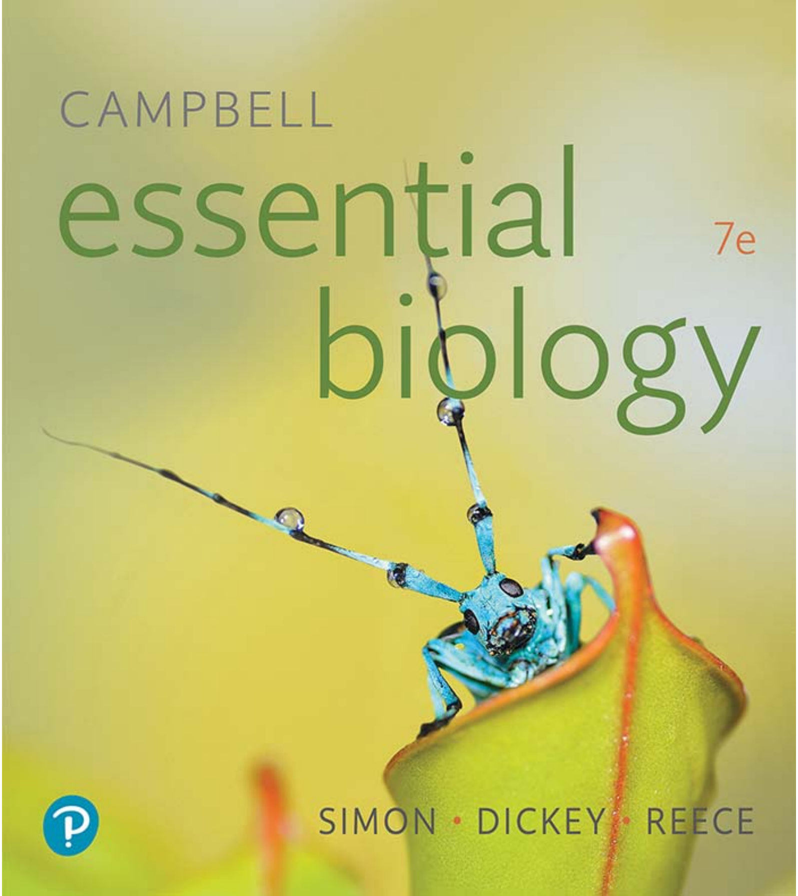
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SIMON • DICKEY • REECE

Brief Contents

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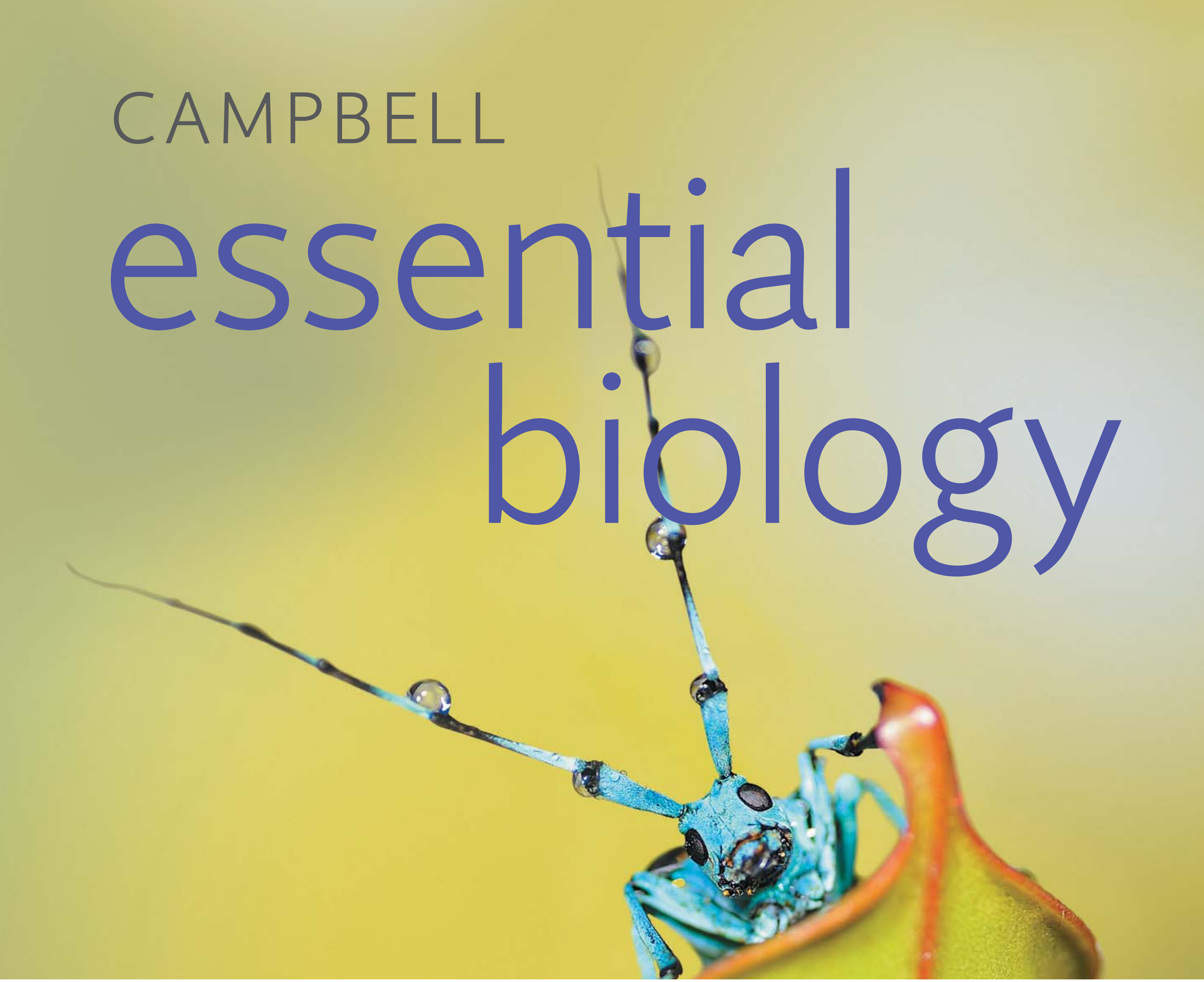

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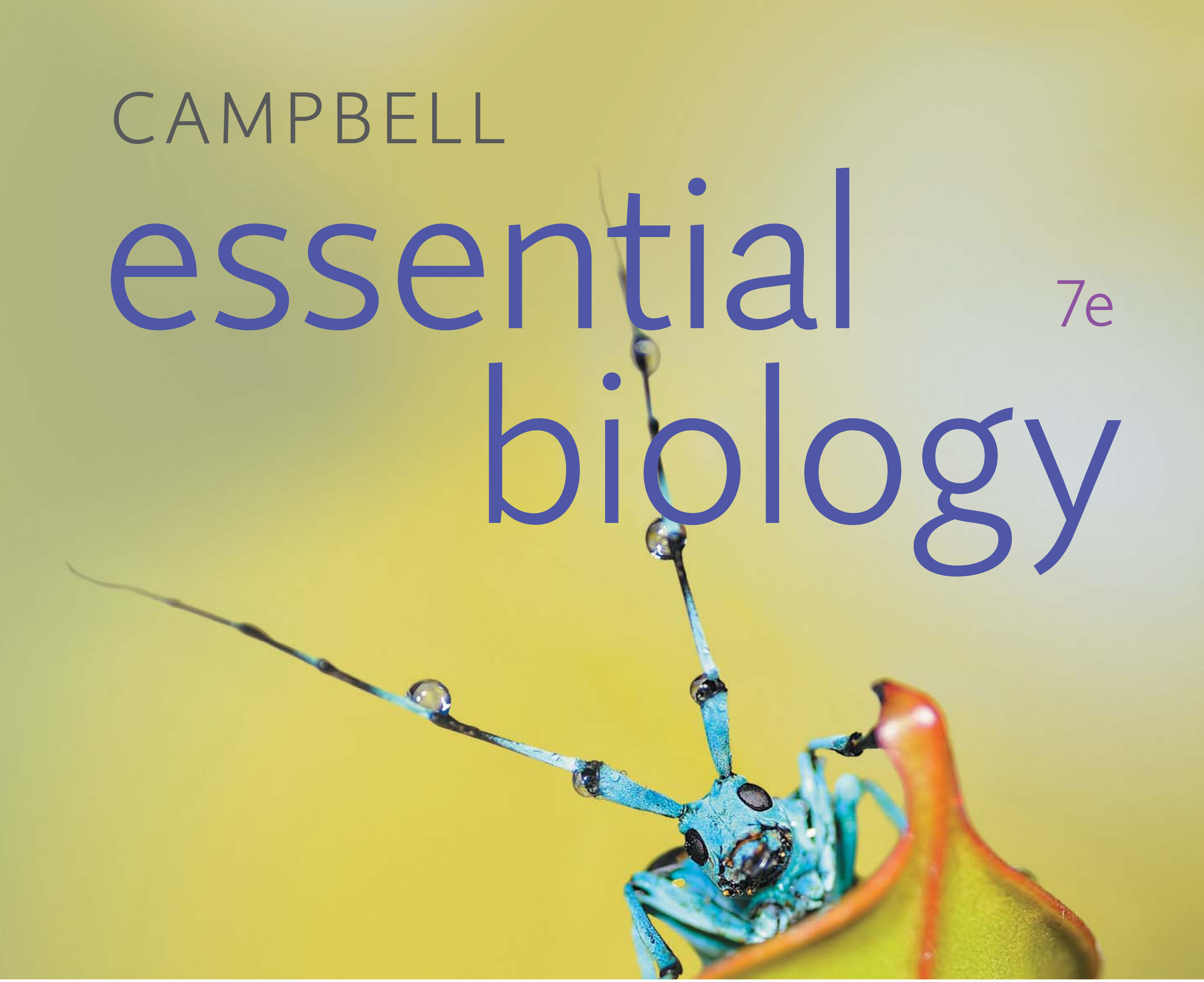

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To my lifelong friends BZ, SR, and SR, who have taught me the value of loyalty and trust during decades of unwavering friendship

JANE B. REECE

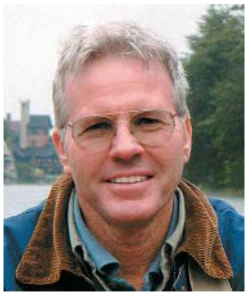
was Neil Campbell's longtime collaborator and a founding author of *Campbell Essential Biology* and *Campbell Essential Biology with Physiology*. Her education includes an A.B. in biology from Harvard University (where she was initially a philosophy major), an M.S. in microbiology from Rutgers University,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

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

JEAN L. DICKEY

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

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



NEIL A. CAMPBELL

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

Preface

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

Goals of the Book

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

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

New to This Edition

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

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

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

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

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

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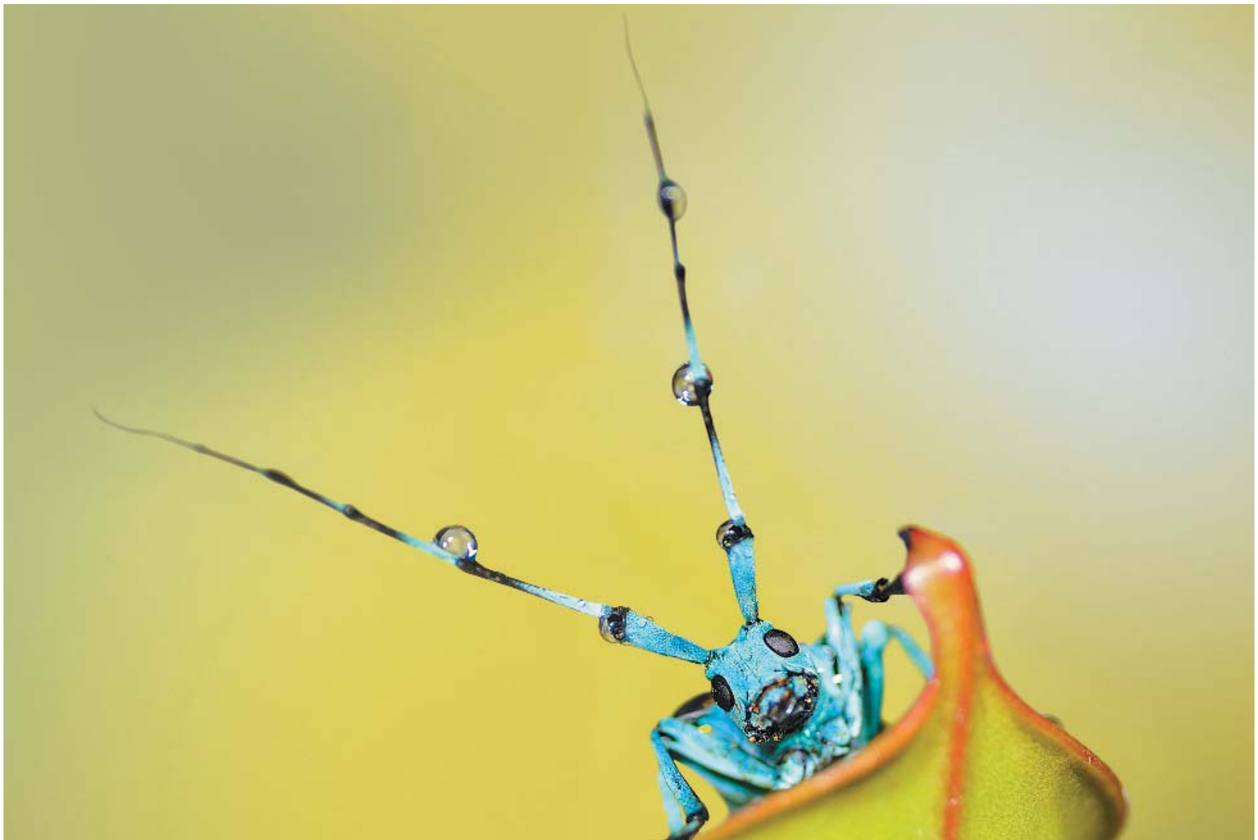


The following Visual Walkthrough highlights key features of *Campbell Essential Biology 7*e.

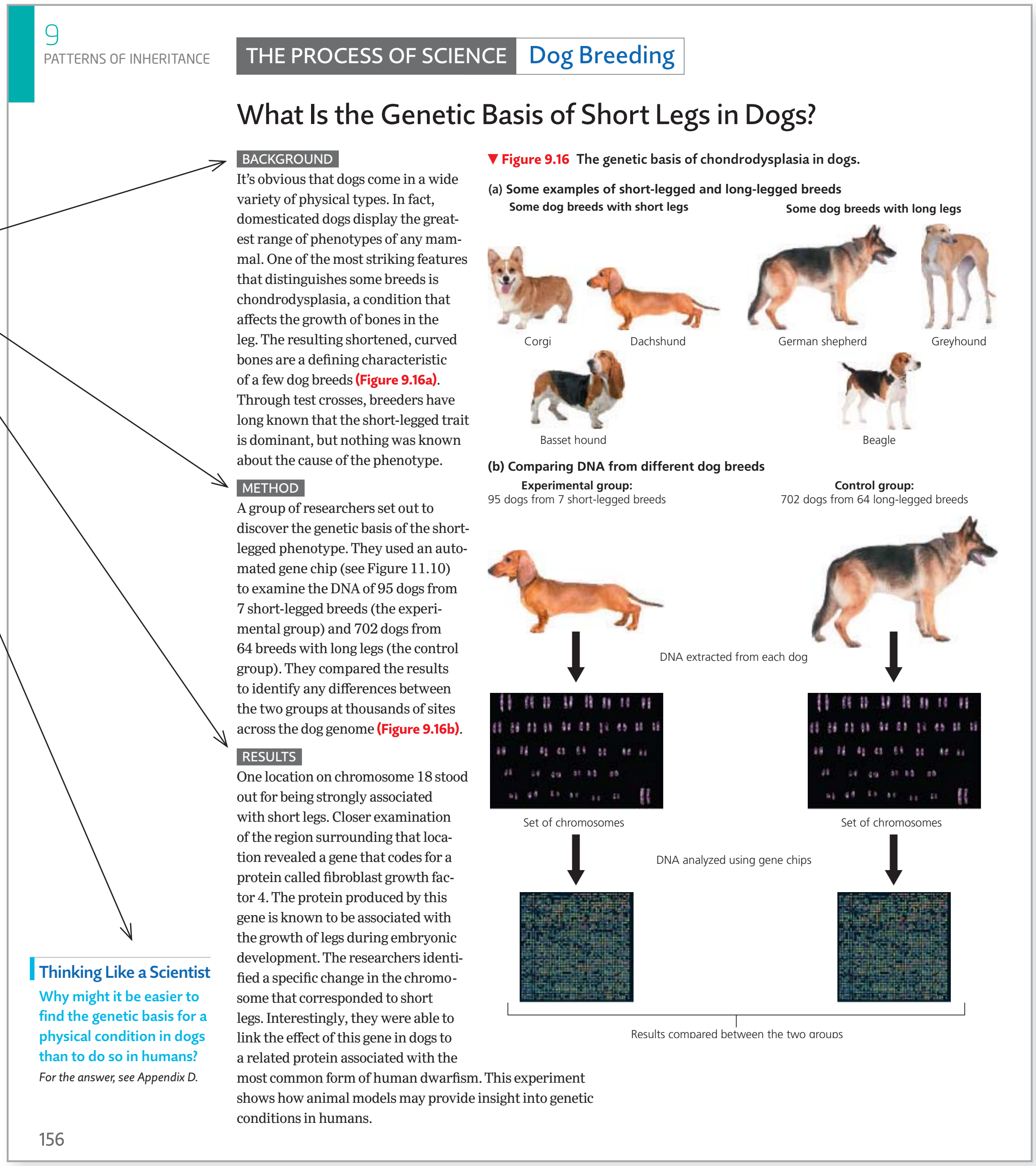
Develop and practice science literacy skills

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

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

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

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



THE PROCESS OF SCIENCE Dog Breeding

What Is the Genetic Basis of Short Legs in Dogs?

BACKGROUND

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

METHOD

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

RESULTS

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

Thinking Like a Scientist

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

For the answer, see Appendix D.

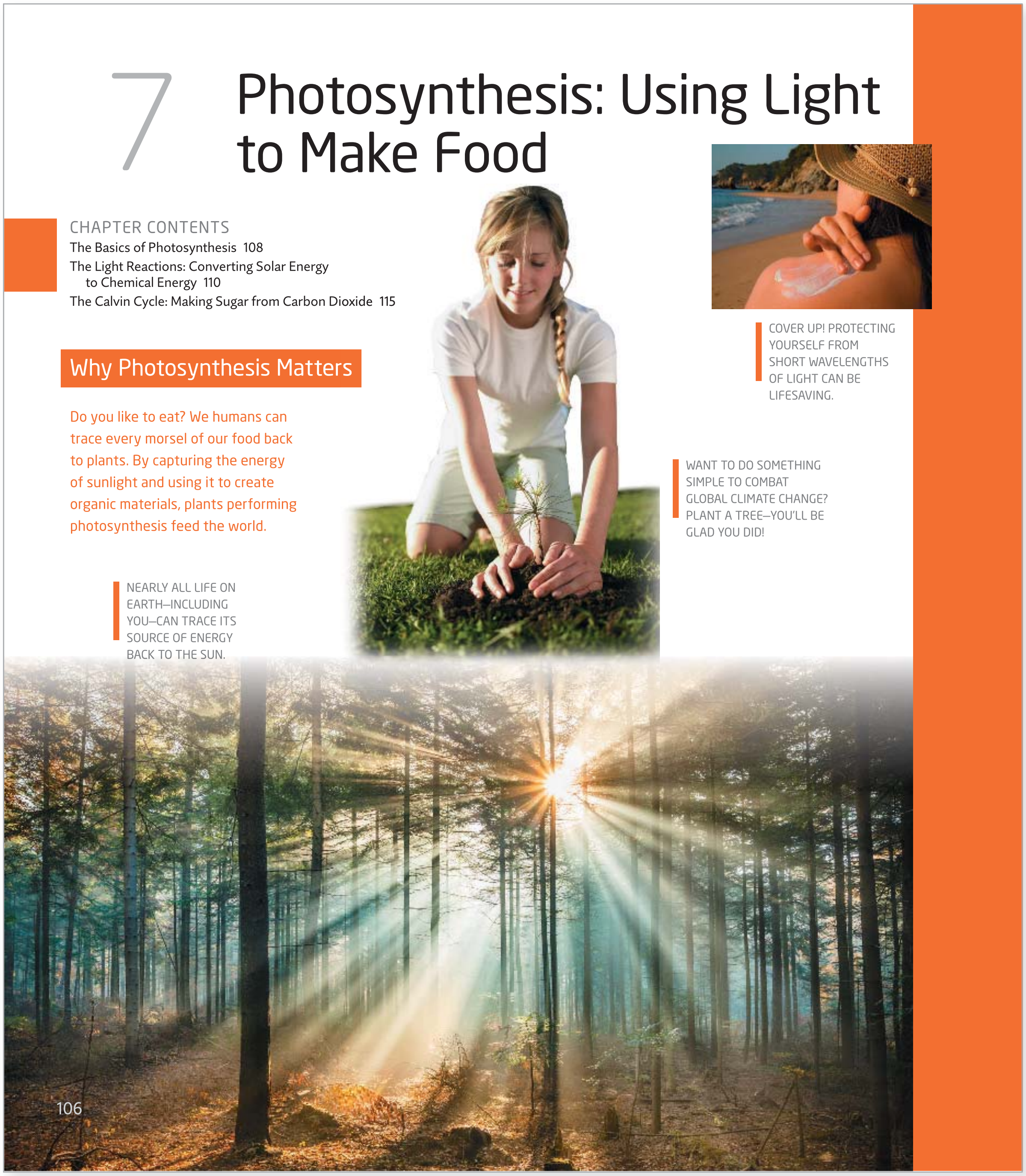
▼ **Figure 9.16 The genetic basis of chondrodysplasia in dogs.**

Examples of new Process of Science topics include:

- Chapter 4: How Was the First 21st-Century Antibiotic Discovered? p. 61
- Chapter 9: What Is the Genetic Basis of Short Legs in Dogs? p.156
- Chapter 11: Can Avatars Improve Cancer Treatment? p.210
- Chapter 16: What Killed the Pines? p.330
- Chapter 20: Does Biodiversity Protect Human Health? p.446

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

Explore biology with . . .



7 Photosynthesis: Using Light to Make Food

CHAPTER CONTENTS

Why Photosynthesis Matters

Do you like to eat? We humans can trace every morsel of our food back to plants. By capturing the energy of sunlight and using it to create organic materials, plants performing photosynthesis feed the world.

COVER UP! PROTECTING YOURSELF FROM SHORT WAVELENGTHS OF LIGHT CAN BE LIFESAVING.

WANT TO DO SOMETHING SIMPLE TO COMBAT GLOBAL CLIMATE CHANGE? PLANT A TREE—YOU'LL BE GLAD YOU DID!

NEARLY ALL LIFE ON EARTH—INCLUDING YOU—CAN TRACE ITS SOURCE OF ENERGY BACK TO THE SUN.

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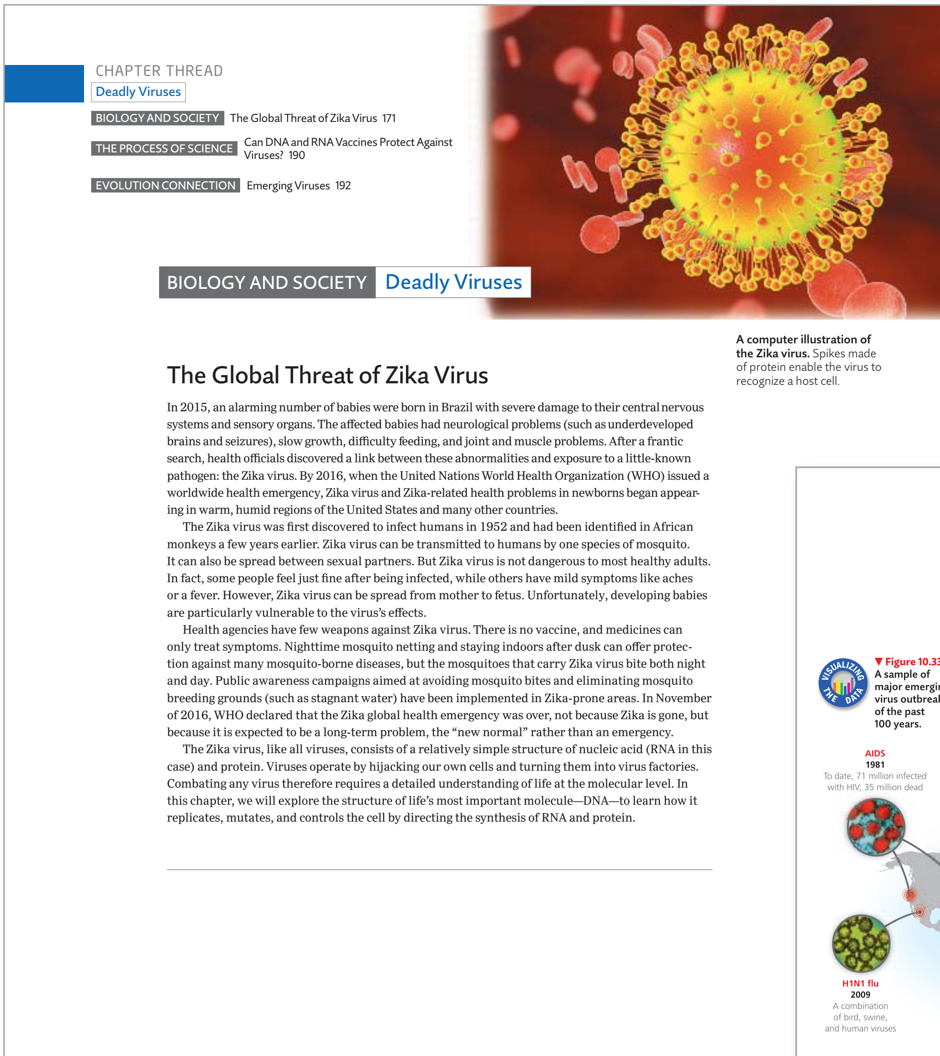
Why It Matters Photo Collages have been updated to give real-world examples to convey why abstract concepts like cellular respiration or photosynthesis matter.

. . . the most relevant, real-world examples

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



CHAPTER THREAD
Deadly Viruses

BIOLOGY AND SOCIETY Deadly Viruses

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

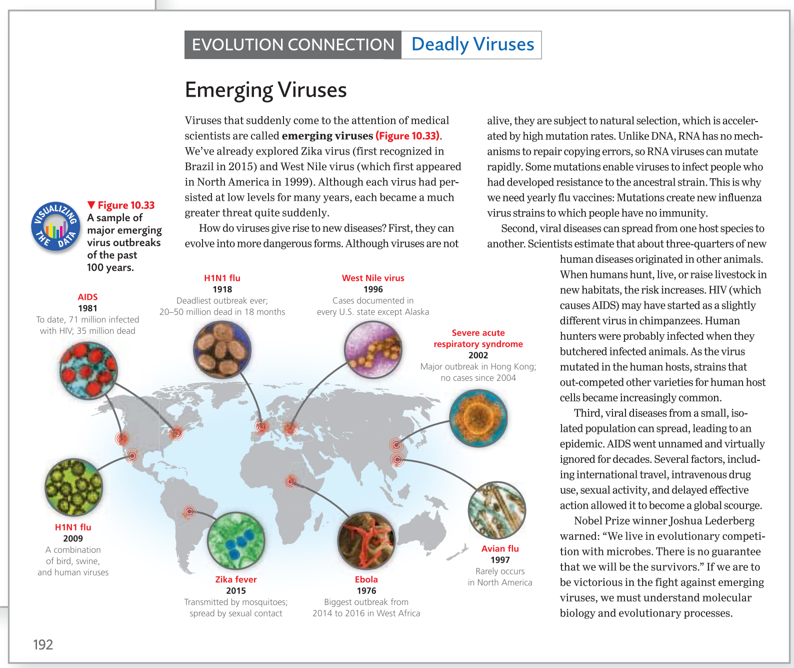
The Global Threat of Zika Virus

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

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

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

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



EVOLUTION CONNECTION Deadly Viruses

Emerging Viruses

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

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

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

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

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

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

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NEW!
New Chapter Threads include:

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

Biology and Society essays

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

- Chapter 7: A Solar Revolution p. 107
- Chapter 10: The Global Threat of Zika Virus p. 171
- Chapter 14: Humanity's Footprint p. 269
- Chapter 17: Evolving Adaptability p. 337

Evolution Connection essays

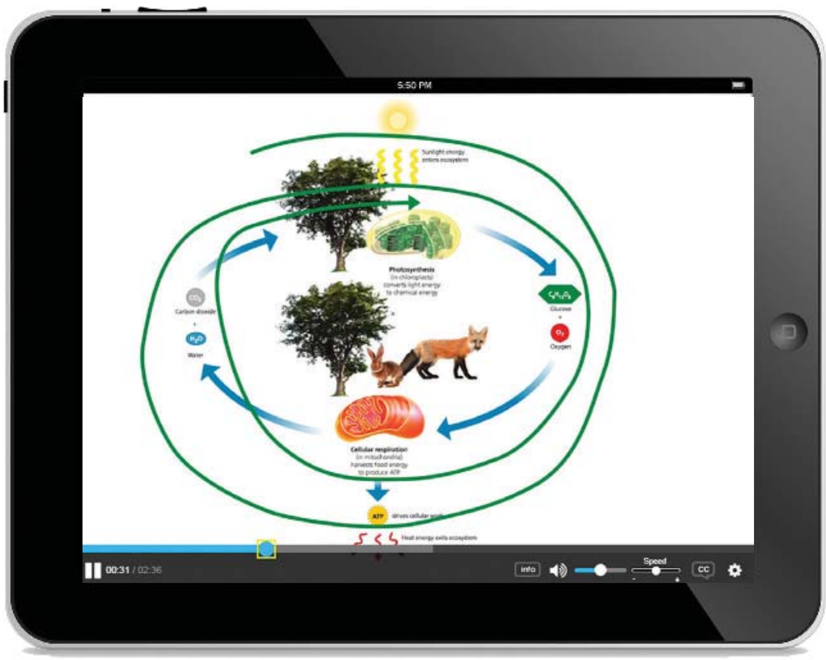
demonstrate the importance of evolution as a theme throughout biology, by appearing in every chapter.
Some new topics:

- Chapter 1 Turtles in the Tree of Life p. 18
- Chapter 10 Emerging Viruses p. 192
- Chapter 20 Saving the Hot Spots p. 449

Complex biological processes are explained . . .

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

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

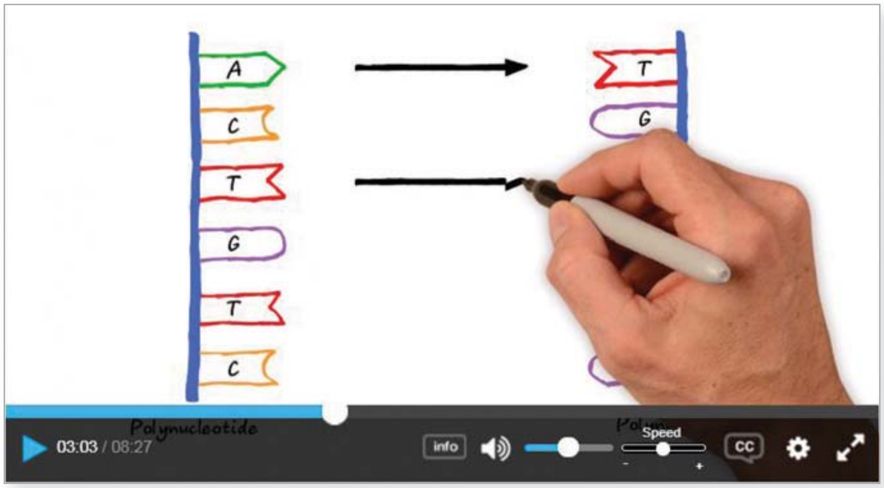


NEW! 20 Figure Walkthrough Videos, created and narrated by the authors, give clear, concise explanations of key figures in each chapter. The videos are embedded in the Pearson eText, accessible through QR codes in the print text, and assignable in Mastering Biology.

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

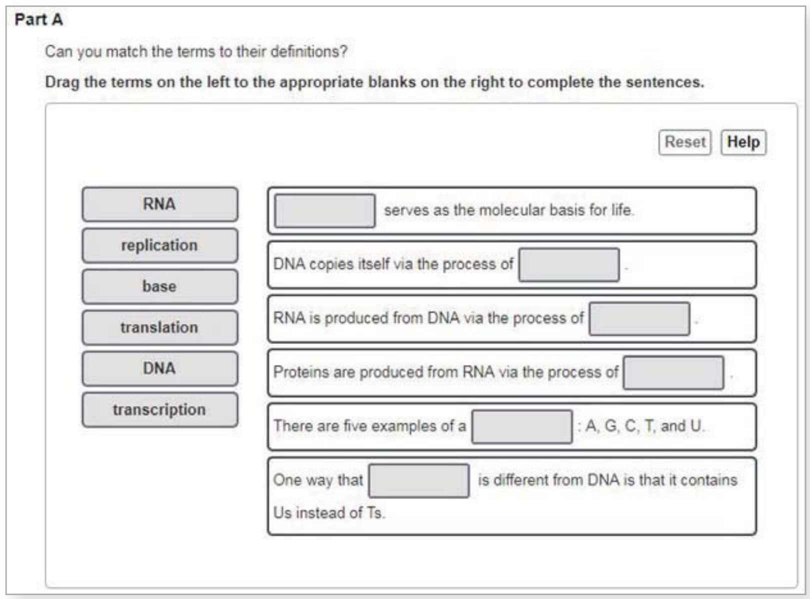
. . . with engaging visuals and narrated examples in Mastering Biology

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



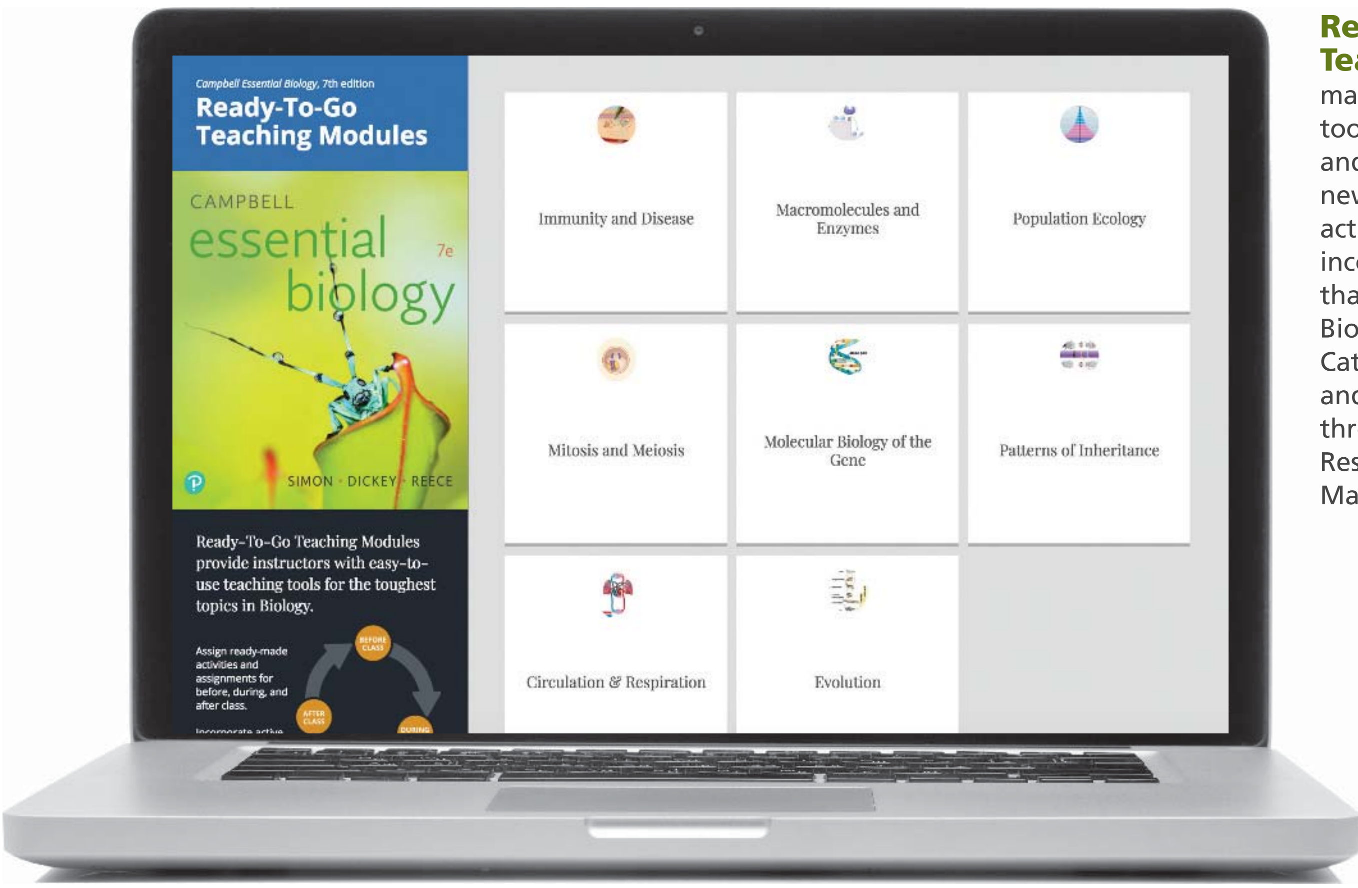
Topics include:

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



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

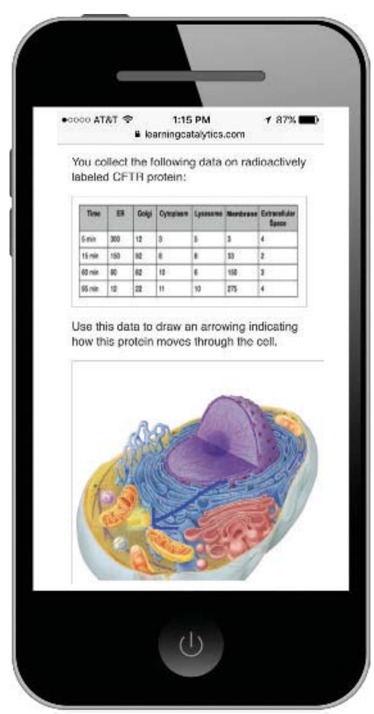
New approaches to teaching and learning . . .



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

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

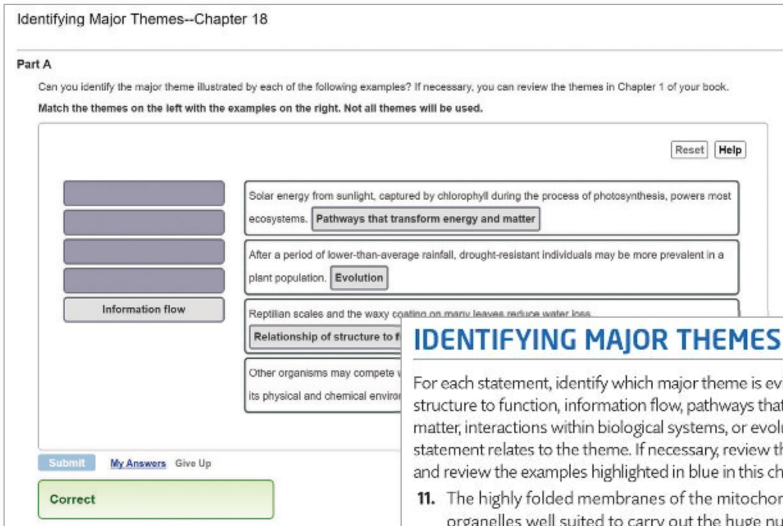
- Help your students develop critical thinking skills
- Monitor responses to find out where your students are struggling
- Rely on real-time data to adjust your teaching strategy



. . . and the resources to accomplish them

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

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



IDENTIFYING MAJOR THEMES

For each statement, identify which major theme is evident (the relationship of structure to function, information flow, pathways that transform energy and matter, interactions within biological systems, or evolution) and explain how the statement relates to the theme. If necessary, review the themes (see Chapter 1) and review the examples highlighted in blue in this chapter.

11. The highly folded membranes of the mitochondria make these organelles well suited to carry out the huge number of chemical reactions required for cellular respiration to proceed.

12. Cellular respiration and photosynthesis are linked, with each process using inputs created by the other.

13. Your body uses many different intersecting chemical pathways that, all together, constitute your metabolism.

For answers to Identifying Major Themes, see Appendix D.

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

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

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

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

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

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow \rightarrow \rightarrow 6\ CO_2 + 6\ H_2O + \text{approx. } 32\ \text{ATP}$$

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

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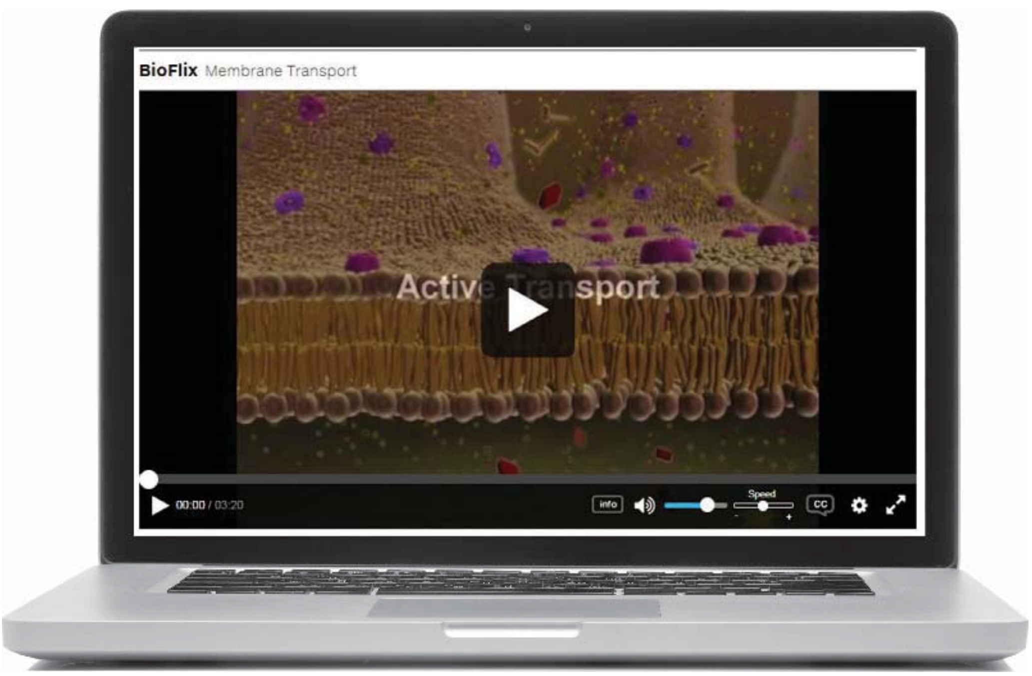

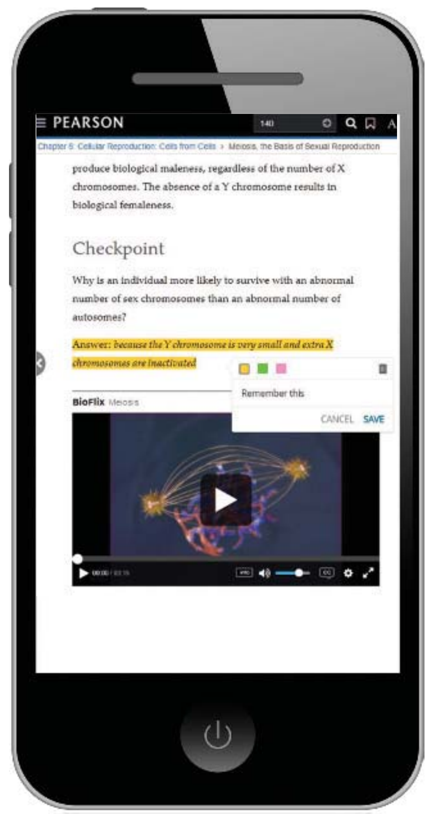

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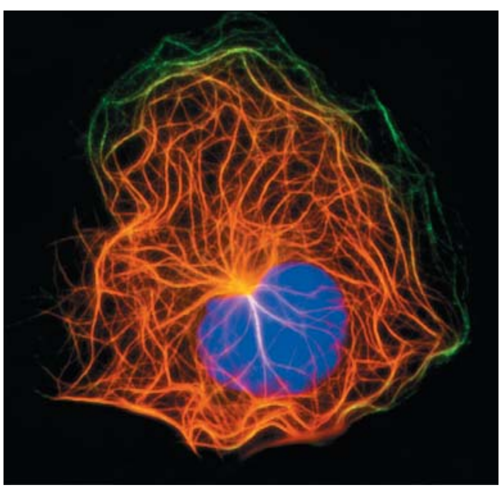

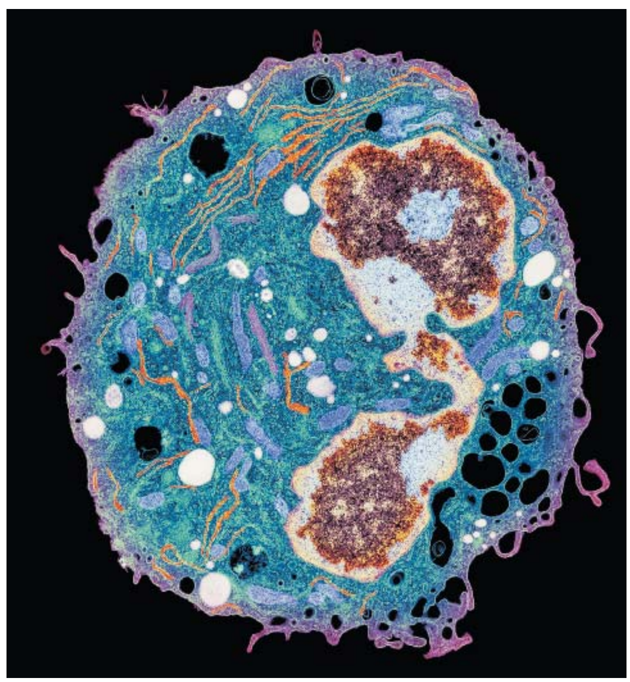

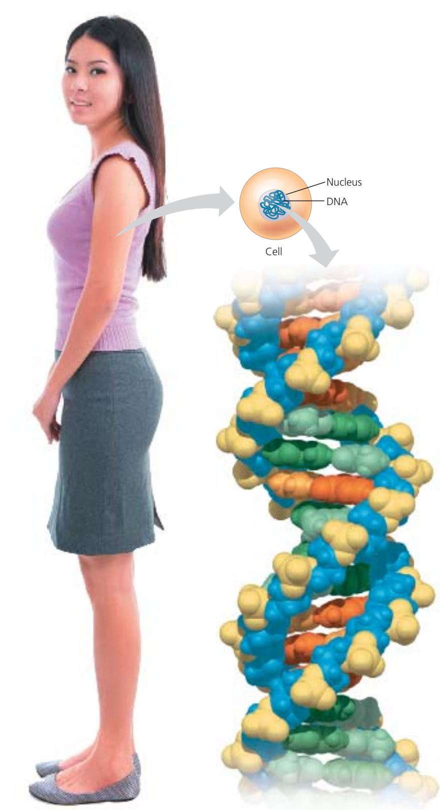

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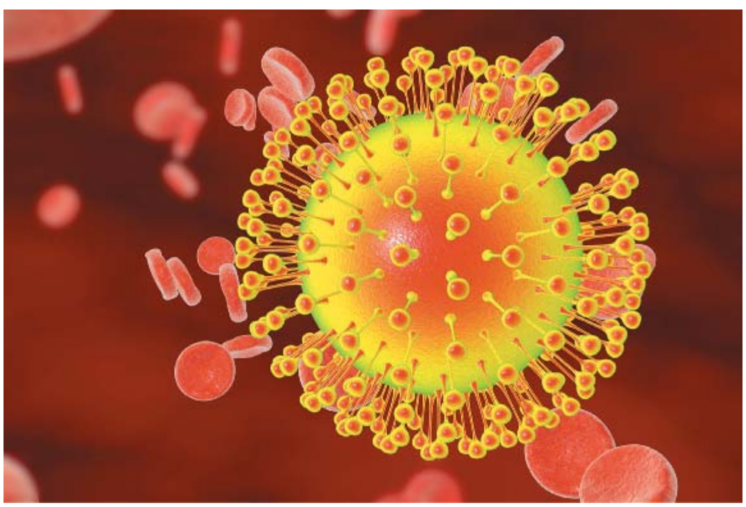

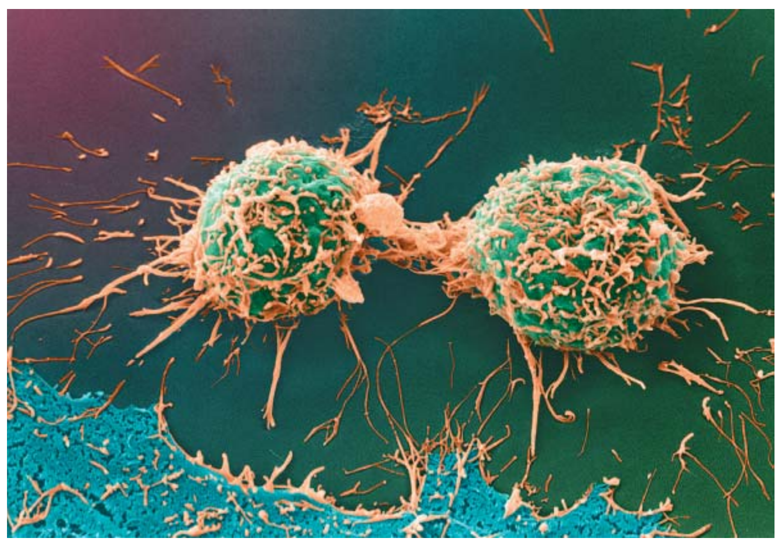

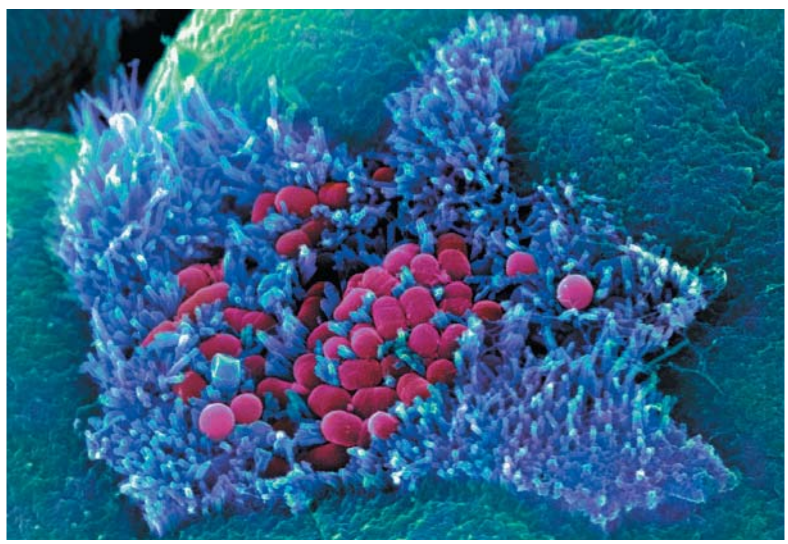

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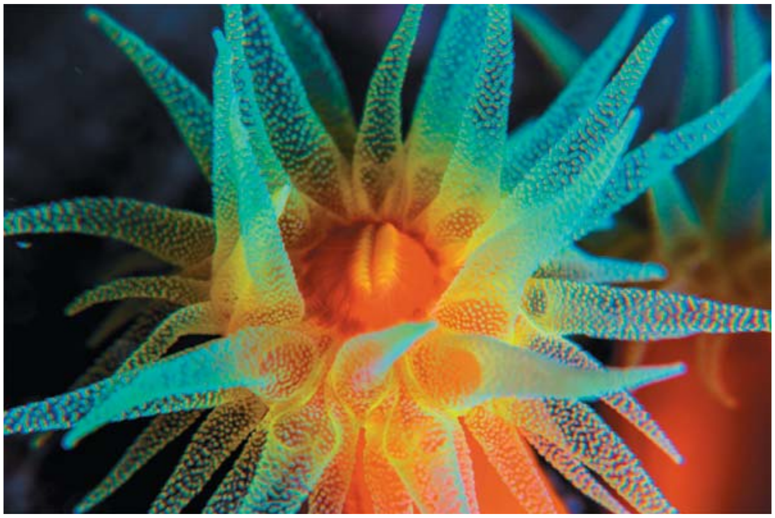

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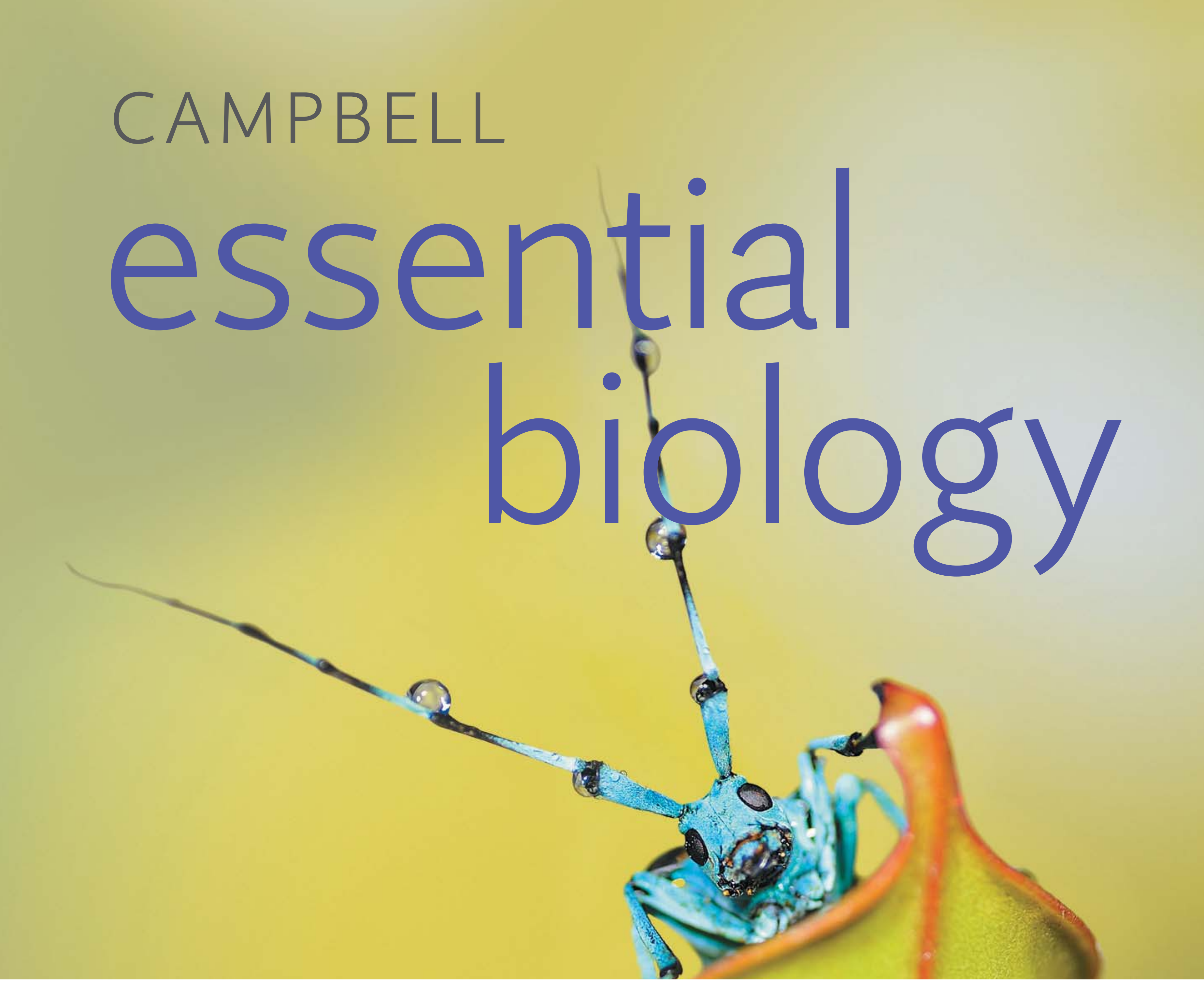

CAMPBELL
essential
biology

1 Learning About Life

CHAPTER CONTENTS

YOU'RE A SCIENTIST! ALTHOUGH YOU MAY NOT REALIZE IT, YOU USE THE PROCESS OF SCIENCE EVERY DAY.

Why Biology Matters

Nearly everyone has an inborn curiosity about the natural world. Whatever your connection to nature—perhaps you have pets; enjoy visiting parks, zoos, or aquariums; or watch TV shows about interesting creatures—this book will help demonstrate how the study of biology connects to your life.

WHAT THE HECK IS THAT? IF YOU'VE WONDERED WHAT AN UNUSUAL OR ESPECIALLY BEAUTIFUL ANIMAL IS CALLED, YOU'RE CURIOUS ABOUT BIOLOGY.

IS THERE LIFE ON MARS? ONE OF THE MISSIONS OF THE MARS ROVER IS TO SEARCH FOR SIGNS OF LIFE.

CHAPTER THREAD

Swimming with the Turtles

BIOLOGY AND SOCIETY Swimming with the Turtles

An inborn urge to learn about life. A college student swims with a green sea turtle off the coast of Belize, Central America.

A Passion for Life

Imagine yourself floating gently in a warm, calm ocean. Through the blue expanse, you spy a green sea turtle gliding toward you. You watch intently as it grazes on seagrass. It's easy to be captivated by this serene sea creature, with its paddle-shaped flippers and large eyes. As you follow it, you can't help but wonder about its life—how old it is, where it is traveling, whether it has a mate.

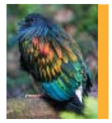
It's very human to be curious about the world around us. Nearly all of us have an inherent interest in life, an inborn fascination with the natural world. Do you have a pet? Are you concerned with fitness or healthy eating? Have you ever visited a zoo or an aquarium for fun, taken a nature hike through a forest, grown some plants, or gathered shells on the beach? Would you like to swim with a turtle? If you answered yes to any of these questions, then you share an interest in biology.

We wrote *Essential Biology* to help you harness your innate enthusiasm for life, no matter how much experience you've had with college-level science (even if it's none!). We'll use this passion to help you develop an understanding of the subject of biology, an understanding that you can apply to your own life and to the society in which you live. 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.

To reinforce the fact that biology does indeed affect you personally, every chapter of *Essential Biology* opens with an essay—called Biology and Society—where you will see the relevance of that chapter's material. Topics as varied as green energy (Chapter 7), pet genetics (Chapter 9), and the importance of biodiversity (Chapter 20) 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.

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 questions such as "What is a scientific study?" and "What does it mean to be alive?"



IF YOU'VE WONDERED WHAT AN UNUSUAL OR ESPECIALLY BEAUTIFUL ANIMAL IS CALLED, YOU'RE CURIOUS ABOUT BIOLOGY.

To start your investigation, this first chapter of *Essential Biology* will explain 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. Finally, we'll introduce a series of broad themes that serve as organizing principles for the information you will learn. Most importantly, throughout this chapter (and all of *Essential Biology*), you'll see 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.

An Overview of the Process of Science

The definition of *biology* as the scientific study of life leads to an obvious first question: What does it mean to study something scientifically? Notice that biology is not defined simply as "the study of life" because there are many nonscientific ways that life can be studied. For example, meditation is a valid way of contemplating life, but it is not a *scientific* means of studying life, and therefore it does not fall within the scope of biology. How, then, do we tell the difference between science and other ways of trying to make sense of the world?

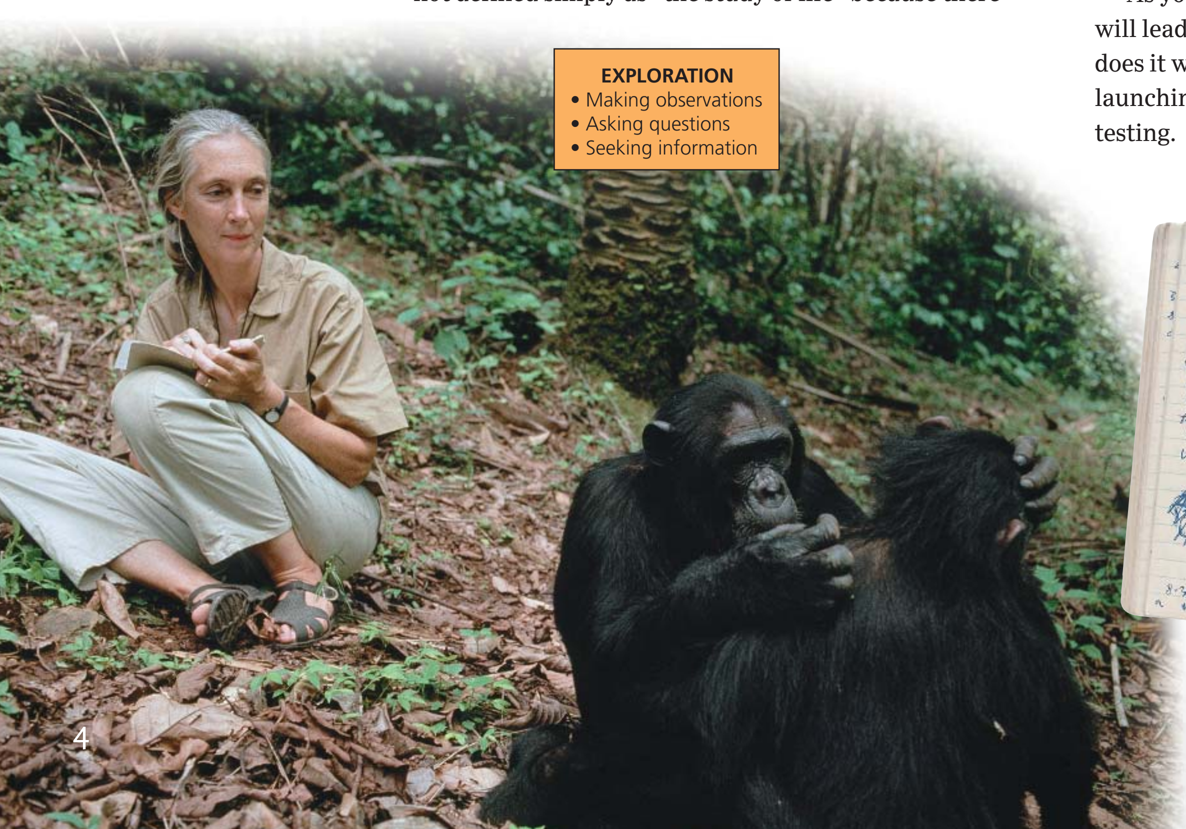
Science is an approach to understanding the natural world that is based on inquiry—a search for information, evidence, explanations, and answers to specific questions. Scientists seek natural causes for natural phenomena. Therefore, they focus solely on the study of structures and processes that can be verifiably observed and measured.

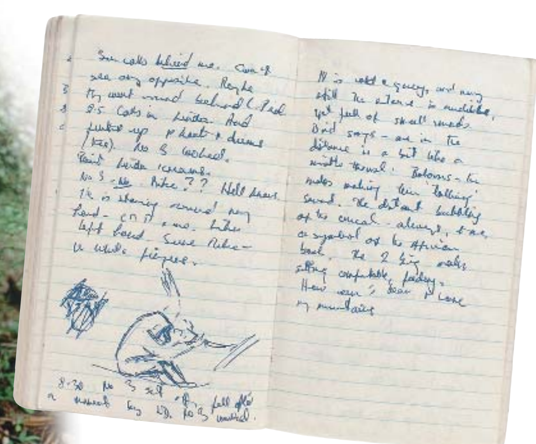
Exploration

If you wanted to understand something—say, the behavior of a sea turtle—how would you start? You'd probably begin by looking at it. Biology, like other sciences, begins with exploration **(Figure 1.1)**. During this initial phase of inquiry, you may simply watch the subject and record your observations. A more intense exploration may involve extending your senses using tools such as microscopes or precision instruments to allow for careful measurement. Whatever the source, recorded observations are called **data**—the evidence on which scientific inquiry is based. In addition to gathering your own data, you may read books or articles on the subject to learn about previously collected data.

As you proceed with your exploration, your curiosity will lead to questions, such as "Why is it this way?" "How does it work?" "Can I change it?" Such questions are the launching point for the next step in the process of science: testing.

▼ **Figure 1.1 Scientific exploration.** Dr. Jane Goodall spent decades recording her observations of chimpanzee behavior during field research in the jungles of Tanzania.





Testing

After making observations and asking questions, you may wish to conduct tests. But where do you start? You could probably think of many possible ways to investigate your subject. But you can't possibly test them all at once. To organize your thinking, you will likely begin by selecting one possible explanation and testing it. In other words, you would make a hypothesis. A **hypothesis** is a proposed explanation for a set of observations. A valid hypothesis must be testable and falsifiable—that is, it must be capable of being demonstrated to be false. A good hypothesis thus immediately leads to predictions that can be tested. Some hypotheses (such as ones involving conditions that can be easily controlled) lend themselves to **experiments**, or scientific tests. Other hypotheses (such as ones involving aspects of the world that cannot be controlled, such as ecological issues) can be tested by making further observations. The results of an experiment will either support or not support the hypothesis.

We all use hypotheses in solving everyday problems, although we don't think of it in those terms. Imagine that 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 probably would not just throw your hands up in the air and say "There's just no way to figure this out!" Instead, you might imagine several possible explanations, but you couldn't 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.

After you've formed a hypothesis, you would make further observations or conduct experiments to investigate this initial idea. In this case, you can predict that if you replace the batteries, the TV will work. Let's say that you conduct this experiment, and the remote still doesn't work. You conclude that this observation does not support your hypothesis. You would then formulate a second hypothesis and test it. Perhaps you hypothesize that the TV is unplugged. You could continue to conduct additional experiments and formulate additional hypotheses until you reach a satisfactory answer to your initial question. As you do this, you are following a series of steps that provide a loose guideline for scientific investigations. These steps are shown in **Figure 1.2** and are sometimes called "the scientific method." They are a rough "recipe" for discovering new explanations, a set of procedures that, if followed, may provide insight into the subject at hand.

The steps are simply a way of formalizing how we usually try to solve problems. If you pay attention, you'll find that you often formulate hypotheses, test them, and draw conclusions. In other words, the process of science is probably your "go-to" method for solving problems. Although the process of science is often presented as a series of linear steps (such as those in Figure 1.2), in reality investigations are almost never this rigid. Different questions will require different paths through the steps. There is no single formula for successfully discovering something new; instead, the process of science suggests a broad outline for how an investigation might proceed. ✓

ALTHOUGH YOU MAY NOT REALIZE IT, YOU USE THE PROCESS OF SCIENCE EVERY DAY.

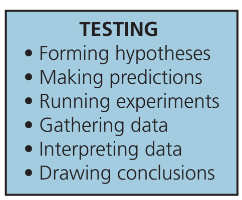
Communication and Outcomes

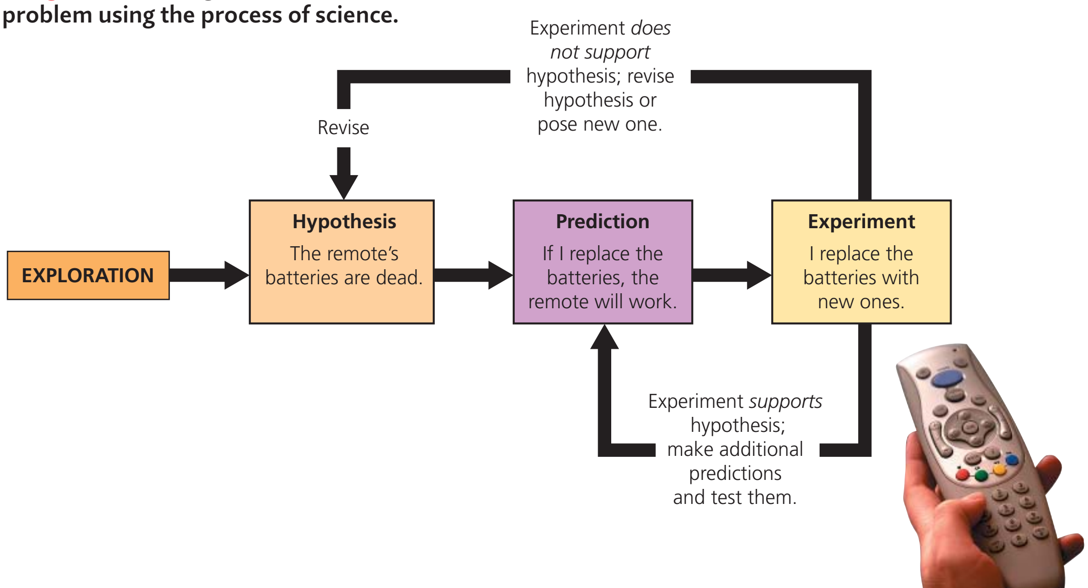
The process of science is typically repetitive and nonlinear. For example, scientists often work through several rounds of making observations and asking questions, with each round informing the next, before settling on hypotheses that they wish to test. In fine-tuning their questions, they rely heavily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

✓ CHECKPOINT

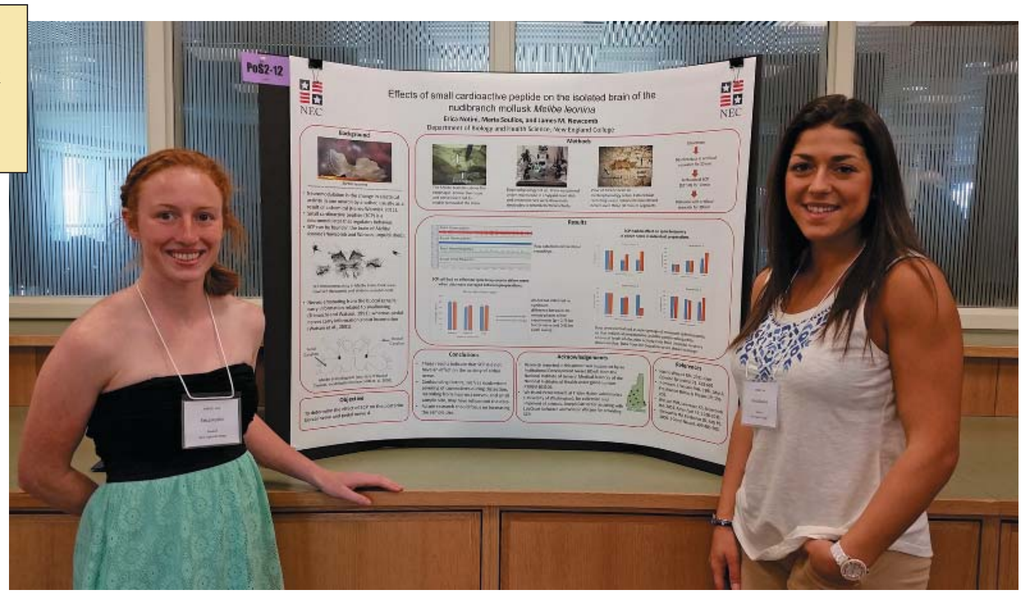
Do all scientific investigations follow the steps in Figure 1.2 in that precise order? Explain.

■ *Answer: No. Different scientific investigations may proceed through the process of science in different ways.*





▶ **Figure 1.2 Testing a common problem using the process of science.**



▶ **Figure 1.3 Scientific communication.** Like these college students, scientists often communicate results to colleagues at meetings.

Additionally, scientists communicate with each other through seminars, meetings, personal communication, and scientific publications **(Figure 1.3)**. Before experimental results are published in a scientific journal, the research is evaluated by qualified, impartial, often anonymous experts who were not involved in the study. This process, intended to provide quality control, is called **peer review**. Reviewers often require authors to revise their paper or perform additional experiments in order to provide more lines of evidence. It is not uncommon for a scientific journal to reject a paper entirely if it doesn't meet the rigorous standards set by fellow scientists. After a study is published, scientists often check each other's claims by attempting to confirm observations or repeat experiments.

Science does not exist just for its own sake. In fact, it is interwoven with the fabric of society **(Figure 1.4)**. Much of scientific research is focused on solving problems that influence our quality of life, 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. Scientific studies may involve basic research (largely concerned with building knowledge) or they may be more applied (largely concerned with developing new technologies). The ultimate aim of most scientific investigations is to benefit society. This focus on outcomes highlights the connections between biology, your own life, and our larger society.

▶ **Figure 1.4 Scientific outcomes.** A 22-year-old woman tries on her new prosthetic hand with individually movable bionic fingers.

Putting all these steps together, **Figure 1.5** presents a more comprehensive model of the process of science. You can see that forming and testing hypotheses (represented in blue) are at the center of science. This core set of activities is the reason that science explains natural phenomena so well. These activities, however, are shaped by exploration (orange) and influenced by communication with other scientists (yellow) and by outcomes (green). Notice that many of these activities connect to others, illustrating that the components of the process of science interact. 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 allow the process of science to be flexible, molded by the needs of each particular challenge.

In every chapter of *Essential Biology*, we include examples of how the process of science was used to study the content presented in that chapter. Some of the questions that will be addressed are Do baby turtles swim (this chapter)? Can avatars improve cancer treatment (Chapter 11)? What can lice teach us about ancient humans (Chapter 17)?

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—through commercials, social media, 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. ✓

▼ Figure 1.5 An overview of the process of science. Notice that performing scientific tests lies at the heart of the entire process.

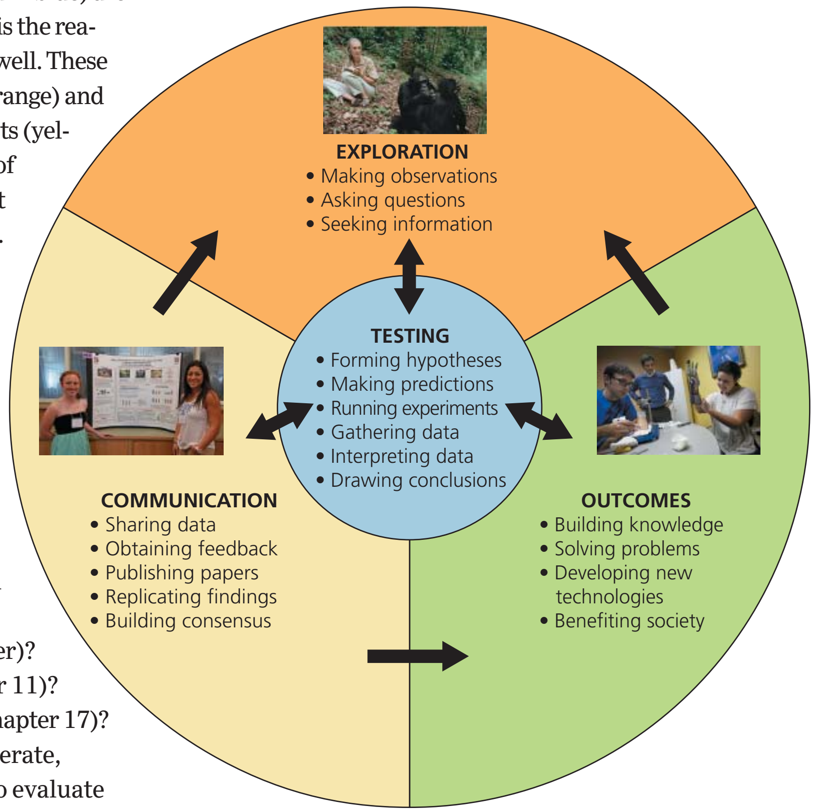


Figure Walkthrough
Mastering Biology
goo.gl/6bRdg9

Hypotheses, Theories, and Facts

Since scientists focus on natural phenomena that can be reliably observed and measured, let's explore how the terms *hypothesis, theory,* and *fact* are related.

As previously noted, a hypothesis is a proposed explanation for an observation. In contrast, a scientific **theory** is much broader in scope than a hypothesis. A theory is a comprehensive and well-substantiated explanation. Theories only become widely accepted by scientists if they are supported by a large, varied, and growing body of evidence. A theory can be used to explain many observations. Indeed, theories can be used to devise many new and testable hypotheses. It is important to note that scientists use the word *theory* differently than many people tend to use it in everyday speech, which implies untested speculation ("It's just a theory!"). In fact, the word *theory* is commonly used in everyday speech in the way a scientist uses the word *hypothesis*. It is therefore improper to say that a scientific theory, such as the theory of evolution, is "just" a theory to imply that it is untested or lacking in evidence. In reality, every scientific theory is backed up by a wealth of supporting evidence, or else it wouldn't be referred to as a theory. However, a theory, like any scientific idea, must be refined or even abandoned if new, contradictory evidence is discovered.

A **fact** is a piece of information considered to be objectively true based on all current evidence. A fact can be verified and is therefore distinct from opinions (beliefs that can vary from person to person), matters of taste, speculation, or inference. However, science is self-correcting: New evidence may lead to reconsideration of information previously regarded as a fact.

Many people associate facts with science, but accumulating facts is not the primary goal of science. A dictionary is an impressive catalog of facts, 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 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. ✓

✓ CHECKPOINT

Why does peer review improve the reliability of a scientific paper?

Answer: A peer-reviewed paper carries a "seal of approval" from impartial experts on the subject.

✓ 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."

Controlled Experiments

To investigate a hypothesis, a researcher often runs a test multiple times with one factor changing and, ideally, all other factors of the test being held constant. **Variables** are factors that change in an experiment. Most well-designed experiments involve the researcher changing just one variable at a time, with all other aspects held the same.

A **controlled experiment** is one that compares two or more groups that differ only in one variable that the experiment is designed to test. The **control group** lacks or does not receive the specific factor being tested. The **experimental group** has or receives the specific factor being tested. The use of a controlled experiment allows a scientist to draw conclusions about the effect of the one variable that did change. For example, you might compare cookie recipes by altering the amount of butter (the variable in this experiment) while keeping all other ingredients the same. In this case, the original cookie recipe is the control group, while the new recipe with more butter is the experimental group. If you were to vary both the butter and the flour at the same time, it would be difficult to know which variable was responsible for any changes in the cookies. To further illustrate this principle, let's look at a controlled experiment that investigated whether baby sea turtles swim or just drift in the water.

THE PROCESS OF SCIENCE **Swimming with the Turtles**

Do Baby Turtles Swim?

BACKGROUND

If you've spent time on the beach during the summer, you may have seen signs about endangered sea turtles, warning people to leave beach nests alone and to turn off lights in the evening. This is because, after emerging from a 2-month incubation, turtle hatchlings dig their way out of the sand and then use moonlight to navigate to the sea **(Figure 1.6a)**. What happens next has long been a mystery to marine biologists. Can the juvenile turtles swim in ocean currents? Or do they just passively drift? No one knows how baby sea turtles travel during their first several years. In fact, some marine biologists refer to this time as "lost years" in the turtle life cycle.

METHOD

In 2015, researchers from the University of Central Florida investigated the question of whether baby green sea turtles swim or drift. They attached tiny satellite trackers to 24 green sea turtles, each between 1 and 2 years old, in the Gulf of Mexico **(Figure 1.6b)**. The researchers also attached trackers to floating buckets and released them at the same time and in the same locations. The experiment was conducted under a scientific research permit from the National Marine Fisheries Service (NMFS).

RESULTS

Including a control group (the floating buckets) allowed the researchers to draw conclusions about the experimental group (the baby turtles). Comparing data on the paths taken by each group revealed that the turtles moved slowly (averaging only 0.4 miles per hour). However, the turtles moved faster and along different tracks than the floating buckets **(Figure 1.6c)**. These data suggest that, despite longstanding assumptions by marine biologists, very young sea turtles travel by swimming, and not just drifting. Such information may help efforts to protect endangered species of sea turtles.

Thinking Like a Scientist

What was the purpose of attaching transmitters to floating buckets?

For the answer, see Appendix D.

▼ Figure 1.6 Tracking baby sea turtles.

(a) Green sea turtle hatchlings scrambling to the sea

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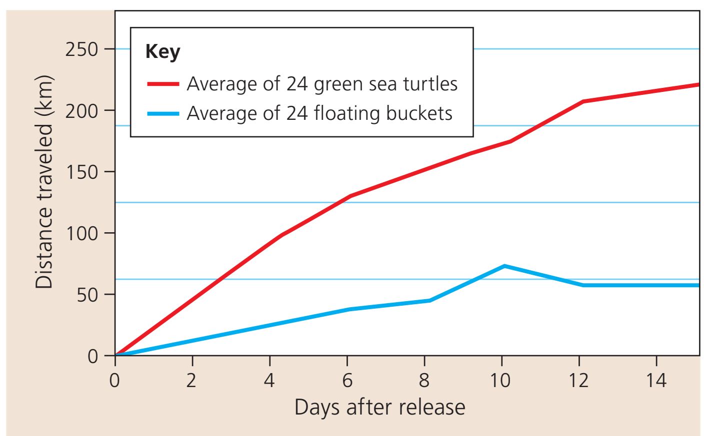
(b) Satellite tracker on the back of a baby turtle



(c) Graph showing the distance traveled by the average turtle (red line) versus the average floating bucket (blue line)

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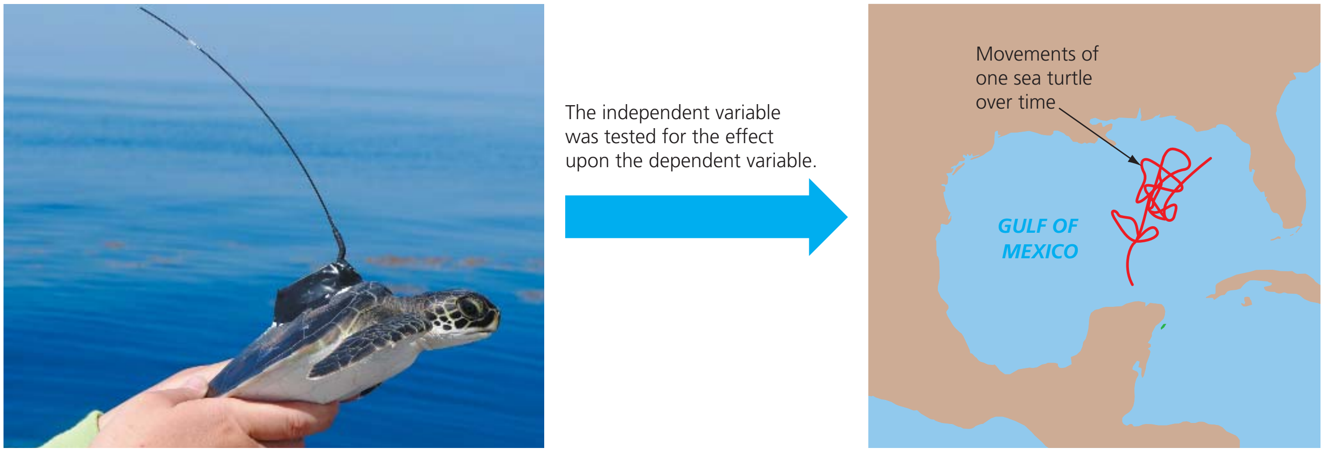

In this experiment, the independent variable (what is being changed) was the type of object being tracked: the sea turtles or the floating buckets.

In this experiment, the dependent variable (the effect under investigation) was the speed of travel.

◀ **Figure 1.7 Independent versus dependent variables.** These hypothetical data on green sea turtle migration show the relationship between these two types of variables.

The study on whether baby sea turtles swim is a good example of a controlled experiment. The variable was the identity of the object followed: turtles versus buckets. Other factors in the experiment—such as the type of satellite tracker used, when and where they were released, how often data were collected, and how speed was calculated—were purposefully kept the same. The control group was the floating buckets, and the experimental group was the baby sea turtles. The buckets were the control group because they lacked the factor being tested: the ability to move on their own. By comparing the movements of the floating buckets with the movements of the baby sea turtles, the experimenters could be confident that any observed differences were due to the turtles being able to swim.

In a controlled experiment, like the one just described, the **independent variable** is what is being manipulated by the researchers as a potential cause—in this case, the object under investigation (either turtles or buckets). The **dependent variable** is the response, output, or effect under investigation that is used to judge the outcome of the experiment—in this case, the speed of movement. The dependent (measured) variable is affected by the independent (manipulated) variable **(Figure 1.7)**. Well-designed experiments often test just one independent variable at a time.

A controlled experiment can sometimes be a blind experiment, in which some information about the experiment is withheld from participants **(Figure 1.8)**. For example, the turtle researchers may have analyzed the trajectory data without knowing whether each track was a turtle or a bucket. The identities of the blinded components are revealed only after the experiment is complete. Performing the study blind removes bias on the part of the investigators. This type of study is called a **single-blind experiment**.

Many medical drug trials include a **placebo**, a medically ineffective treatment that allows the placebo group to serve as a control group. Typically, the placebo group does not know that they are receiving an ineffective substitute. An experiment in which neither the participant nor the experimenter knows which group is the control group is called a **double-blind experiment**. The "gold standard" for a medical trial is a "double-blind placebo-controlled study," meaning that neither the patients nor the doctors know which patients received the real treatment and which received a placebo. Such a design prevents bias on the part of the researchers and also takes into account the placebo effect, a well-documented phenomenon whereby giving patients a fake treatment nonetheless causes them to improve due to their belief that they are receiving an effective treatment. ✅

Evaluating Scientific Claims

The process of science involves evaluating scientific claims. Sometimes claims are made using scientific jargon with the intention of appearing to conform to scientific standards without actually doing so. **Pseudoscience** is any field of study that is falsely presented as having a scientific basis. Given our access to huge amounts of information, much of it unreliable, the ability to recognize pseudoscience is a very important thinking skill. Although the difference between valid science and pseudoscience can at times

▼ **Figure 1.8 How to recognize blind studies.**

TYPE OF STUDY	TEST SUBJECTS KNOW WHICH GROUP IS WHICH?	RESEARCHERS KNOW WHICH GROUP IS WHICH?
Not blind	Yes	Yes
Single blind	No	Yes
Double blind	No	No

✅ **CHECKPOINT**

You bake two recipes of cookies and label them "A" and "B." You ask a group of friends to rate the recipes. Design a double-blind experiment to determine which recipe is superior.

■ Answer: A third party should label the cookies and collect the data so that neither the investigator (you) nor the subjects (your friends) know which recipe is which.