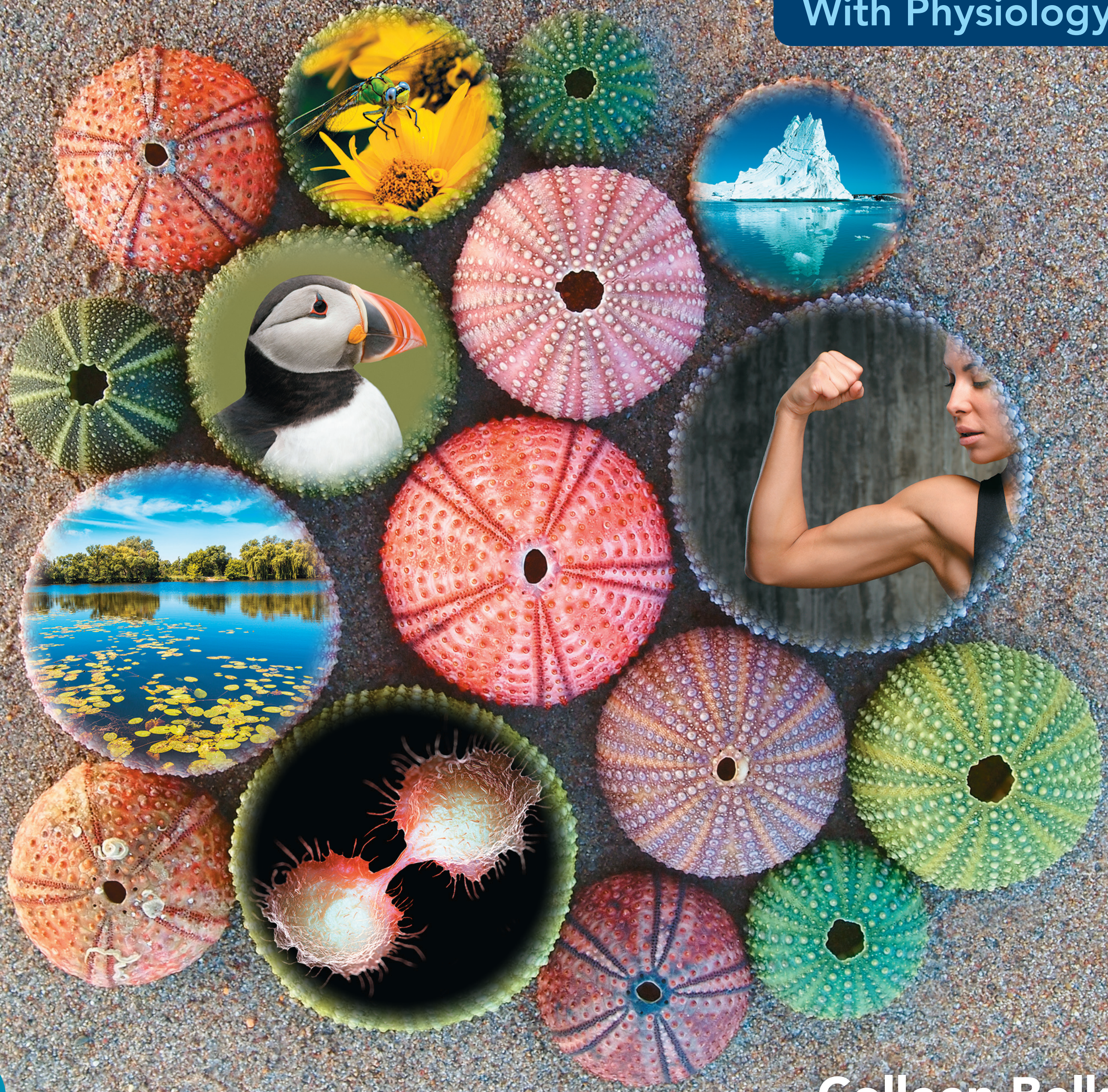
BIOLOGY

SCIENCE FOR LIFE

SIXTH EDITION

With Physiology



Colleen Belk
Virginia Borden Maier

Brief Contents

Sixth Edition

Biology

Science for Life

WITH PHYSIOLOGY

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Pearson

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About the Authors

Colleen Belk and **Virginia Borden Maier** collaborated on teaching biology to nonmajors for more than a decade at the University of Minnesota Duluth. This collaboration has continued for an additional decade through Virginia's move to St. John Fisher College in Rochester, New York, and has been enhanced by their differing but complementary areas of expertise. In addition to the nonmajors course, Colleen teaches general biology for majors, genetics, cell biology, and molecular biology courses. Virginia teaches general biology for majors, evolutionary biology, zoology, plant biology, ecology, and conservation biology courses.

After several somewhat painful attempts at teaching the breadth of biology to nonmajors in a single semester, the two authors came to the conclusion that they needed to find a better way. They realized that their students were more engaged when they understood how biology directly affected their lives. Colleen and Virginia began to structure their lectures around stories they knew would interest students. When they began letting the story drive the science, they immediately noticed a difference in student engagement and willingness to work harder at learning biology. Not only has this approach increased student understanding, but it has also increased the authors' enjoyment in teaching the course—presenting students with fascinating stories infused with biological concepts is simply a lot more fun.

Preface

To the Student

Is it acceptable to clone humans? When does human life begin? What should be done about our warming planet? Who owns living organisms? What are our responsibilities toward endangered species? Having taught this course for nearly 45 combined years, we understand that no amount of knowledge alone will provide satisfactory answers to these questions. Addressing them requires the development of a scientific literacy that surpasses the rote memorization of facts. To make decisions that are individually, socially, and ecologically responsible, you must not only understand some fundamental principles of biology but also be able to use this knowledge as a tool to help you analyze ethical and moral issues involving biology. This is the aim of this textbook.

To help you understand biology and apply your knowledge to an ever-expanding suite of issues, we have structured each chapter of *Biology: Science for Life with Physiology* around a compelling story in which biology plays an integral role. Through the story you not only will learn the relevant biological principles but also will see how science can be used to help answer complex questions. As you learn to apply the strategies modeled by the text, you will also be strengthening your critical thinking skills.

Even though you may not be planning to be a practicing biologist, well-developed critical thinking skills will enable you to make better decisions about issues that affect your own life and form well-reasoned, fact-based opinions about personal, social, and ecological issues.

To the Instructor

You are probably all too aware that teaching nonmajors students is very different from teaching biology majors. You know that most of these students will never take another formal science course; therefore, your course may be the last chance for these students to appreciate how biology is woven throughout the fabric of their lives and to develop a deep understanding of the process of science. You recognize the importance of engaging nonmajors because you know that these students will one day be voting on issues of scientific importance, holding positions of power in the community, serving on juries, and making health care decisions for themselves and their families. This text is designed to help you reach your goals.

By now, most nonmajors biology instructors are aware that this book differs from other books in that we use a compelling storyline woven throughout the entire text of each chapter to garner student interest. Once we draw students in, we keep them engaged by returning to the storyline again and again until the end of the chapter, when students should be able to form their own data-driven opinions about each topic. Storylines are carefully crafted to allow the same depth and breadth of coverage as any other nonmajors biology text.

Our experience has taught us that students will not remember as many facts as we hope they will, but they can and do remember how to apply the scientific method to novel questions involving biology, and they can retain a strong appreciation for how science differs from other methods of understanding the world. To ensure our students leave our course with the ability to critically evaluate information they may come across, this text focuses heavily on the process of science, providing opportunities for students to practice applying the scientific method and analyze data at every opportunity.

New to the Sixth Edition

The positive feedback obtained in previous editions assured us that presenting science alongside a story works for students and instructors alike. In the sixth edition, we have added several new features, a new chapter, and several reorganized chapters. We also updated storylines and continued to improve popular features from previous editions as well as our supplements.

New Features: Got It?, Show You Know, Go Find Out, Make the Connection, and The Big Question

In this edition, we have added many active learning features to help engage student readers. Each text section includes a series of fill-in-the-blank **Got It?** questions to help students actively assess their content comprehension. The Chapter Review Summary now contains **Show You Know** questions to make reviewing the summary a more active process for students. **Go Find Out** includes activities students can perform on their own or in class in groups that challenge them to find information to answer contemporary questions. The Chapter Review ends with a **Make the Connection** exercise where students draw lines between statements about the storyline and the science in the chapter to help enhance their understanding. Lastly, each chapter ends with **The Big Question,** a feature that presents a topic, followed by some smaller questions—some answerable by science and some not. Once students determine which of the smaller questions science can answer, data is presented related to one of these questions. Students analyze the data in light of both the smaller question addressed and the big question that headlines the feature.

Revised Unit One Coverage and New Chapters

Because we have found that our students are interested in their own fertility, we have reorganized the mitosis and meiosis chapter into two separate chapters. **Chapter 6** still deals with mitosis and cancer, but a new **Chapter 7** now addresses human fertility and reproduction along with meiosis. **Chapter 8** discusses Mendelian genetics in a new storyline, addressing the development and use of newborn screening tests. A newly reorganized **Chapter 9** uses the storyline of wrongful convictions to help students learn about the inheritance of complex traits such as those used in identification of suspects by witnesses. In addition, the heritability section helps counter the notion that criminals are born not made, and the DNA profiling section explains how positive identification has been used to exonerate many wrongfully convicted individuals.

Updated Storylines

In addition to the new storylines listed above associated with content revisions, we've revised the storylines of some chapters without strongly modifying content. **Chapter 5** continues to address photosynthesis within a storyline about global climate change, but is updated to reflect humanity's response via the Paris Agreement. Our chapter on speciation (**Chapter 13**) still addresses the issue of supposed human races, but now through the lens of swimmer Simone Manuel's historic gold medal in the 2016 Olympics. The chapter covering climate and biomes (**Chapter 17**) now addresses the concept of the human "footprint." Our summary of the respiratory and cardiovascular systems (**Chapter 20**) addresses the known and unknown health issues of electronic cigarettes and the practice of "vaping." And the spread of Zika virus is now the storyline for **Chapter 23,** which describes the virus's effects on reproduction and embryonic development.

Supplements and Media

The supplements package continues to be updated and expanded by Judi Roux, Ed.D., a talented college instructor with years of classroom experience in nonmajors biology and colleague of Colleen Belk at the University of Minnesota Duluth. We think you will find that the supplements she has developed are brimming with ideas for how to reach this particular population of students. In addition to the Instructor's Manual (for use in traditional lectures as well as flipped classrooms) and a test bank, we also provide slides, animation, and videos to enrich instruction efforts. Available online, the *Biology: Science for Life with Physiology* resources are easy to navigate and support a variety of learning and teaching styles. Judi authored not only the Instructor Guide, but also many Mastering Biology Quiz and Test Items and the PowerPoint lectures as well.

New features in Mastering Biology include **figure walk-throughs** on tough topics, which provide students with the dynamic guidance of the authors to help them solidify their understanding of the concepts within challenging illustrations. **Ready-to-Go Teaching Modules** for select chapters provide instructors with assignments to use before and after class, as well as in-class activities that use Clickers or Learning Catalytics for assessment. Each Ready-to-Go Teaching Module also includes an **Instructor How-To** video, in which Colleen and Virginia provide additional background and helpful hints for presenting the content in the context of particular storylines.

We believe you will find that the design and format of this text and its supplements will help you meet the challenge of helping students both succeed in your course and develop science skills—for life.

We look forward to learning about your experience with *Biology: Science for Life with Physiology*, Sixth Edition.

Acknowledgments

Reviewers

Each chapter of this book was thoroughly reviewed several times as it moved through the development process. Reviewers were chosen on the basis of their demonstrated talent and dedication in the classroom. Many of these reviewers are already trying various approaches to actively engage students in lectures and to raise the scientific literacy and critical thinking skills among their students. Their passion for teaching and commitment to their students were evident throughout this process. These devoted individuals scrupulously checked each chapter for scientific accuracy, readability, and coverage level.

All of these reviewers provided thoughtful, insightful feedback, which improved the text significantly. Their efforts reflect their deep commitment to teaching nonmajors and improving the scientific literacy of all students. We are very thankful for their contributions.

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Bryan Spohn Florida, *Community College at Jacksonville, Kent Campus*
Carol St. Angelo, *Hofstra University*
Brooke Stabler, *University of Central Oklahoma*
Amanda Starnes, *Emory University*
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Timothy Stewart, *Longwood College*
Jennifer Stovall, *Southcentral Kentucky Community & Technical College*
Shawn Stover, *Davis and Elkins College*
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Joyce Tamashiro, *University of Puget Sound*
Jeffrey Taylor, *Slippery Rock University*
Martha Taylor, *Cornell University*
Glena Temple, *Viterbo University*
Alice Templet, *Nicholls State University*
Tania Thalkar, *Clarion University of Pennsylvania*
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Jeffrey Thomas, *University of California, Los Angeles*
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John Zook, *Ohio University*
Michelle Zurawski, *Moraine Valley Community College*

The Book Team

The sixth edition has been energized by the work and ideas of our new editor Cady Owens. She has brought a fresh and insightful perspective that is much appreciated by both authors. We remain indebted to our editor for the previous three editions, Star MacKenzie, who was instrumental in helping us develop the revision plan for this edition. Our development editor for much of the sixth edition, Debbie Hardin, played a key role in shaping new and heavily revised chapters. Her talented successor, Evelyn Dahlgren, has drawn on her extensive experience to further improve the final product. We are also grateful for the steady hand of the Director of Courseware Portfolio Management Beth Wilbur, who is always thoughtful, responsive, and supportive of us and this project. We continue to feel fortunate to work with such a talented and devoted team.

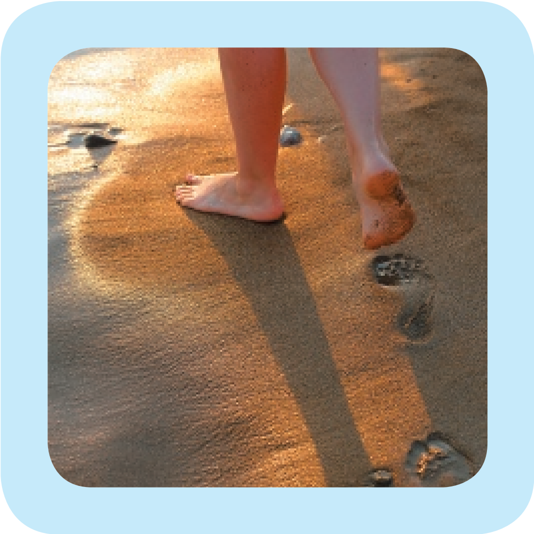
This book is dedicated to our families, friends, and colleagues who have supported us over the years. Having loving families, great friends, and a supportive work environment has enabled us to make this heartfelt contribution to nonmajors biology education.

Colleen Belk
Virginia Borden Maier

"Because science, told as a story, can intrigue and inform the nonscientific minds among us, it has the potential to bridge the two cultures into which civilization is split—the sciences and the humanities. For educators, stories are an exciting way to draw young minds into the scientific culture."

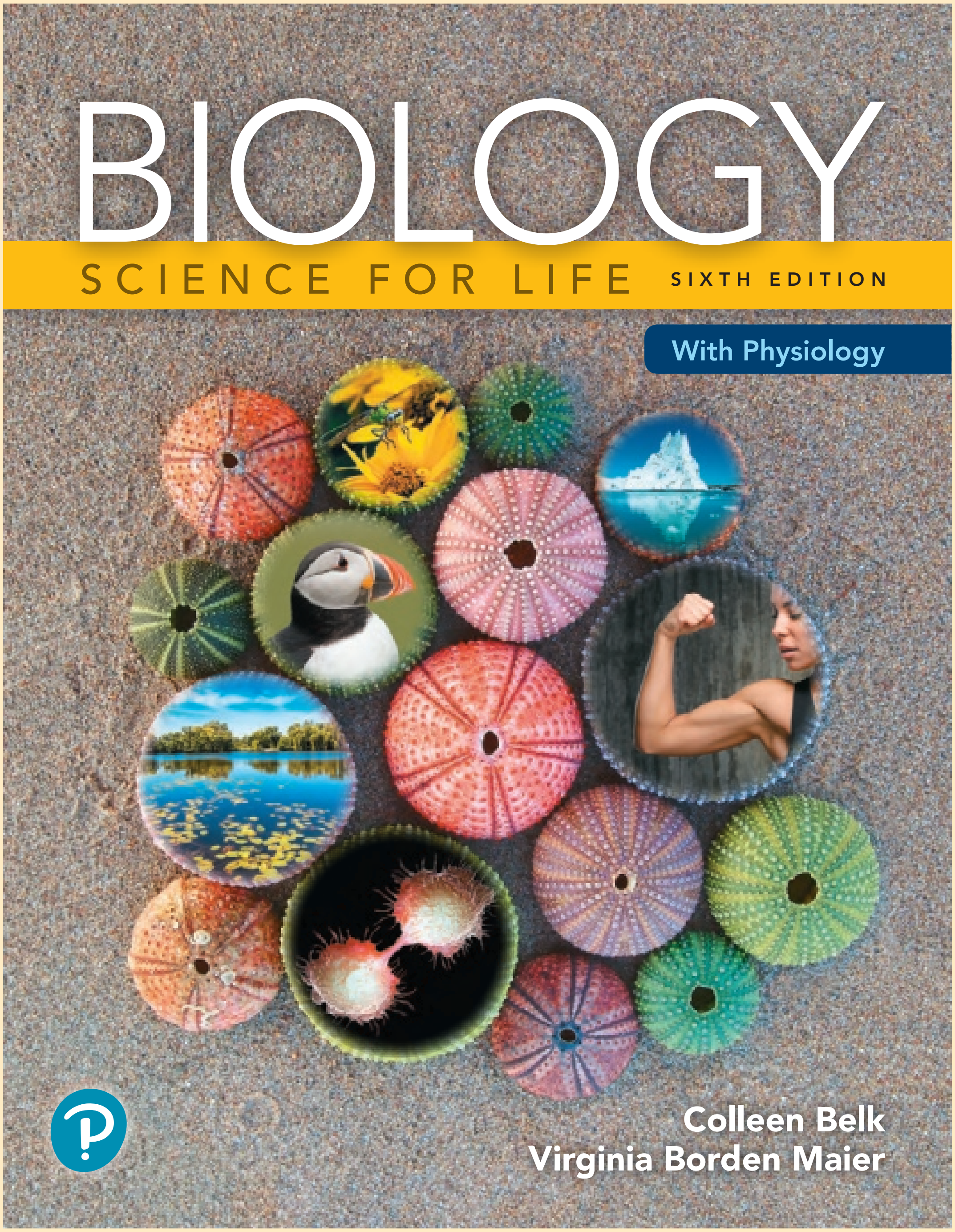
—E. O. Wilson

Contents



Engage Students in Science with Stories That Relate to Their Lives

Biology: Science for Life with Physiology **weaves a compelling storyline throughout each chapter to grab student attention, exploring high-interest topics such as genetic testing, global warming, and the Zika virus. The authors return to the storyline again and again, using it as the basis on which they introduce the biological concepts behind each story.**



Capture Student Attention with

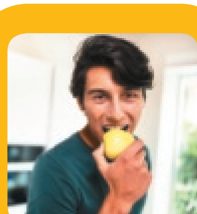
Each chapter weaves in a story based on a current issue or hot topic through which biological concepts, examples, and applications are presented and explained.

3

Is It Possible to Supplement Your Way to Better Performance and Health?

Do sports drinks enhance athletic performance?

Do nutritional supplements enhance academic performance or health?



Or is it more healthful to eat whole foods?

Nutrients and Membrane Transport

Gingko to improve your memory, kava to reduce stress, ginseng to boost energy, and melatonin to help you sleep. Sounds like a recipe for success for a busy student. For good measure, chase those supplements down with some coconut water to slow aging and prevent cancer. You may have heard claims about the health benefits of nutritional supplements like vitamins, minerals, herbs, yeast, and even enzymes. If these are truly good for you, why not replace some of the food you eat with products that have a longer shelf life than most foods? Instead of going to the grocery store every weekend, you could stock your pantry with energy drinks, vitamin-enriched waters, protein powders, nutrition bars, vitamins, and minerals. These can be bought in bulk and don't rot like fruits and vegetables. But are they as good for you as food?

Is it possible to supplement your way to enhanced academic performance or better health? It seems that most Americans think so—we spend around $6 billion a year on these items and more than two-thirds of us are taking at least one such supplement. Let's investigate whether these products are doing what we hope they are.

NEW! Storylines in the 6th edition:
- Chapter 7: Fertility
- Chapter 8: Does Testing Save Lives?
- Chapter 9: Biology of Wrongful Convictions
- Chapter 17: The Human Footprint

Relevant, Engaging Storylines

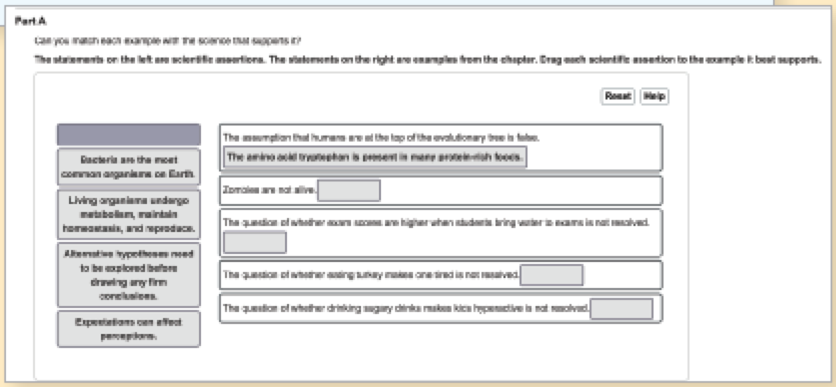
NEW! Make the Connection Activities tie the storyline of the chapter to the key scientific concepts behind it to ensure that students truly understand the relationship between the story and the science. These are also assignable in Mastering Biology.

MAKE THE CONNECTION

The science that you learned in this chapter has helped you better understand the real-world example used throughout this discussion. Draw a line from the statement on the left to the science that supports it on the right.

Zombies are not alive.	The amino acid tryptophan is present in many protein rich foods.
The question of whether exam scores are higher when students bring water to exams is not resolved.	Living organisms undergo metabolism, maintain homeostasis, and reproduce.
The question of whether drinking sugary beverages make kids hyperactive is not resolved.	Alternative hypotheses need to be explored before drawing any firm conclusions.
The question of whether eating turkey makes one tired is not resolved.	Bacteria are the most common organisms on Earth.
The assumption that humans are at the top of the evolutionary tree is false.	Expectations can effect perceptions.

Answers to Got It?, Visualize This, Working with Data, Sounds Right, But Is It?, Show You Know, and Chapter Review questions can be found in the Answers section at the back of the book.



Sounds right, but is it?

In the Harry Potter books and movies, many of the characters who knew Harry's parents tell him that he resembles his mother or note his similarity to his father in his willingness to bend the rules. To many fans, these comments make sense, because a child receives half of his genetic information from his mother and half from his father. Thus, it seems fair to say that:

Harry Potter has his mother's eyes.

Sounds right, but it isn't.

Answer the following questions to understand why.

1. Do you think it is more likely that the color and shape of a person's eyes are determined by one gene or many genes?
2. Did Harry receive copies of genes that determine eye color and shape from his mother?
3. Did he receive copies of genes that determine eye color and shape from his father?
4. Think back to the Punnett squares you've viewed and drawn. Do genes for only one or both parents likely influence eye color and shape?
5. Reflect on your answers to questions 1–4. Explain why the statement bolded above sounds right, but isn't.

Sounds Right, But Is It? activities at the end of each chapter address common student misconceptions about biology concepts.

Help Students Interpret and Apply Data

THE **BIG** QUESTION

Should I routinely use detox products?

Detoxification teas, sometimes called teatoxes, are endorsed by celebrities on social media. How—or if—these products work to detox your body are open questions. Most detox supplements are thought to act on the liver, which is the major site of detoxification in your body. Let's look at the science behind these products to determine if they are useful and safe.

What should I know?

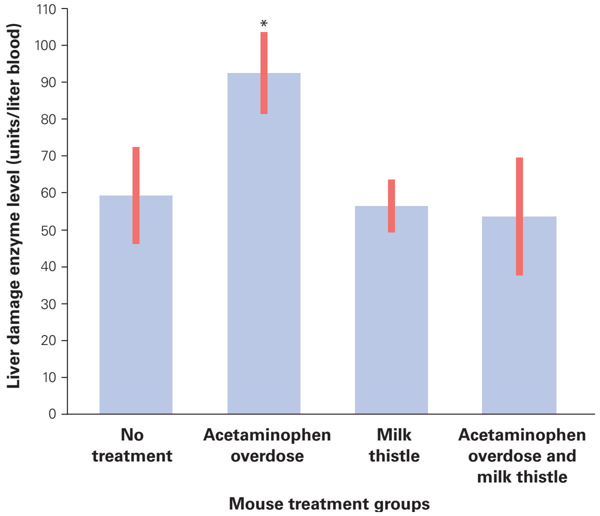
What follows are some smaller questions that need to be resolved to answer the Big Question. Place a checkmark next to the questions that science can answer.

Smaller Questions	Can Science Answer?
Do toxins accumulate in the liver?	
Do most manufacturers of supplements care more about profit than helping people detoxify?	
Is toxin accumulation harmful to health?	
Can using detox teas or supplements be harmful?	
Are detox products helpful under normal conditions?	
If celebrities are paid for their endorsements, should we trust the products they are endorsing?	

What does the science say?

Let's examine what the data say about this smaller question:

Are detox products helpful under normal conditions?
Milk thistle is an herbal supplement that is thought to act on the liver. The data shown in the illustration that follows show levels of an enzyme whose concentration in the blood increases with liver damage.

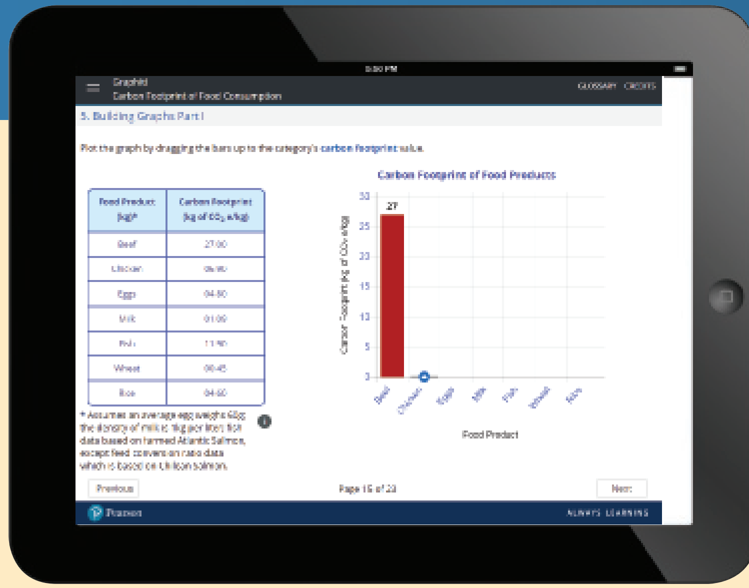


1. Describe the results. Does it appear that milk thistle helps prevent liver damage under normal conditions?
2. Given these data, do you think the smaller question is answered? If not, propose another study that would help answer this question.
3. Does this information help you answer the Big Question? What else do you need to consider?

Data source: N. Bektur, E. Sahin, C. Baycu, and G. Unver, "Protective Effects of Silymarin against Acetaminophen-Induced Hepatotoxicity and Nephrotoxicity in Mice," *Toxicology and Industrial Health* 32, no. 4 (2016): 589–600.

NEW! Big Question features present a topic, followed by a series of smaller questions—some answerable by science and some not. Once students determine which of the smaller questions science can answer, students explore data related to one of these questions. Students analyze the data in light of both the smaller question addressed and the big question that headlines the feature.

NEW! 10 GraphIt! Coaching activities help students read, interpret, and create graphs that explore real environmental issues using real data. They are presented in an entirely new mobile experience with accessible design.



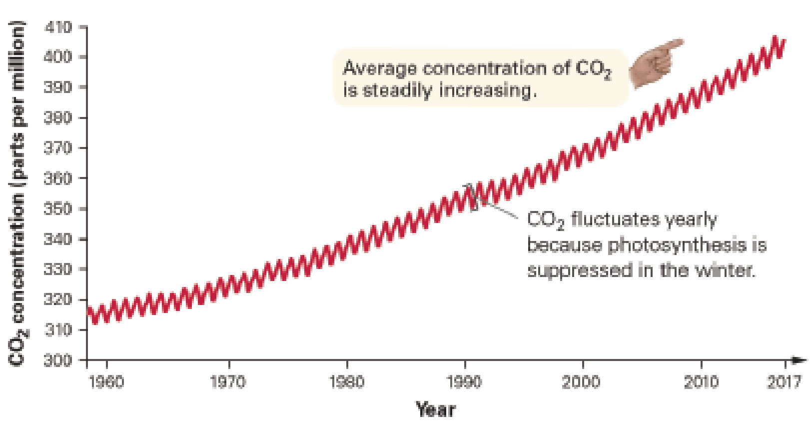
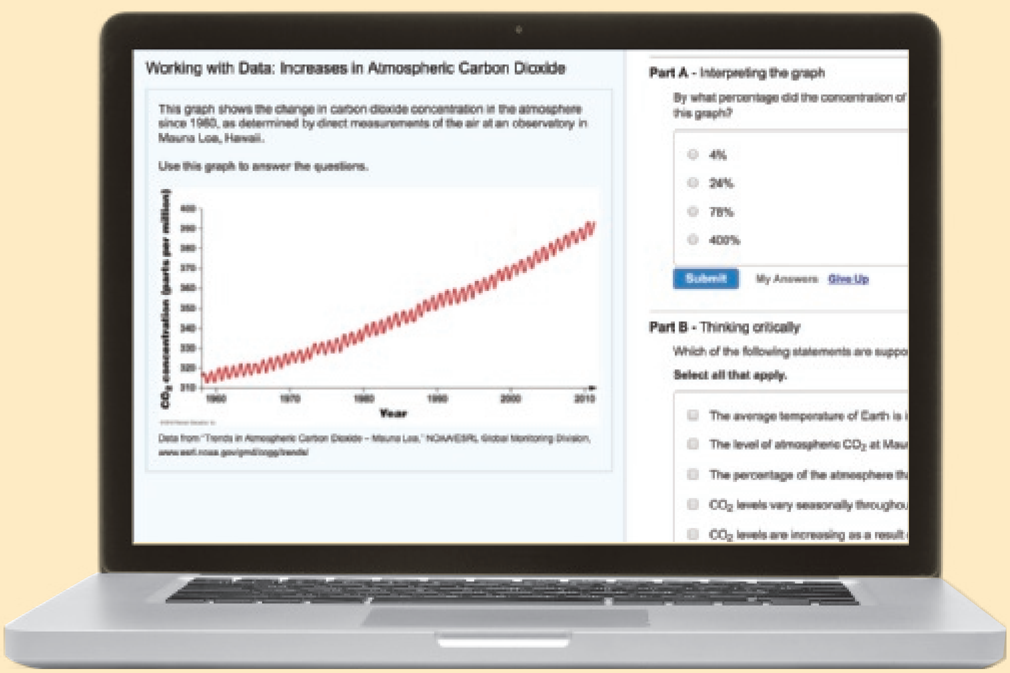


FIGURE 5.6 Increases in atmospheric carbon dioxide. Carbon dioxide levels from 1960 to present as measured by instruments at Mauna Loa observatory in Hawaii.

WORKING WITH DATA

What evidence in the graph demonstrates the increased rate of carbon dioxide accumulation from 2000 to 2017 compared with the 1960s?

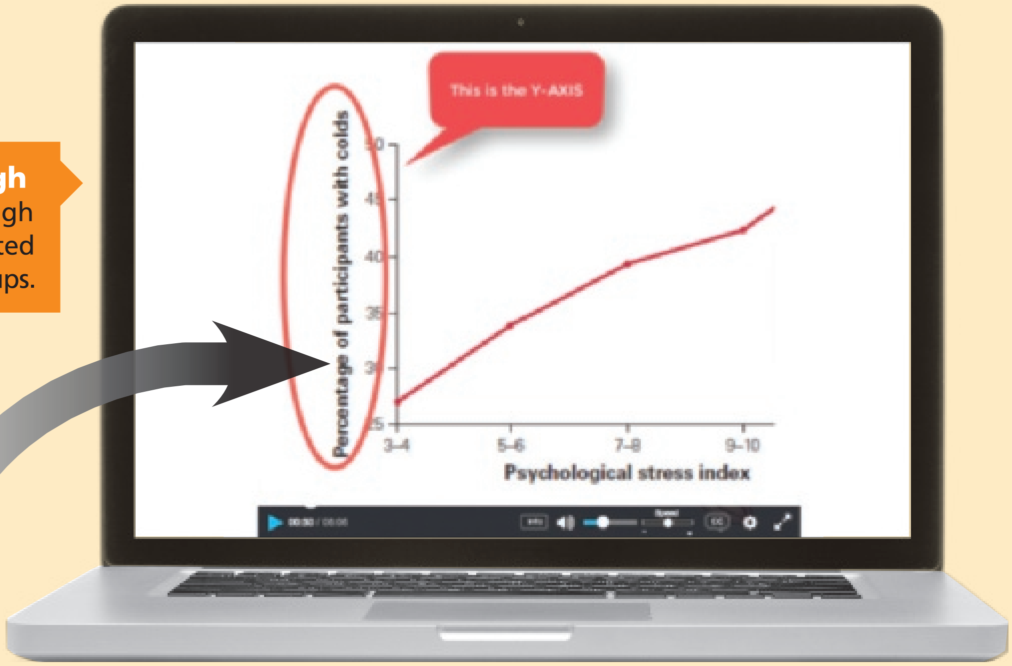
Working with Data questions challenge students to analyze and apply their knowledge of biology to a graph or set of data.



Select **Working with Data** questions are also assignable as activities in Mastering Biology.

Bring the Story to Life with

NEW! Figure Walkthrough videos guide students through key figures with author-narrated explanations and figure markups.



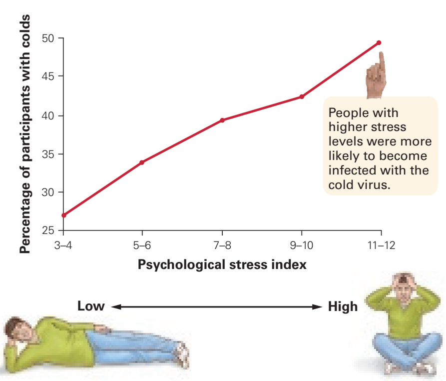


FIGURE 1.10 Correlation between stress level and illness. The graph indicates that people reporting higher levels of stress became infected after exposure to a cold virus more often than did people who reported low levels of stress.

WORKING WITH DATA

This graph groups people with similar but not identical, stress index measures. Why might this have been necessary? If people with stress indices 3 and 4 have the same susceptibility to colds, does this call into question the correlation? Why?

Watch **Correlation** in Mastering Biology

Visualize This questions within select figure legends encourage students to look more closely at figures to more fully understand their content.

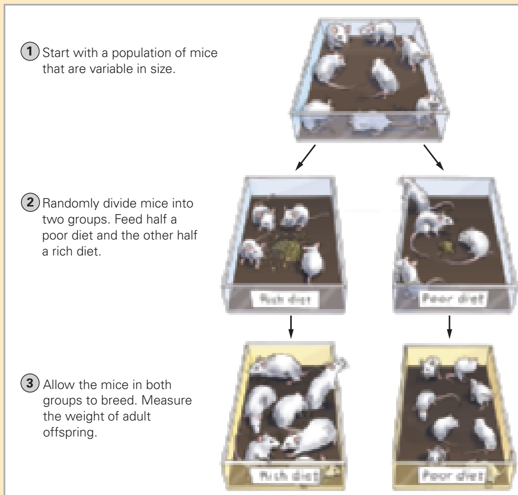


FIGURE 9.9 The environment can have powerful effects on highly heritable traits. If genetically similar populations of mice are raised in radically diverse environments, then differences between the populations are entirely due to environment.

VISUALIZE THIS

What would happen to the appearance of the mice in the next generation on both sides of this figure if all mice were switched back to the normal diet?

Average weight of the mice in the rich-diet environment is twice the average weight of the population in the poor-diet environment. However, there is no genetic difference between the two groups.

Best-in-Class Artwork and Animations

several ingredients, in protein synthesis we use tRNAs that are dedicated to one specific ingredient.) The measuring spoons and cups bring the ingredients to the kitchen counter. Like the ingredients in a cake that can be used in many

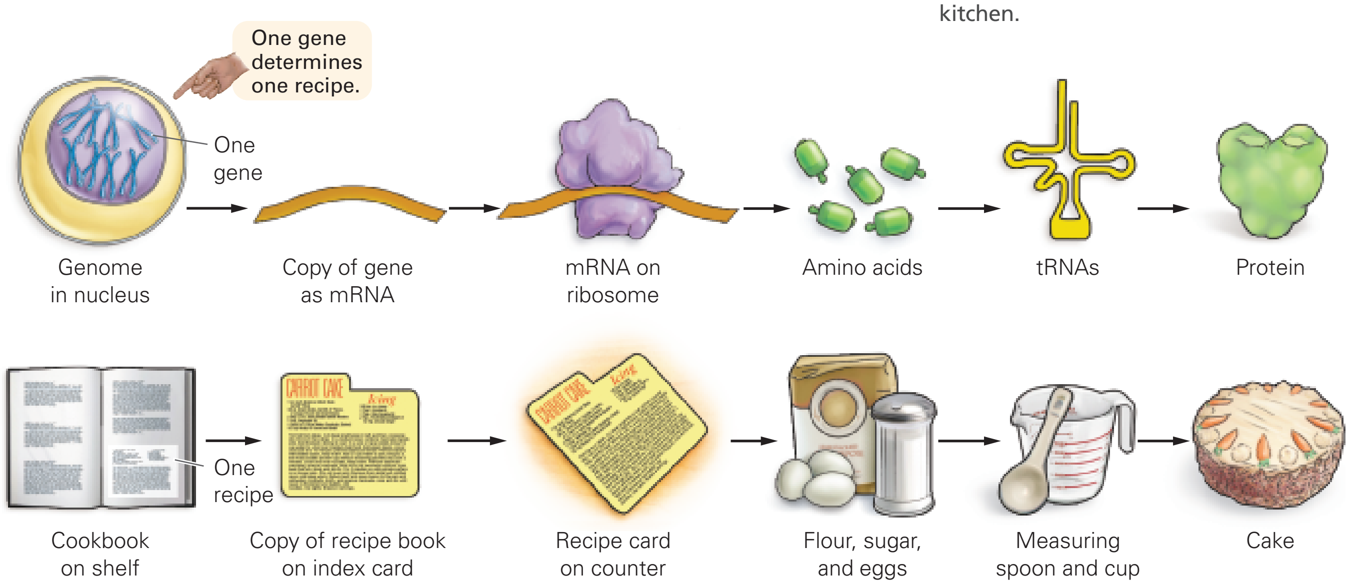


FIGURE 10.6 Protein synthesis and cake baking. Making a protein in a cell is analogous to making a cake in your kitchen.

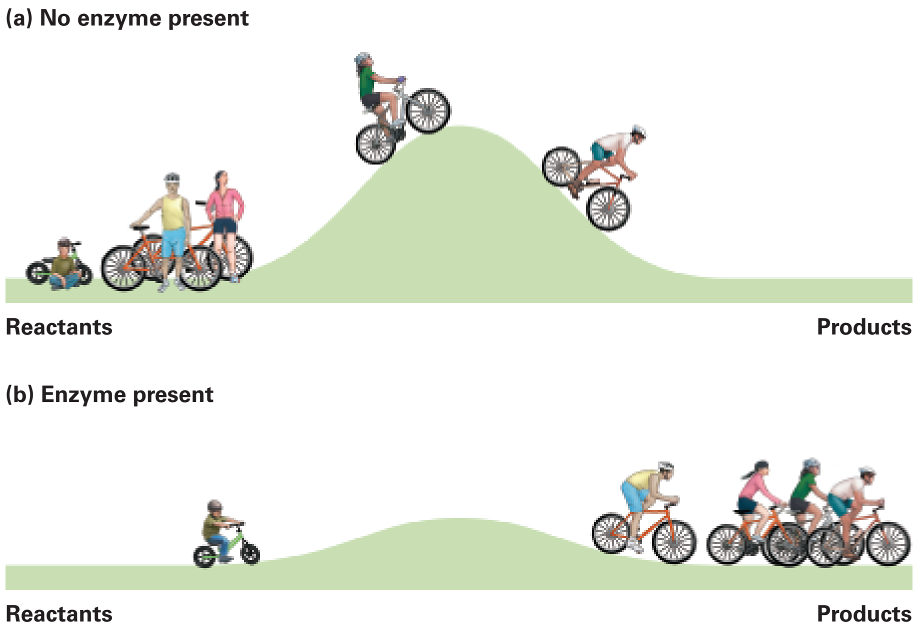


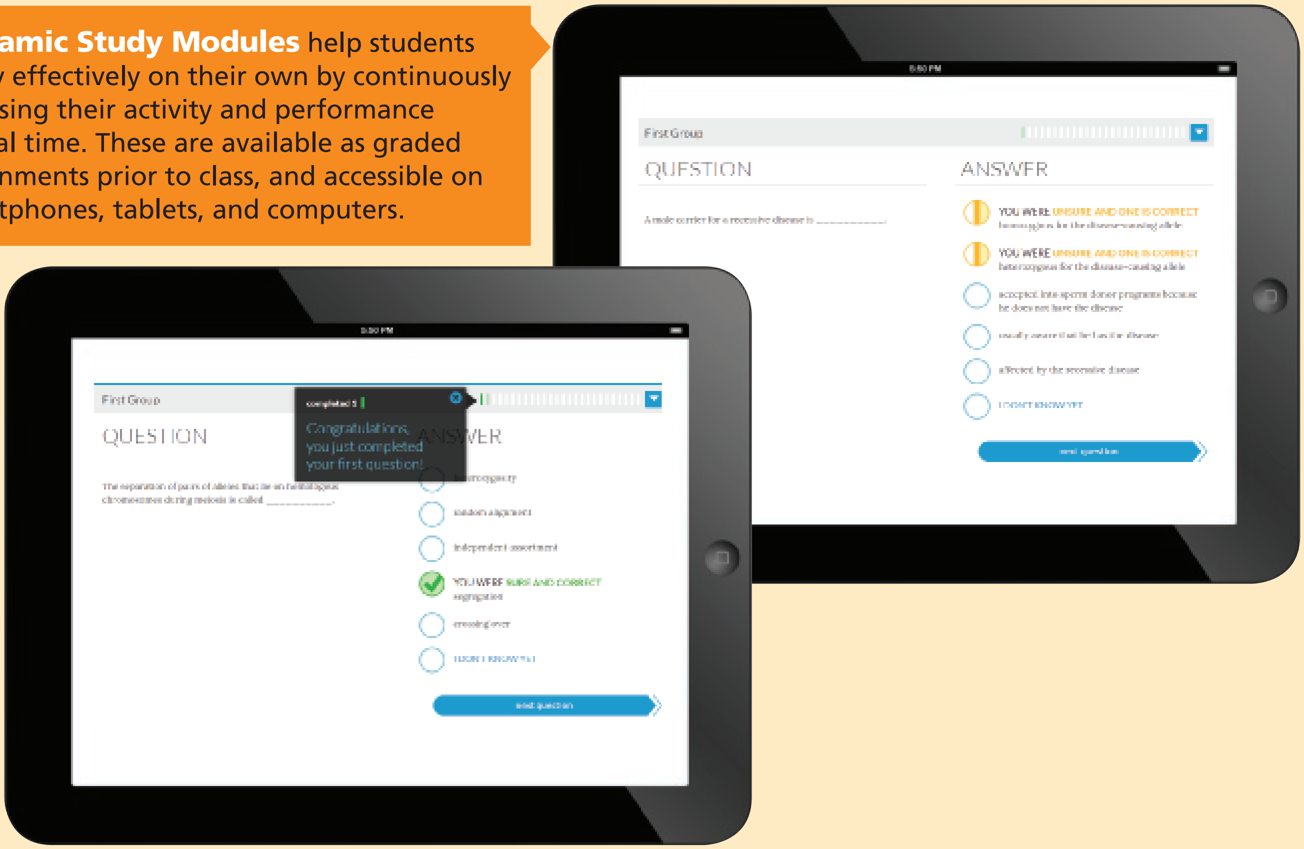
FIGURE 4.1 Activation energy. (a) The activation energy barrier present in cells can be likened to an uphill bike ride. Once you are at the top of the hill, it takes much less energy to continue moving forward. (b) If you smooth out the grade of the hill, more people will make it. In cells, there is an energy barrier that prevents chemical reactions from occurring. Adding an enzyme helps lower this barrier.

Visual Analogies simplify complex topics so students conceptualize and recall important concepts when they need them.

Personalize Learning with

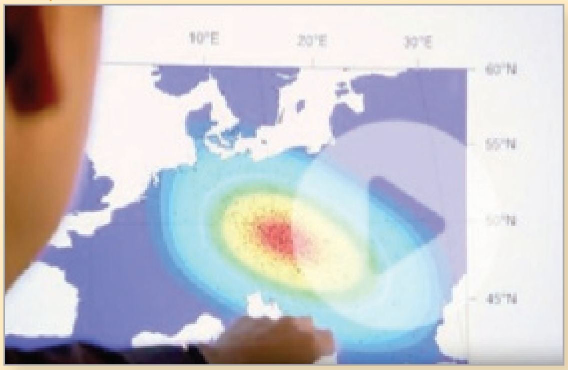
Mastering™ Biology is an online homework, tutorial, and assessment platform that improves results by helping students quickly master concepts and skills. Features in the textbook and Mastering Biology work together, creating a seamless learning suite to support student learning.

Dynamic Study Modules help students study effectively on their own by continuously assessing their activity and performance in real time. These are available as graded assignments prior to class, and accessible on smartphones, tablets, and computers.

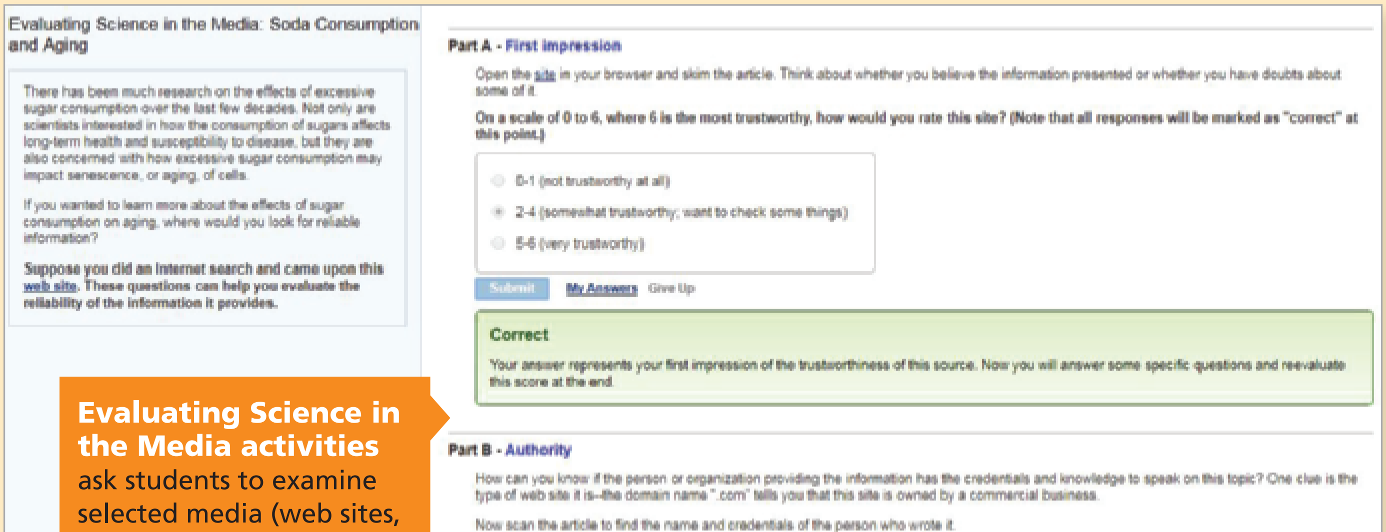


BioFlix™ 3D movie-quality animations help your students visualize complex biology topics and include automatically graded coaching activities with personalized feedback and hints.

Everyday Biology Videos briefly explore interesting and relevant biology topics that relate to concepts that students are learning in class.

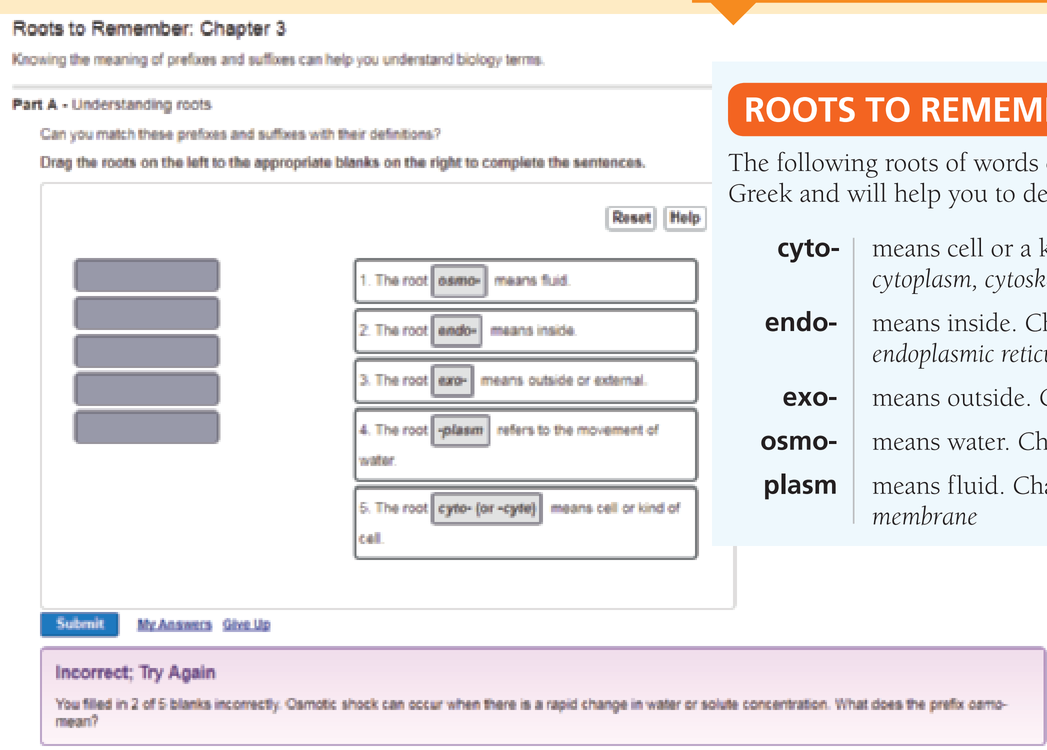


Mastering Biology



Evaluating Science in the Media activities ask students to examine selected media (web sites, articles, videos) with a critical look at the sources and methods used to convey information.

Roots to Remember references appear in context within chapter discussions to help students learn the language of biology using word roots and include assignable activities in Mastering Biology.



ROOTS TO REMEMBER

The following roots of words come mainly from Latin and Greek and will help you to decipher terms:

cyto- means cell or a kind of cell. Chapter terms: *cytoplasm, cytoskeleton*

endo- means inside. Chapter terms: *endocytosis, endoplasmic reticulum*

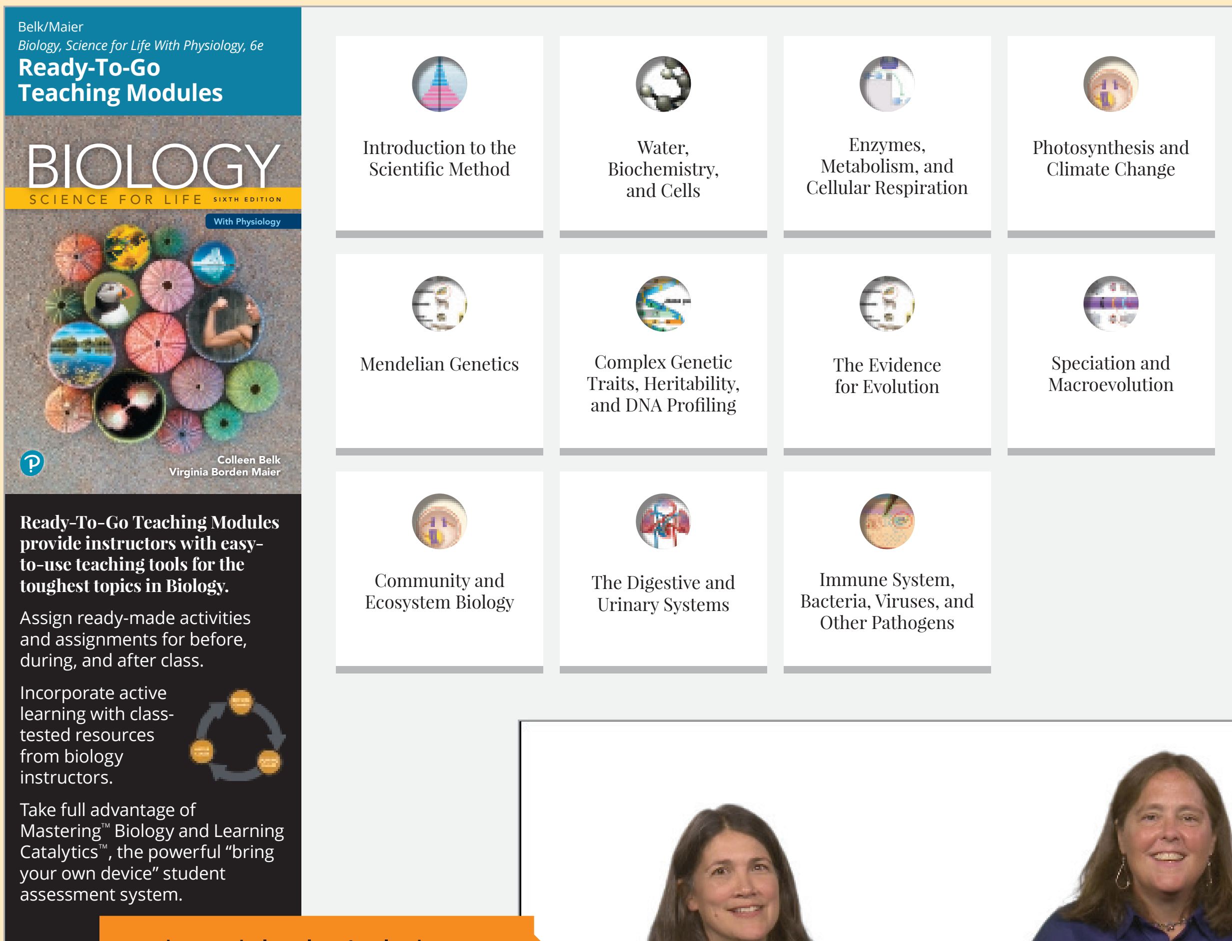
exo- means outside. Chapter term: *exocytosis*

osmo- means water. Chapter term: *osmosis*

plasm means fluid. Chapter term: *cytoplasm, plasma membrane*

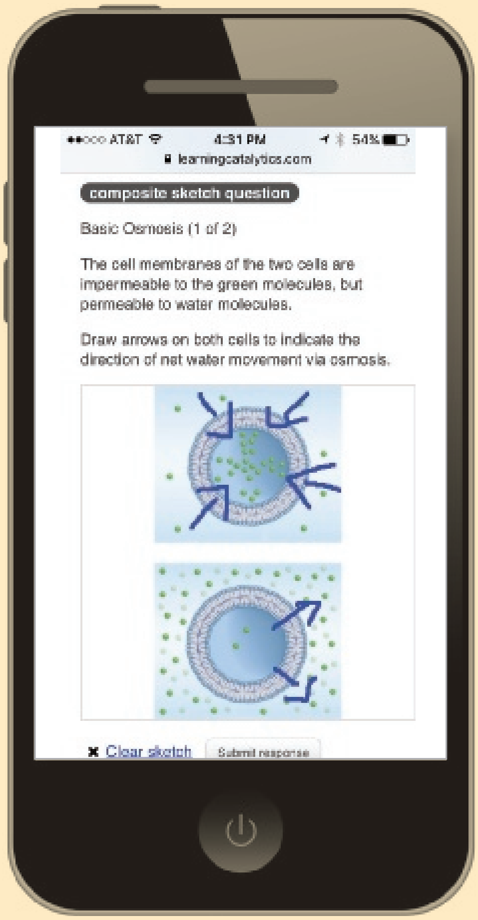
Bring Science to Life with

NEW! Ready-to-Go Teaching Modules make use of teaching tools for before, during, and after class, including new ideas for in-class activities. The 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.



Each module also includes a **NEW! Teaching Tips** video, in which Colleen and Ginny provide additional background and helpful hints for presenting the content in the context of particular storylines, in the classroom or online.

Active Learning Resources



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.

GO FIND OUT

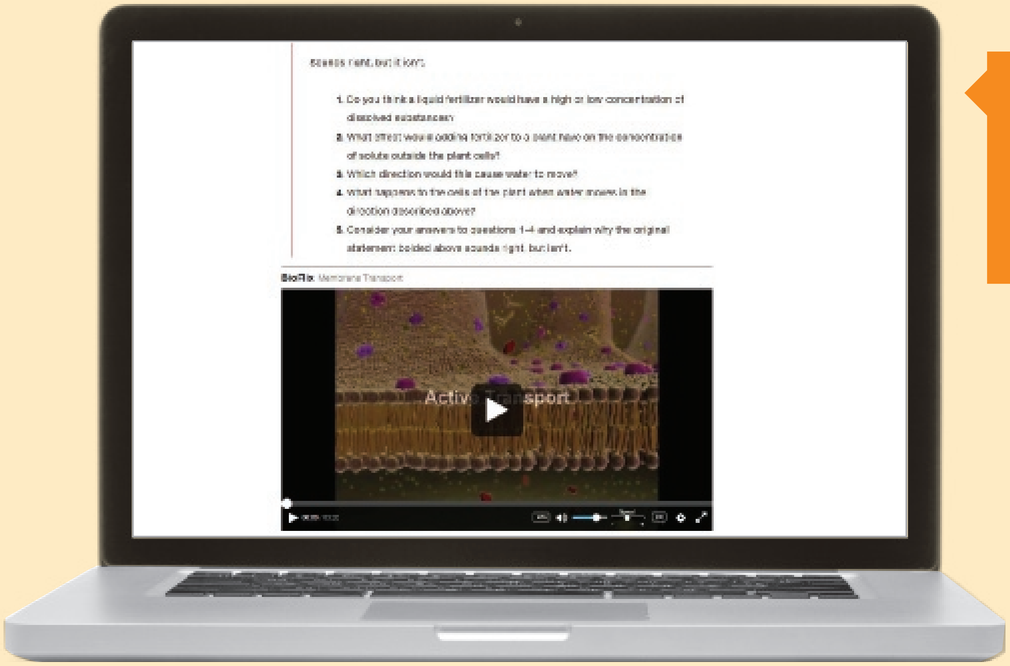
1. Select one supplement you have wondered about and spend a few minutes doing some web-based research on whether the claims made on its label are backed up by scientific evidence.
2. Some cities have banned restaurants from using trans fats when cooking. Has such a ban been enacted in your city? Do you think the government should be involved in regulating the use of trans fats? Why or why not?

Bring ideas for active learning into your class with **NEW! Go Find Out** activities, located at the conclusion of each chapter.

Additional Resources:

- **"Flipped Classroom" Instructor's Manual** includes many activities that have been tested in the authors' own classes. Each text chapter is supplemented with a selection of in-class activities, suggestions for student "pre-work" outside of class, media references, and more. The new edition also includes implementation suggestions for the in-text "Go Find Out" activities.
- **PowerPoint presentations** centered around the storylines accompany each chapter to help instructors highlight the relevance of biology to everyday life.

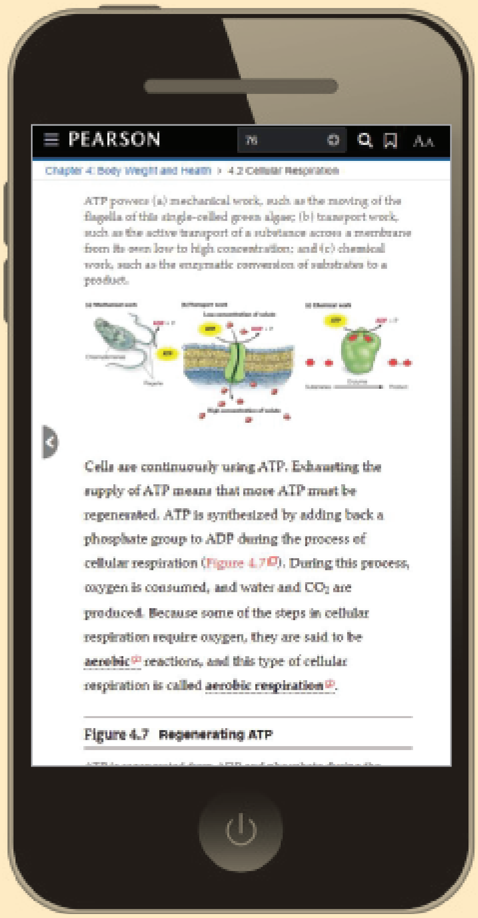
Access the Text Anytime, Anywhere with Pearson eText



NEW! Pearson eText integrates rich media assets, including new author-created Figure Walkthroughs into an electronic version of the text.

Pearson eText Mobile App offers offline access and can be downloaded for most iOS and Android phones/tablets from the Apple App Store or Google Play, providing:

- Seamlessly integrated videos and other rich media assets
- ADA accessibility (screen-reader ready)
- Configurable reading settings, including resizable type and night reading mode
- Instructor and student note-taking, highlighting, bookmarking, and search capabilities.

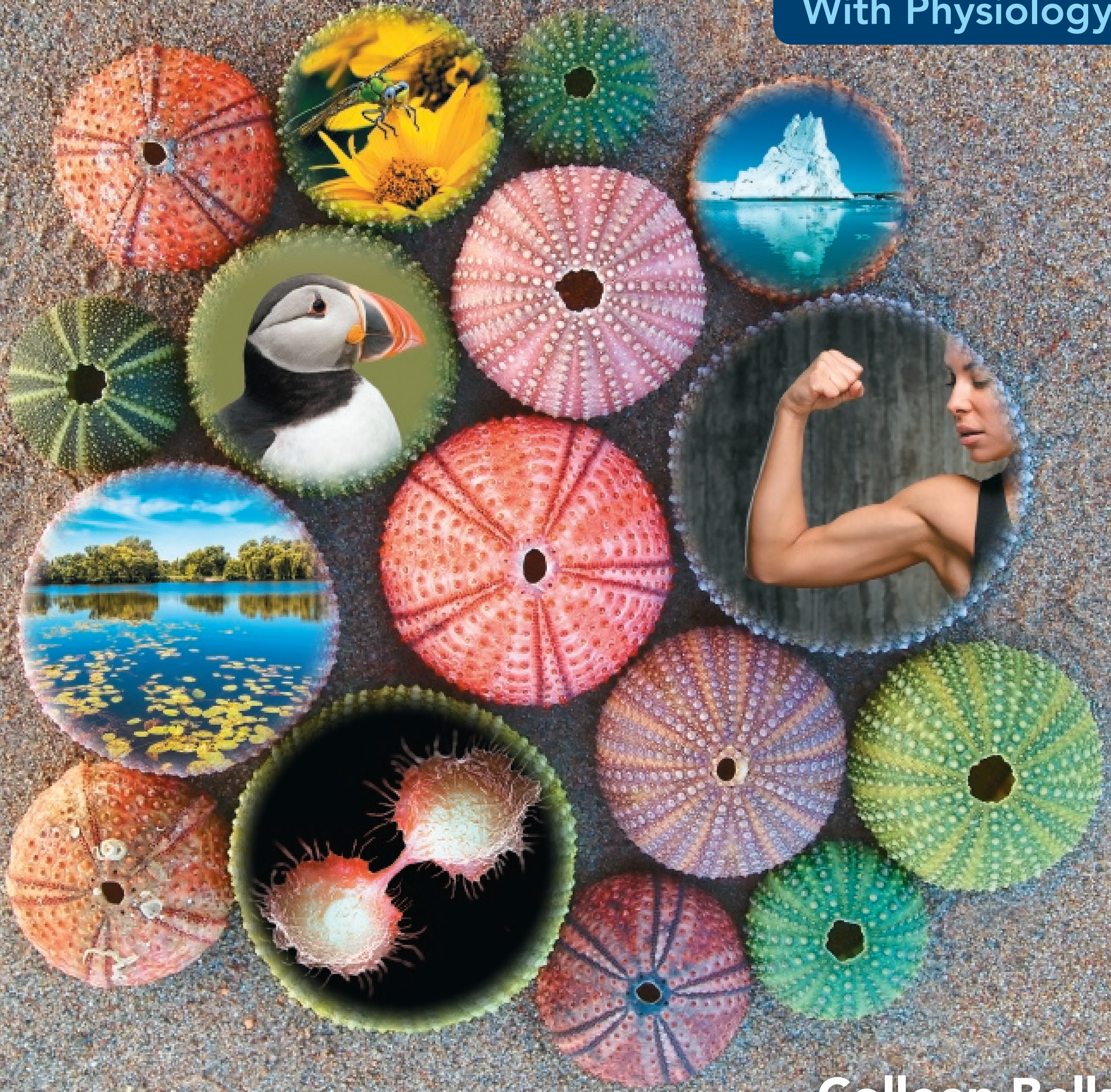


BIOLOGY

SCIENCE FOR LIFE

SIXTH EDITION

With Physiology



Colleen Belk
Virginia Borden Maier

1

Can Science Cure the Common Cold?

Another cold! What can I do?

Take massive doses of vitamin C?

How would a scientist determine which advice is best?

Introduction to the Scientific Method

We have all been there—you just recover from one bad head cold and on a morning soon after you notice that scratchy feeling in your throat that signals a new one is about to begin. It is always at the worst time, too, when you have an important exam coming up, a term paper due, and a packed social calendar. Why are you sick yet again? What can you do about it?

If you ask your friends and relatives, you will hear the usual advice on how to prevent and treat colds: Take massive doses of vitamin C. Suck on zinc lozenges. Drink plenty of echinacea tea. Meditate. Spend more time with others. Get more rest. Exercise vigorously. Put that hat on when you go outside! You are left with an overwhelming list of options, often contradictory and some contrary to common sense. If you keep up with health news, you may be even more confused. One website reports that a popular over-the-counter cold treatment is effective, whereas a local TV news story details the risks of using this remedy and highlights its ineffectiveness. How do you decide what to do?

Faced with this bewildering situation, most people follow the advice that makes the most sense to them, and if they find they still feel terrible, they try another remedy. Testing ideas and discarding ones that don't work is a kind of "everyday science." We use this trial-and-error technique extensively, but it has its limitations—for example, even if you feel better after trying a new cold treatment, you can't know if your recovery occurred because the treatment was effective or because the cold was ending anyway.

Professional scientists conduct a more refined version of this process—using strategies that help eliminate other possible explanations for a result. And although some fields of science may use unfamiliar words or complicated and expensive equipment, the basic process for testing ideas is simple and universal to all areas of science. An understanding of this process can help you evaluate information about many issues that may concern and intrigue you—from health issues, to global warming, to the origin of life and the universe—with more confidence. In this chapter, we introduce you to the powerful process scientists use by asking the question we've considered here: Is there a cure for the common cold?

1.1 The Process of Science

The term *science* can refer to a body of knowledge—for example, the science of **biology** is the study of living organisms. You may believe that science requires near-perfect recall of specific sets of facts about the world. In reality, this goal is impossible and unnecessary—we do have reference books, after all. The real action in science is not memorizing what is already known but using the process of science to discover something previously unknown.

This process—making observations of the world, proposing ideas about how something works, testing those ideas, and discarding (or modifying) our ideas in response to the test results—is the essence of the **scientific method.** The scientific method allows all of us to solve problems and answer questions efficiently and effectively. Can we use the scientific method to solve the complicated problem of preventing and treating colds?

bio- means life.

-ology means the study of or branch of knowledge about.

The Nature of Hypotheses

When your mom says "wear a hat," that generates a question: Does wearing a hat in the winter actually prevent colds? That your mom believes the answer to this question is "yes" means that she has developed an understanding of how a body resists colds. This understanding is known as a **hypothesis—**that is, an idea about how things work (**FIGURE 1.1**). Science is the process of putting these ideas to the test.

hypo- means under, below, or basis.

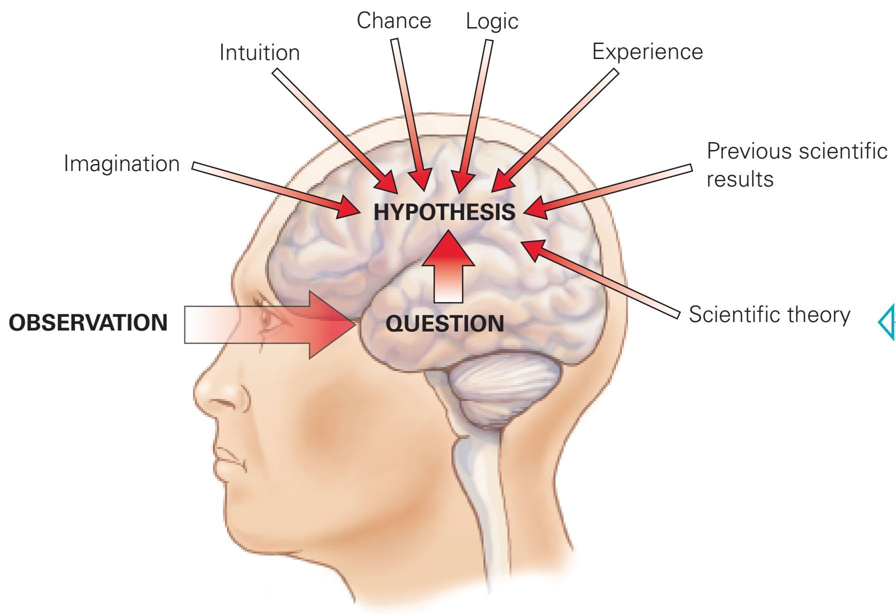


FIGURE 1.1 Hypothesis generation. All of us generate hypotheses. Many different factors, both logical and creative, influence the development of a hypothesis. Scientific hypotheses are both testable and falsifiable.

VISUALIZE THIS

Most colleges require students who are science majors to take courses in the humanities and social sciences, just as they require students in these majors to take science courses. What aspects of hypothesis generation listed in this figure are improved by study in the humanities and social sciences?

Hypotheses in biology come from knowledge about how the body and other biological systems work, experiences in similar situations, our understanding of other scientific research, and logical reasoning; they are also shaped by our creative mind. When your mom tells you to dress warmly to avoid colds, she is basing her advice on the following hypothesis: Becoming chilled makes you more susceptible to illness.

The hallmark of science is that hypotheses are subject to rigorous testing. Therefore, scientific hypotheses must be **testable—**it must be possible to evaluate a hypothesis through observations of the measurable universe. Not all hypotheses are testable. For instance, the statement that "colds are generated by disturbances in psychic energy" is not a scientific hypothesis because psychic energy has not been demonstrated to exist and thus cannot be measured by any known instrument.

A scientific hypothesis must also be **falsifiable;** that is, an observation or set of observations could potentially prove the hypothesis is false. The hypothesis that exposure to cold temperatures increases your susceptibility to colds is falsifiable; we can imagine an observation that would cause us to reject this hypothesis (for instance, the observation that people exposed to cold temperatures do not catch more colds than people protected from chills). Of course, not all hypotheses are proved false, but it is essential in science that incorrect ideas be discarded, which can occur only if it is *possible* to prove those ideas false. Lack of falsifiability is why hypotheses that require the intervention of a supernatural force cannot be tested scientifically. If something is **supernatural,** it is not constrained by any laws of nature, and therefore its behavior cannot be predicted using our current understanding of the natural world. Because a supernatural force can cause any possible result, hypotheses that rely on supernatural forces can never be falsified.

Finally, statements that are value judgments, such as, "It is wrong to cheat on an exam," are not scientific because different people have different ideas about right and wrong. It is impossible to falsify these types of statements. To find answers to questions of morality, ethics, or justice, we turn to other methods of gaining understanding—such as philosophy and religion.

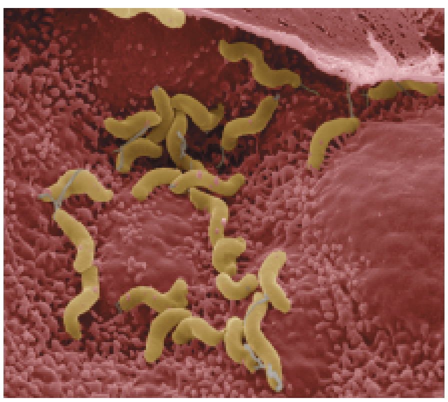
Scientific Theories

Most hypotheses fit into a larger picture of scientific understanding. We can see this relationship when examining how research upended a commonly held belief about diet and health—that chronic stomach and intestinal inflammation was caused by eating too much spicy food. This belief directed the standard medical practice for stomach ulcer treatment for decades. Patients with ulcers were prescribed drugs that reduced stomach acid levels and advised to avoid eating acidic or highly spiced foods. These treatments were rarely successful, and ulcers were considered chronic problems.

In 1982, Australian scientists Robin Warren and Barry Marshall discovered that the bacterium *Helicobacter pylori* was present in nearly all samples of ulcer tissue that they examined (**FIGURE 1.2**). From this observation, Warren and Marshall reasoned that *H. pylori* infection—invasion of the stomach wall by the bacteria—was the cause of most ulcers. If Warren and Marshall's hypothesis was correct, then stomach ulcers are best treated by drugs that kill bacteria, not by dietary changes. Marshall first tested this hypothesis on himself by consuming live *H. pylori*. He subsequently suffered from acute stomach inflammation, which was cured by a course of antibiotics.

Warren and Marshall's colleagues were at first unconvinced that ulcers could have such a simple cause. But today, the hypothesis that *H. pylori* infection is responsible for most ulcers is accepted as fact. Why? First, no reasonable

(a)



(b)

FIGURE 1.2 A scientific breakthrough.
(a) *Helicobacter pylori* on stomach lining (image from electron microscope).
(b) Robin Warren and Barry Marshall won the 2005 Nobel Prize in Medicine for their discovery of the link between *H. pylori* and ulcers.

alternative hypotheses about the causes of ulcers (for instance, consumption of spicy foods) has been consistently supported by hypothesis tests; and second, Warren and Marshall's hypothesis has not been rejected—that is, there have been no carefully designed experiments that show that antibiotic treatment of *H. pylori* fails to cure most ulcers.

Third, the relationship between *H. pylori* and ulcers is considered fact because this understanding conforms to a well-accepted scientific principle—namely, the germ theory of disease. A **scientific theory** is an explanation for a set of related observations that is based on well-supported hypotheses from several different, independent lines of research. The basic premise of germ theory is that microorganisms (that is, organisms too small to be seen with the naked eye) are the cause of some or all human diseases.

The biologist Louis Pasteur first observed that bacteria cause milk to become sour. From this observation, he reasoned that these same types of organisms could injure humans. Later, Robert Koch demonstrated a link between anthrax bacteria and a specific set of fatal symptoms in mice, providing additional evidence for the theory. Germ theory is further supported by the observation that antibiotic treatment that targets particular microorganisms can cure certain illnesses—as is the case with bacteria-caused ulcers.

In everyday speech, the word *theory* is synonymous with untested ideas based on little information. In contrast, scientists use the term when referring to ideas that form the basis of their understanding of the world. The supporting foundation of all scientific theories is multiple hypothesis tests.

The Logic of Hypothesis Tests

One common hypothesis about cold prevention is that taking vitamin C supplements keeps you healthy. This hypothesis is very appealing, especially given the following generally accepted facts:

1. Fruits and vegetables contain a lot of vitamin C.
2. People with diets rich in fruits and vegetables are generally healthier than people who skimp on these food items.
3. Vitamin C is known to be an anti-inflammatory agent, reducing throat and nose irritation.

With these facts in mind, we can state the following testable and falsifiable hypothesis: *Consuming vitamin C decreases the risk of catching a cold.* This hypothesis makes sense given the statements just listed and the experiences of the many people who insist that vitamin C keeps them healthy.

The process we used to construct the hypothesis above is called **inductive reasoning**—combining a series of specific observations (here, statements 1–3) to discern a general principle. Inductive reasoning is an essential tool for understanding the world. However, a word of caution is in order: Just because the inductive reasoning that led to a hypothesis seems to make sense does not mean that the hypothesis is necessarily true.

induc- means to rely on reason to derive principles (also, to cause to happen).

Consider the ancient hypothesis that the sun revolves around Earth. This hypothesis was induced based on the observations that the sun rose in the east every morning, traveled across the sky, and set in the west every night. For almost all of history, this hypothesis was considered to be a "fact" by nearly all of Western society. It wasn't until the early seventeenth century that this hypothesis was overturned—as the result of Galileo Galilei's observations of Venus. His observations proved false the hypothesis that the sun revolved around Earth. Galileo's work helped to confirm the more modern hypothesis, proposed by Nicolaus Copernicus, that Earth revolves around the sun, and rotates as it does so.

deduc- means to reason out, working from facts.

So, even though the hypothesis about vitamin C is sensible, it needs to be tested to see if it can be proved false. Hypothesis testing is based on **deductive reasoning** or deduction. Deduction involves using a general principle to predict an expected observation. This **prediction** concerns the outcome of an action, test, or investigation. In other words, the prediction is the result we expect from a hypothesis test.

Deductive reasoning takes the form of "if/then" statements. That is, if our idea is correct, then we predict a specific outcome from a hypothesis test. A prediction based on the vitamin C hypothesis could be: *If* vitamin C decreases the risk of catching a cold, *then* people who take vitamin C supplements with their regular diets will experience fewer colds than will people who do not take supplements.

Deductive reasoning, with its resulting predictions, is a powerful method for testing hypotheses. However, the structure of such a statement means that hypotheses can be clearly rejected if untrue but impossible to prove if true. This shortcoming can be illustrated using the if/then statement concerning vitamin C and colds (**FIGURE 1.3**).

Consider the possible outcomes of a comparison between people who supplement with vitamin C and those who do not. People who take vitamin C supplements may suffer through more colds than people who do not; they may have the same number of colds as the people who do not supplement; or supplementers may in fact experience fewer colds. What does each of these results tell us about the hypothesis?

If, in a well-designed test, people who take vitamin C have more colds or the same number of colds as those who do not supplement, then the hypothesis that vitamin C provides protection against colds can be rejected. But what if people who supplement with vitamin C *do* experience fewer colds? If this is the case, then we can only say that the hypothesis has been supported and not disproven.

Why is it impossible to say from this experimental result that the hypothesis that vitamin C prevents colds is true? Because there are **alternative hypotheses** that explain why people with different vitamin-taking habits vary in their cold susceptibility. In other words, demonstrating the truth of the *then* portion of a deductive statement does not prove that the *if* portion is true.

Consider the alternative hypothesis that frequent exercise reduces susceptibility to catching a cold. And suppose that people who take vitamin C supplements are more likely to engage in regular exercise. If both of these hypotheses are true, then the prediction that vitamin C supplementers experience fewer colds than people who do not supplement would be true but not because the original hypothesis (vitamin C reduces the risk of colds) is true. Instead, people who take vitamin C supplements experience fewer colds because they are also more likely to exercise, and it is exercise that reduces cold susceptibility.

A hypothesis that seems to be true because it has not been rejected by an initial test may be rejected later because of a different test. This is what happened to the hypothesis that vitamin C consumption reduces susceptibility to colds. The argument for the power of vitamin C was popularized in 1970 by

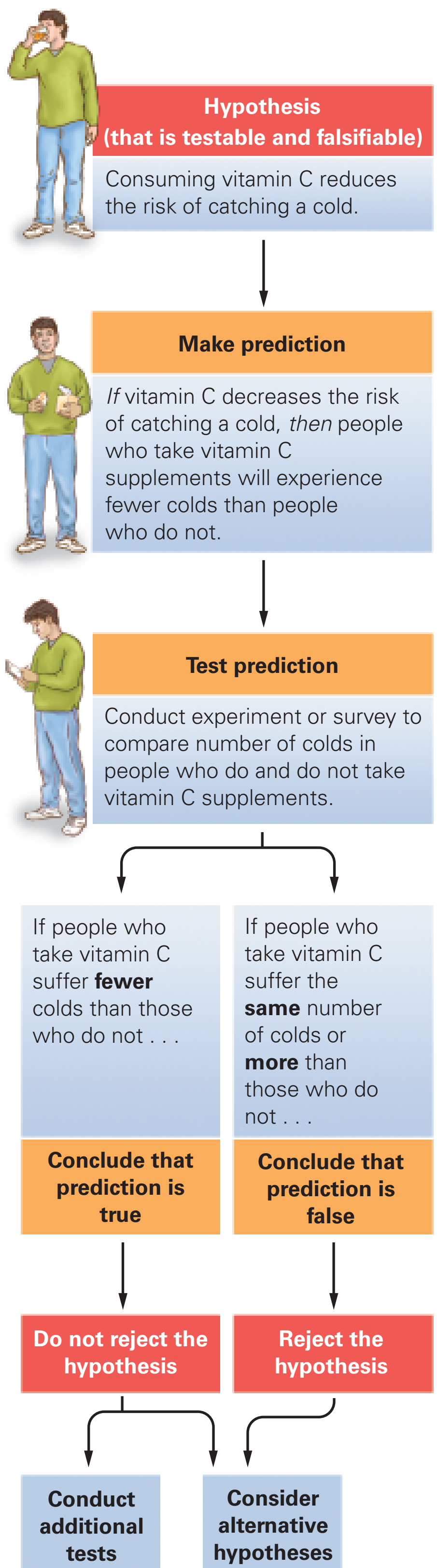


FIGURE 1.3 The scientific method. Tests of hypotheses follow a logical path. This flowchart illustrates the process of deduction as practiced by scientists.

VISUALIZE **THIS**

According to this flowchart, scientists should consider alternative hypotheses even if their hypothesis is supported by their research. Explain why this is the case.

Nobel Prize–winning chemist Linus Pauling. Pauling based his assertion—that large doses of vitamin C reduce the incidence of colds by as much as 45%—on the results of a few studies that had been published between the 1930s and 1970s. However, repeated, careful tests of this hypothesis have since failed to support it. In many of the studies Pauling cited, it appears that alternative hypotheses explain the difference in cold incidence between vitamin C supplementers and nonsupplementers. Today, most health scientists agree that the hypothesis that vitamin C prevents colds has been convincingly falsified.

The example of the vitamin C hypothesis also highlights a challenge of communicating scientific information. You can see why the belief that vitamin C prevents colds is so widespread. If you don't know that scientific knowledge relies on rejecting incorrect ideas, a book by a Nobel Prize–winning scientist may seem like the last word on the benefits of vitamin C. It took many years of careful research to show that this "last word" was, in fact, wrong.

Got It?

1. A(n) __________ is a proposed explanation for how things work.
2. A statement that is "falsifiable" must be able to be __________ __________.
3. A statement that is "testable" must be able to be evaluated through __________ of the known universe.
4. Deductive reasoning relies on testing the __________ of a hypothesis test.
5. If a hypothesis test returns the predicted results, the hypothesis is supported but not definitively __________.

1.2 Hypothesis Testing

The previous discussion may seem discouraging: How can scientists determine the truth of any hypothesis when there is a chance that the hypothesis could be falsified by a later test? Even if one of the hypotheses about cold prevention is supported, does the difficulty of eliminating alternative hypotheses mean that we will never know which approach is truly best? The answer is yes—and no.

Hypotheses cannot be proven absolutely true; it is always possible that the true cause of a phenomenon may be found in a hypothesis that has not yet been tested. However, in a practical sense, a hypothesis can be proven beyond a reasonable doubt. That is, when one hypothesis has not been disproven through repeated testing and all reasonable alternative hypotheses have been eliminated, scientists accept that the well-supported hypothesis is, in a practical sense, true. The hypothesis that *H. pylori* infection—and not spicy food—causes the majority of stomach ulcers is accepted as true. *Truth* in science can therefore be defined as *what we know and understand based on all currently available information*. But scientists remain open to the possibility that what seems true now may someday be proven false.

An effective way to test many hypotheses is through rigorous scientific experiments. Experimentation has enabled scientists to prove beyond a reasonable doubt that the common cold is caused by a virus. A virus is a microscopic entity with a simple structure—it typically consists of a short strand of genetic material and a few proteins encased in a relatively tough protein shell, sometimes surrounded by a membrane. A virus must infect a host cell to reproduce. Of the more than 200 types of viruses that are known to cause the common cold, most infect the cells in our noses and throats. The

VISUALIZE **THIS**

Find two points in this process where intervention by drugs or other treatment could disrupt either the virus or the immune response and therefore lead to fewer cold symptoms.

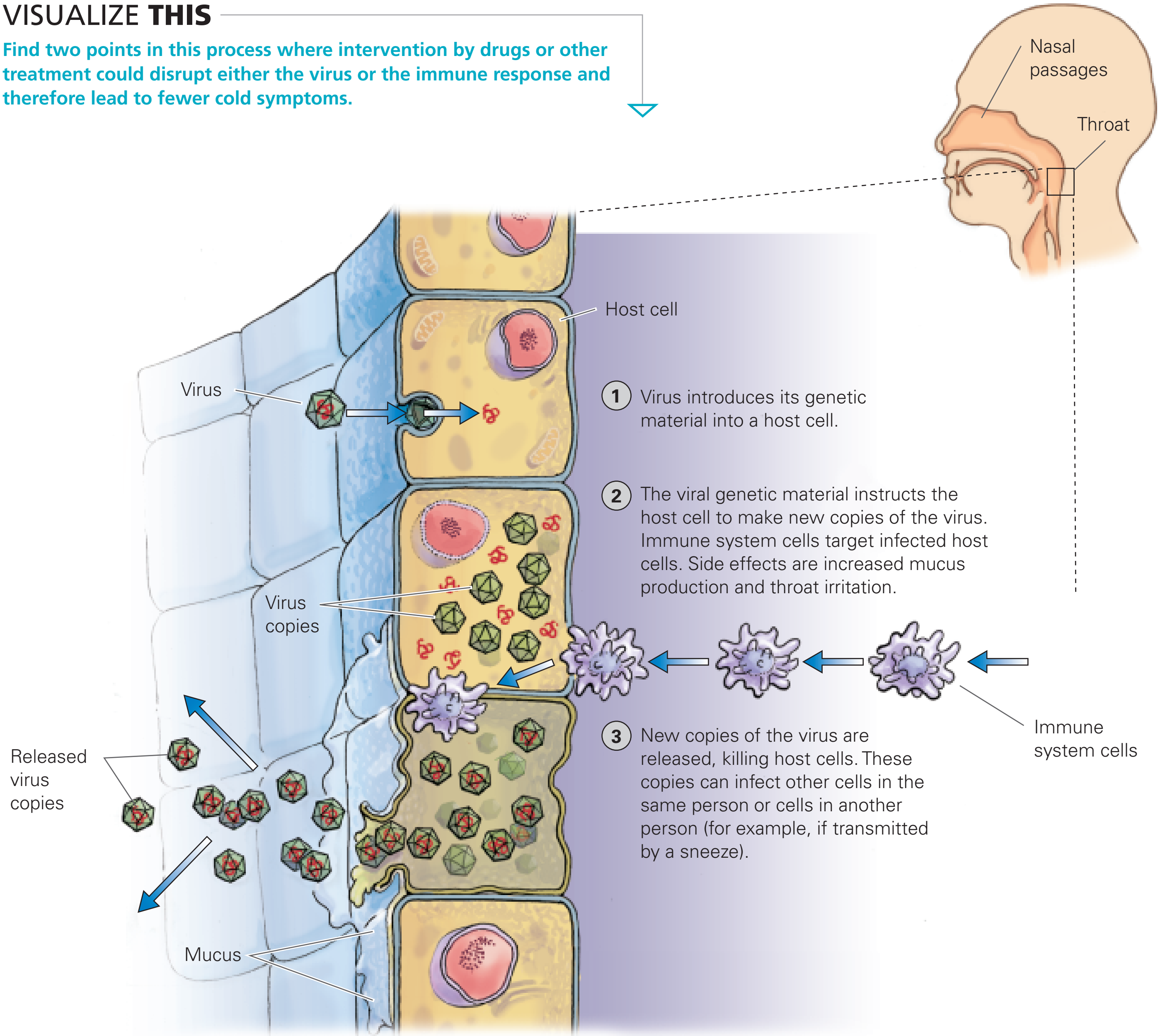


FIGURE 1.4 A cold-causing virus. A rhinovirus causes illness by invading nose and throat cells and using them as "factories" to make virus copies. Cold symptoms result from immune system attempts to eliminate the virus.

sneezing, coughing, congestion, and sore throat of a cold appear to result from the body's protective response to a viral invasion, established by our immune system (**FIGURE 1.4**).

As you may know, if we survive certain viral infections, we are unlikely to experience a recurrence of the disease the virus causes. For example, it is extremely rare to suffer from chicken pox twice because one exposure to the chicken pox virus (through either infection or vaccination) usually provides lifelong immunity to future infection. However, for common viruses, like the one that causes flu, the large number of infections that occur each year means that there are many varieties of the virus. We require yearly flu vaccinations because the virus type that is most common changes slightly over time. The huge variety of cold viruses makes immunity to the common cold—and the development of a vaccine to prevent it—improbable. Scientists thus focus their experimental research about common colds on methods of prevention and treatment.

The Experimental Method

Experiments are sets of actions or observations designed to test specific hypotheses. Generally, an experiment allows a scientist to control the conditions that may affect the subject of study. Manipulating the environment allows a scientist to eliminate some alternative hypotheses that may explain the result.

Experimentation in science is analogous to what a mechanic does when diagnosing a car problem. There are many reasons why a car engine might not start. If a mechanic begins by tinkering with numerous parts to apply all possible fixes before restarting the car, she will not know what exactly caused the problem (and will have an unhappy customer who is charged for unnecessary parts and labor). Instead, a mechanic begins by testing the battery for power; if the battery is charged, then she checks the starter motor; if the car still doesn't start, she looks over the fuel pump; and she continues in this manner until identifying the problem. Likewise, a scientist systematically attempts to eliminate hypotheses that do not explain a particular phenomenon.

Not all scientific hypotheses can be tested through experimentation. For instance, hypotheses about how life on Earth originated or the cause of dinosaur extinction are usually not testable in this way. These hypotheses are instead tested using careful observation of the natural world. For instance, the examination of fossils and other geological evidence allows scientists to test hypotheses regarding the extinction of the dinosaurs (**FIGURE 1.5**).

FIGURE 1.5 Testing hypotheses through observation. Not all hypotheses can be tested experimentally. Questions about the evolutionary history of life are tested by examining the data provided by the fossil record.

The information collected by scientists during hypothesis testing is known as **data.** The data are collected on the **variables** of the test, that is, any factor that can change in value under different conditions. In an experimental test, scientists manipulate an **independent variable** (one whose value can be freely changed) to measure its effect on a **dependent variable.** The dependent variable may or may not be influenced by changes in the independent variable, but it cannot be systematically changed by the researchers. For example, to measure the effect of vitamin C on cold prevention, scientists can vary individuals' vitamin C intake (the independent variable) and measure their susceptibility to illness upon exposure to a cold virus (the dependent variable).

Data obtained from well-designed experiments should allow researchers to convincingly reject or support a hypothesis. This is more likely to occur if the experiment is controlled.

Controlled Experiments

Control has a specific meaning in science. A **control** for an experiment is a subject similar to an experimental subject except that the control is not exposed to experimental treatment. Controlled experiments are thus designed to eliminate as many alternative hypotheses as possible.

Once subjects are enlisted in an experiment, they are assigned to a control or an experimental group. If members of the control and experimental groups differ at the end of a well-designed test, then the difference is likely to be due to the experimental treatment.

Our question about effective cold treatments lends itself to a variety of controlled experiments on possible drug therapies. For example, an extract of *Echinacea purpurea* (a common North American prairie plant) in the form of echinacea tea has been promoted as a treatment to reduce the likelihood as well as the severity and duration of colds (**FIGURE 1.6**). A scientific

FIGURE 1.6 *Echinacea purpurea*, an American coneflower. Extracts from the leaves and roots of this plant are among the most popular herbal remedies sold in the United States.