure 1.7 The three domains of life.**

be, the enormous diversity of life presents organizational challenges to biologists who study it.

Grouping Species: The Basic Concept

To make sense of nature, people tend to group diverse items according to similarities. We may speak of "squirrels" and "butterflies," even though we recognize that each group actually includes many different species. A **species** is generally defined as a group of organisms that live in the same place and time and have the potential to interbreed with one another in nature to produce healthy offspring (more on this in Chapter 14). We may even sort groups into broader categories, such as rodents (which include squirrels) and insects (which include butterflies). **Taxonomy**, the branch of biology that names and classifies species, is the arrangement of species into a hierarchy of broader and broader groups. Have you ever seen a fish, or found a mushroom, or watched a bird and wondered what kind it was? If so, you were asking a question of taxonomy. Before we dive into biodiversity in greater detail in later chapters, let's summarize the broadest units of classification of life.

If you've ever wondered what an unusual or especially beautiful animal is called, you're curious about taxonomy.

The Three Domains of Life

On the broadest level, biologists divide the diversity of life into three domains: Bacteria, Archaea, and Eukarya **(Figure 1.7)**. Every organism on Earth belongs to one of these three domains. The first two domains, Bacteria and Archaea, identify two very different groups of organisms that have prokaryotic cells—that is, relatively small and simple cells that lack a nucleus or other compartments bounded by internal membranes. All the eukaryotes (organisms with eukaryotic cells—that is, relatively large and complex cells that contain a nucleus and other membrane-enclosed compartments) are grouped into the domain Eukarya.

The domain Eukarya in turn includes three smaller divisions called kingdoms—Plantae, Fungi, and Animalia. Most members of the three kingdoms are multicellular. The kingdoms are distinguished partly by how the organisms obtain food. Plants produce their own sugars and other foods by photosynthesis. Fungi are mostly decomposers, obtaining food by digesting dead organisms and organic wastes. Animals—the kingdom to which we belong—obtain food by ingesting (eating) and digesting other organisms. Those eukaryotes that do not fit into any of the three kingdoms fall into a catch-all group called the protists. Most protists are single-celled; they include microscopic organisms such as amoebas. But protists also include certain multicellular forms, such as seaweeds. Scientists are in the process of organizing protists into multiple kingdoms, although they do not yet agree on exactly how to do this. ☑

☑ CHECKPOINT

1. Name the three domains of life. To which do you belong?
2. Name three kingdoms found within the domain Eukarya. Name a fourth group within this domain.

Answers: **1.** *Bacteria, Archaea, Eukarya; Eukarya* **2.** *Plantae, Fungi, Animalia; the protists*