Anne Houtman ◦ Megan Scudellari ◦ Cindy Malone

BIOLOGY NOW

SECOND EDITION

Biology Now

Biology Now

ANNE HOUTMAN
ROSE-HULMAN INSTITUTE OF TECHNOLOGY

MEGAN SCUDELLARI
SCIENCE JOURNALIST

CINDY MALONE
CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

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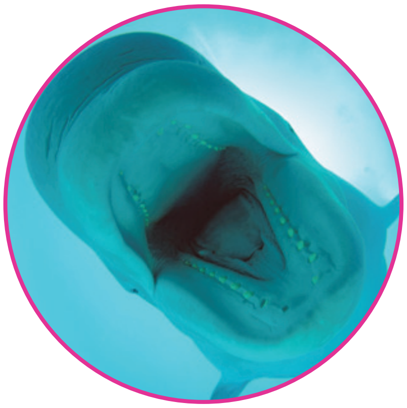

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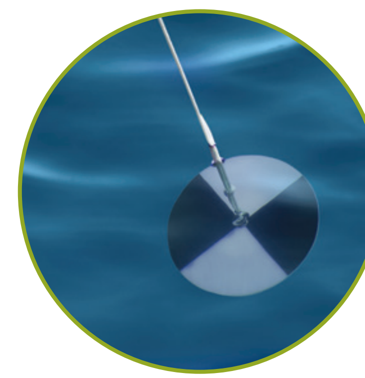


Here and Gone

About the Authors

ANNE HOUTMAN is Provost and Vice President of Academic Affairs at Rose-Hulman Institute of Technology, where she is also a full professor of biology. Anne has over 20 years of experience teaching nonmajors biology at a variety of private and public institutions, which gives her a broad perspective of the education landscape. She is strongly committed to evidence-based, experiential education and has been an active participant in the national dialogue on STEM (science, technology, engineering, and math) education for over 20 years. Anne's research interests are in the ecology and evolution of hummingbirds. She grew up in Hawaii, received her doctorate in zoology from the University of Oxford, and conducted postdoctoral research at the University of Toronto.

MEGAN SCUDELLARI is an award-winning freelance science writer and journalist based in Boston, Massachusetts, specializing in the life sciences. She has contributed to *Newsweek*, *Scientific American*, *Discover*, *Nature*, and *Technology Review*, among others, and she was a health columnist for the *Boston Globe*. For five years she worked as a correspondent and later as a contributing editor for *The Scientist* magazine. In 2013, she was awarded the prestigious Evert Clark/Seth Payne Award in recognition of outstanding reporting and writing in science. She has also received accolades for investigative reporting on traumatic brain injury and a feature story on prosthetics bestowed with a sense of touch. Megan received an MS from the Graduate Program in Science Writing at the Massachusetts Institute of Technology and worked as an educator at the Museum of Science, Boston.

CINDY MALONE began her scientific career wearing hip waders in a swamp behind her home in Illinois. She earned her BS in biology at Illinois State University and her PhD in microbiology and immunology at UCLA. She continued her postdoctoral work at UCLA in molecular genetics. She is currently a distinguished educator and a professor at California State University, Northridge, where she is the director of the CSUN-UCLA Stem Cell Scientist Training Program funded by the California Institute for Regenerative Medicine. Her research is aimed at training undergraduates and master's degree candidates to understand how genes are regulated through genetic and epigenetic mechanisms that alter gene expression. She has been teaching nonmajors biology for almost 20 years and has won teaching, mentorship, and curriculum enhancement awards at CSUN.

Preface

A good biology class can improve the quality of students' lives. Biology is a part of so many decisions that students will need to make as individuals and as members of society. It helps parents to see the value of vaccinating a child, because they will understand what viruses are and how the immune system works. It helps homeowners in Texas, Florida, and Puerto Rico as they decide how to respond to the ongoing cleanup from 2017's Hurricanes Harvey, Irma, and Maria, because they understand how an ecosystem functions. It helps students make more informed decisions about their own nutrition because they understand the effects of fat, cholesterol, and vitamins, and minerals on our health. The examples are endless. Making informed decisions on these real-world issues requires students to be comfortable with scientific concepts and the process of scientific discovery.

How do we instill that capability in students? The last decade has seen an explosion of research on how students learn best. In a nutshell, they learn best when they see the relevance of a subject to their lives, when they are actively engaged in their learning, and when they are given opportunities to practice critical thinking.

In addition, most faculty who teach nonmajors biology would agree that our goal is to introduce students to both the key concepts of biology (for example, cells, DNA, evolution) and the tools to think critically about biological issues. Many would add that they want their students to leave the class with an appreciation for the value of science to society, and with an ability to distinguish between science and the nonscience or pseudoscience that bombards them on a daily basis.

How can a textbook help combine the ways students learn best with the goals of a nonmajors biology class? At the most basic level, if students don't read the textbook, they can't learn from it. When students read them, traditional textbooks are adept at teaching key concepts, and they have recently begun to emphasize the relevance of biology to students' lives. But students may be intimidated by the length of chapters and the amount of difficult text, and they often cannot see the connections between the story and the science. More important, textbooks have not been successful at helping students become active learners and critical thinkers, and none emphasize the process of science or how to assess scientific claims. It was our goal to make *Biology Now* relevant and interactive, and to be sure that it emphasized the process of science in short chapters that students *want* to read, while still covering the essential content found in other nonmajors biology textbooks.

Following the model of the first edition, each chapter in our book covers a current news story about people *doing* science, reported firsthand by Megan, an experienced journalist who specializes in reporting scientific findings in a compelling and accurate way, and fleshed out with a concise introduction to the science by Anne and Cindy. For this second edition we decided to direct our energies toward writing five current stories that will help instructors keep their courses grounded in real world events, and toward adding content requested by our first-edition adopters. Specifically, we've added a full unit—comprising two new chapters and two revised chapters—on the amazing diversity of life on planet Earth. Not only was more substantial coverage of this topic a common request in feedback about the first edition; it is also essential material for non-biology-major students, for it is partly through an appreciation of the diversity of life that students develop a personal relationship with the natural world.

Finally, we are thrilled for our book to be part of the online-assessment revolution! The second edition is accompanied by two excellent online homework platforms: a formative system called InQuizitive, and a summative system called Smartwork5. We no longer worry that our students aren't seeing the forest for the trees when they read the textbook. These systems are a rich learning environments for students and automatically graded assignment platforms for instructors.

We sincerely hope you enjoy the fruits of our long labors.

Anne Houtman
Megan Scudellari
Cindy Malone

What's New in the Second Edition?

- New chapter stories on current, fun, and unexpected topics like the Zika virus outbreak, the human microbiome, and the discovery of a CRISPR gene editing technology. New stories include:

Chapter 5: How Cells Work—Rock Eaters
Unusual electricity-"eating" microbes could someday provide a new way to store and produce energy as "bacterial batteries."

Chapter 9: What Genes Are—Pigs to the Rescue
CRISPR is perhaps one of the most exciting discoveries of the last century. Chapter 9 describes one application of the CRISPR genome editing technology: creating organs for transplant . . . in pigs.

Chapter 15: Bacteria and Archaea—Navel Gazing
A team at North Carolina State University leads a citizen science project to sequence the human belly button microbiome and gets some surprising results.

Chapter 16: Plants, Fungi, and Protists—The Dirt on Black-Market Plants
Poaching is illegal, and trafficking of tropical plants such as orchids threatens their survival. A group of scientists is tracking illegal plants from the United States to their source.

Chapter 19: Growth of Populations—Zika-Busting Mosquitoes
The spread of Zika throughout the Americas quickly became a health crisis. Genetically modifying mosquitoes is one of the ways that scientists are using to try to control Zika's spread.

- A new unit on biodiversity, which significantly expands coverage of the vast diversity of life on Earth, with two completely new chapters and two significantly revised chapters. Instructors who wish to continue teaching a brief introduction to biodiversity can do so with the "overview" chapter (Chapter 14). But for those wishing to spend time exploring life on Earth, Chapters 15, 16, and 17 provide thorough science coverage and lively stories.
- New, earlier placement of the chapter on applying science to making critical choices. The "capstone" final chapter in the second edition is now Chapter 2: Evaluating Scientific Claims. Introducing the concept of scientifically literate evaluation of scientific claims early in the book gives students the maximum amount of time to benefit from that skill.
- A new end-of-chapter question type—Challenge Yourself—which encourages students to think critically about the chapter's important biological concepts.
- New animation, interactive, and visually based questions in Smartwork5 and InQuizitive that promote critical thinking, interaction with data, and engagement with biology in the real world.
- New resources in the *Ultimate Guide to Teaching with Biology Now*, which will be accessible through the online Interactive Instructor's Guide platform, providing instructors with the ability to easily search and sort for active learning resources by topic, objective, and type of resource.

The perfect balance of science and story

Every chapter is structured around a story about people doing science that motivates students to read and stimulates their curiosity about biological concepts.

Dynamic chapter-opening spreads inspired by each chapter's story draw students in to the material.

"After reading this chapter you should be able to" introduces learning outcomes that preview the concepts presented in each chapter.

Cast-of-character bios

highlight the scientists, researchers, and professors at the center of each story.

GORDON LARK

A geneticist at the University of Utah in Salt Lake City, Gordon Lark initiated the Georgie Project in 1996 to study the genetics of Portuguese water dogs. The national research project has led to valuable knowledge about the genetic basis of health and disease in humans and dogs.

J. G. M. "HANS" THEWISSEN

Paleontologist and embryologist J. G. M. "Hans" Thewissen is a professor and whale expert at Northeast Ohio Medical University in the Department of Anatomy and Neurobiology. He and his lab study ancestral whale fossils and modern whale species.

LISA COOPER

Lisa Cooper is an assistant professor at Northeast Ohio Medical University in the Department of Anatomy and Neurobiology. She earned her PhD in Thewissen's lab.

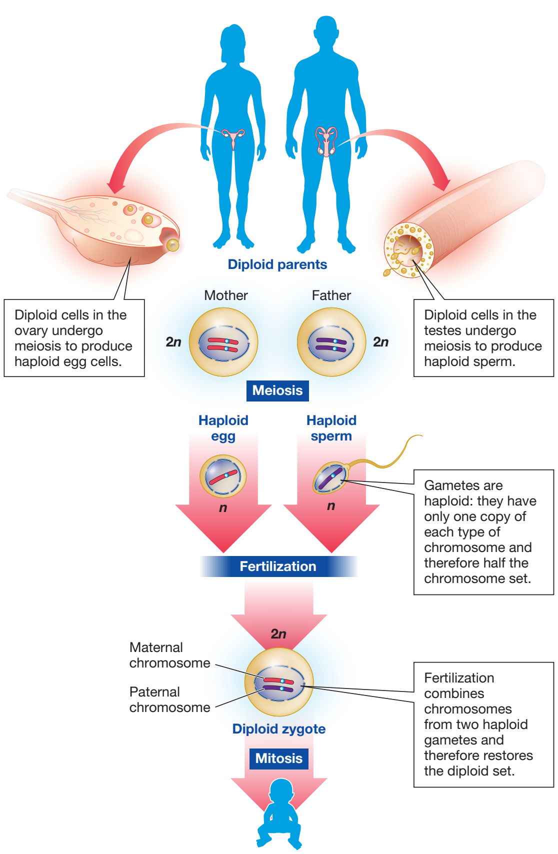
MICHAEL HELLBERG AND CARLOS PRADA

Michael Hellberg (right) is an evolutionary biologist at Louisiana State University who studies how species evolve in marine environments. Carlos Prada (left) was a graduate student in Hellberg's lab, and is now a postdoctoral researcher at Penn State studying how organisms cope with changes in the environment.

XU XING

Xu Xing is a paleontologist at the Chinese Academy of Sciences in Beijing. He has discovered more than 60 species of dinosaurs and specializes in feathered dinosaurs and the origins of flight.

An inquiry-based approach that builds science skills—asking questions, thinking visually, and interpreting data.

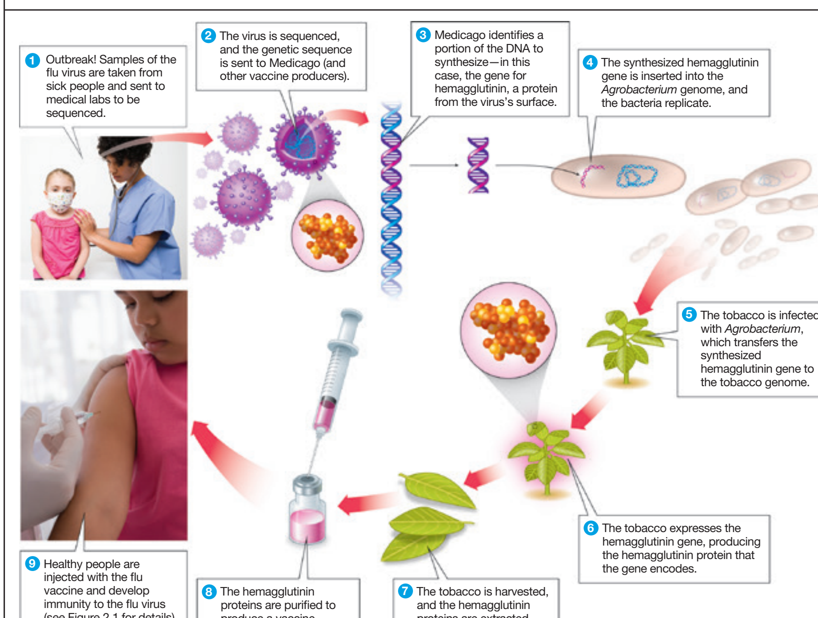


Q1: Is a zygote haploid or diploid?

Q2: Which cellular process creates a baby from a zygote?

Q3: If a mother or father was exposed to BPA prior to conceiving a child, how might that explain potential birth defects in the fetus?

Most **figures** in the book are accompanied by three questions that promote understanding and encourage engagement with the visual content. Answers are provided at the back of the book, making the questions a useful self-study tool.

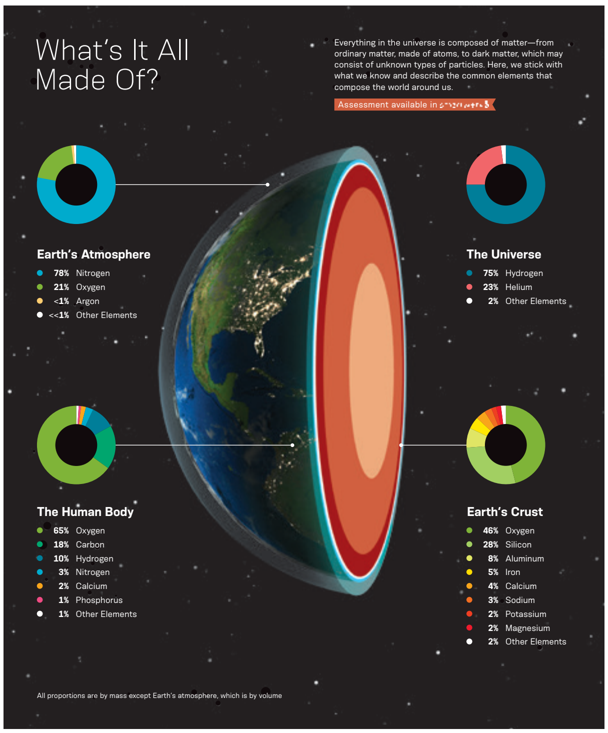


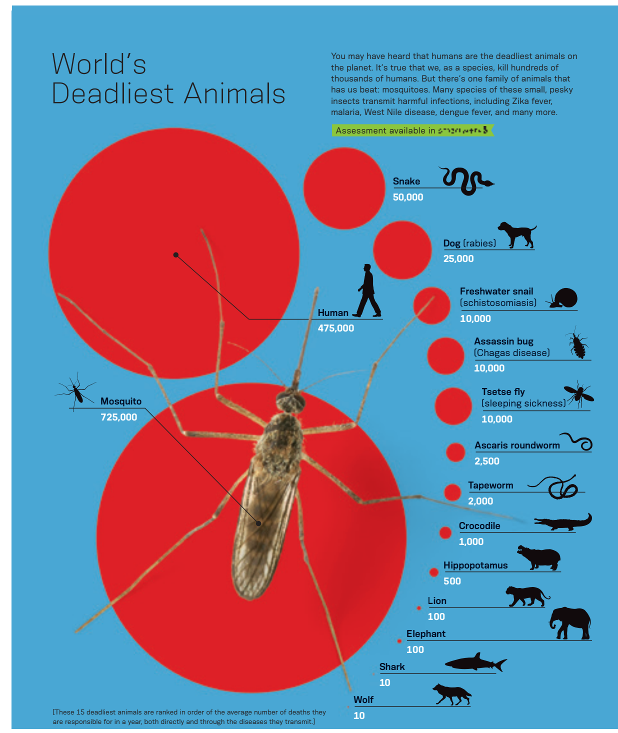
Q1: In which of the step(s) illustrated here does DNA replication occur? In which step(s) does gene expression occur?

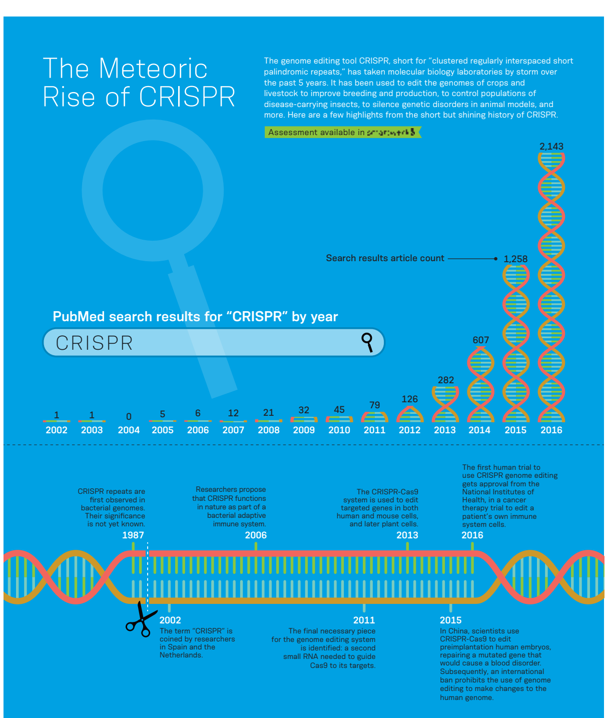
Q2: Why do vaccine producers not simply replicate the entire viral genome, instead isolating the gene for one protein and replicating only that gene?

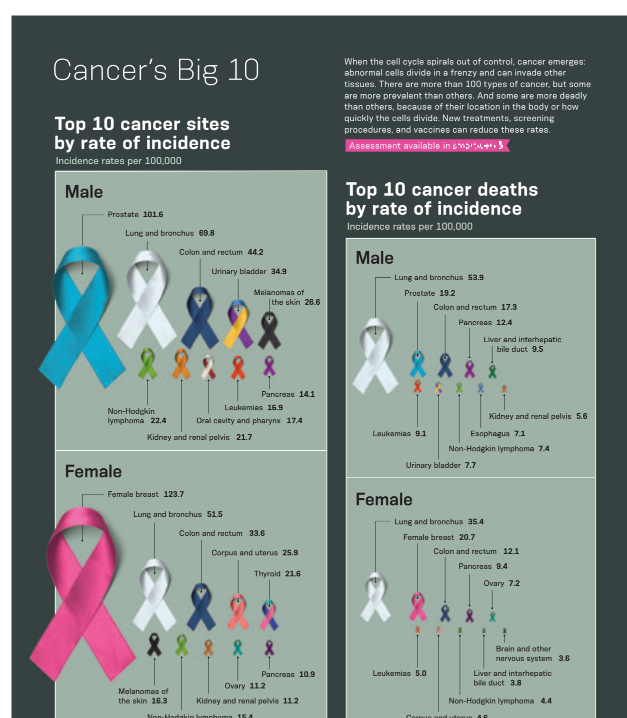
Q3: What role do the bacteria play in this process? Why are they needed?

Engaging, data-driven **infographics** appear in every chapter. Topics range from global renewable energy consumption (Chapter 5) to genetic diseases affecting Americans (Chapter 8) and many more. The infographics expose students to scientific data in an engaging way.



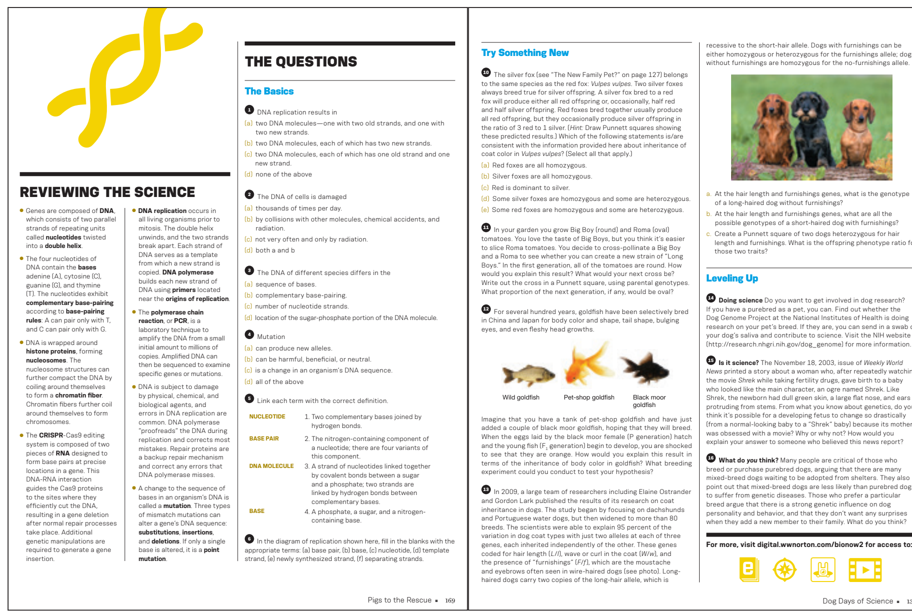






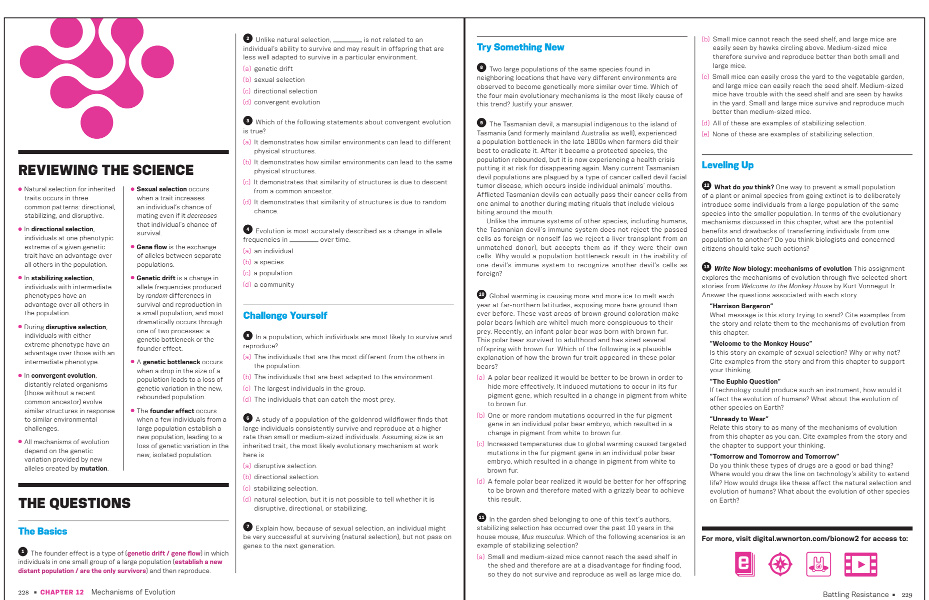
Extensive end-of-chapter review ensures that students see the forest for the trees.

Reviewing the Science identifies each chapter's key science concepts, providing students with a guide for studying.

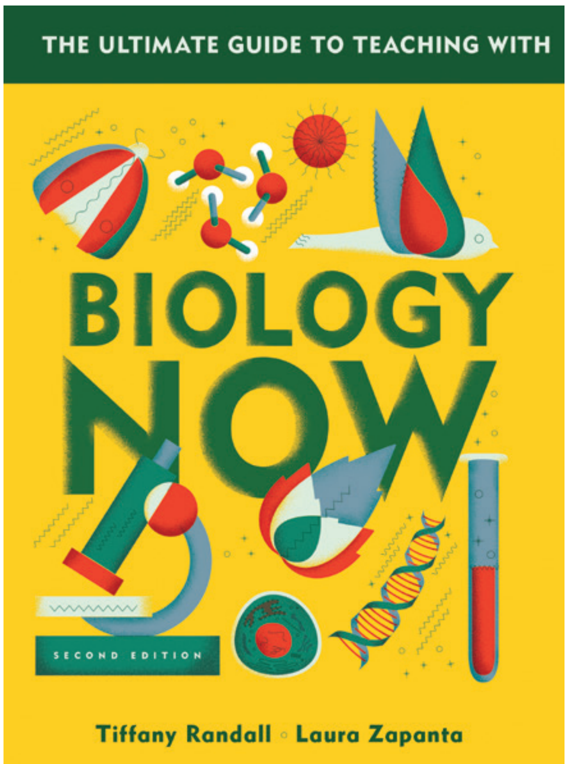


End-of-chapter questions follow Bloom's taxonomy, moving from review (The Basics), to synthesis (Try Something New), to critical thinking (Challenge Yourself), to application (Leveling Up).

Leveling Up questions, based on questions the authors use in their classrooms, prompt students to relate biology concepts to their own lives. The questions focus on one of the following themes: "Doing science," "Is it science?," "Life choices," "Looking at data," "What do *you* think?," and "*Write Now* biology."



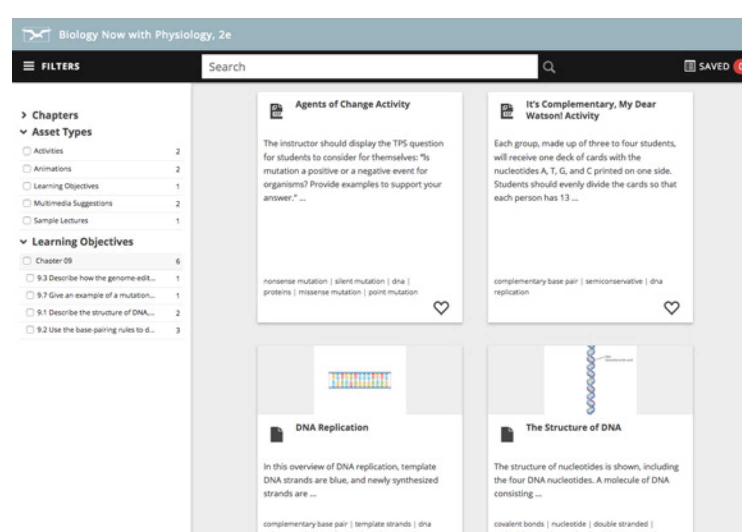
Powerful resources for teaching and assessment



Laura Zapanta, University of Pittsburgh
Tiffany Randall, John Tyler Community College

The **Ultimate Guide** helps instructors bring *Biology Now*'s inquiry-based approach into the classroom through a wealth of resources, including activities useful in a variety of classroom sizes and setups, suggested online videos with discussion questions, clicker questions, sample syllabi, and suggested lecture outlines. The second-edition *Ultimate Guide* has been thoroughly reviewed and updated with new activities, Leveling Up rubrics, and descriptions of animations with discussion questions.

The **Interactive Instructor's Guide** is a searchable database of all the valuable teaching and active learning resources available in the *Ultimate Guide*. Instructors can easily filter by chapter, phrase, topic, or learning objective to find activities with downloadable handouts, streaming video with discussion questions, animations with discussion questions, lecture PowerPoints, and more.



Other presentation tools for instructors

InQuizitive InQuizitive is Norton's easy-to-use adaptive-learning and quizzing tool that improves student understanding of important learning objectives. Students receive personalized quiz questions on the topics they need the most help with. When instructors assign InQuizitive, students come better prepared to lectures and exams. The second-edition course includes new animation questions, story-based questions, and critical-thinking questions.

Smartwork5 Smartwork5 delivers engaging, interactive online homework to students, helping instructors and students reach their teaching and learning goals. The second edition features:

- New infographic questions, which promote interaction with data and engagement with biology in the real world, while making this popular visual feature of the text an assignable activity.
- New story-based questions, which help students to learn and understand the science behind the stories in the text.
- New critical-thinking questions, which prompt students to think critically about important concepts in biology.
- New animation questions, which engage students with the book-specific animations covering biology concepts.

Coursepacks Norton's free coursepacks offer a variety of concept-based opportunities for assessment and review. The Leveling Up questions from the text are available as writing activities, accompanied by grading rubrics, making them easy to assign. Also included are reading quizzes that contain modified images from the text and animation questions, infographic quizzes that help students build skills in reading charts and graphs, and flashcards for student self-study of key terms.

Ebook Norton ebooks give students and instructors an enhanced reading experience at a fraction of the cost of a print textbook. Students are able to have an active reading experience and can take notes, bookmark, search, highlight, and even read offline. Instructors can even add their own notes for students to see as they read the text. Norton ebooks can be viewed on—and synced among—all computers and mobile devices.

Animations Key concepts and processes are explained clearly through high-quality, ADA-compliant animations developed from the meticulously designed art in the book. These animations are available for lecture presentation in the Interactive Instructor's Guide, PowerPoint outlines, and the coursepacks, as well as within our ebook, InQuizitive, and Smartwork5.

Test Bank The test bank is based on an evidence-centered design that was collaboratively developed by some of the brightest minds in educational testing. Each chapter's test bank now includes 75 or more questions structured around the learning objectives from the textbook and conforms to Bloom's taxonomy. Questions are further classified by text section and difficulty, and are provided in multiple-choice, fill-in-the-blank, and short-answer form. New infographic questions in every chapter help test student interpretation of charts and graphs.

Art Files All art and photos from the book are available, in presentation-ready resolution, as both JPEGs and PowerPoints for instructor use.

Lecture Slides Comprehensively revised by book author Cindy Malone, complete lecture PowerPoints thoroughly cover chapter concepts and include images and clicker questions to encourage student engagement.

Acknowledgments

We could not have created this textbook without the enthusiasm and hard work of many people. First and foremost, we'd like to thank our indefatigable editor, Betsy Twitchell, for her keen eye to the market, terrific visual sense, and endless author-wrangling skills. Andrew Sobel has done far more than ought to be required of a developmental editor to ensure that our book is both accurate and readable (not to mention his tireless work on the eye-catching infographics you'll see in these pages), and for that he has our eternal gratitude.

Thank you to our supremely focused and talented project editor, Christine D'Antonio, for creating such a superior layout and for keeping our chapters moving. Thank you to our talented copy editor, Stephanie Hiebert, for being so meticulous with our manuscript, and so pleasant to work with.

We are grateful to photo researcher Fay Torresyap for her reliable and creative work, and to Ted Szczepanski for managing the photo process. Production manager Ashley Horna skillfully oversaw the translation of our raw material into the beautiful book you hold in your hands; she, too, has our thanks. Special thanks to book designer Hope Miller Goodell and cover designer Jennifer Heuer for creating such an extraordinary and truly gorgeous book.

Media editor Kate Brayton, associate editor Cailin Barrett-Bressack, and media assistant Gina Forsythe worked tirelessly to create the instructor and student resources accompanying our book. Their determination, creativity, and positive attitude resulted in supplements of the highest quality that will truly make an impact on student learning. Jesse Newkirk's commitment to quality as media project editor ensured that every element of the resource package meets Norton's high standards. Likewise, assistant editor Taylere Peterson contributed in myriad ways, large and small, and for that she has our thanks.

We appreciate the tireless enthusiasm of marketing manager Todd Pearson and his colleagues, director of marketing Steve Dunn and marketing director Stacy Loyal. We thank director of sales Michael Wright and every single one of Norton's extraordinary salespeople for spreading the word about our book. Finally, we thank Marian Johnson, Julia Reidhead, Roby Harrington, Drake McFeely, and everyone at Norton for believing in our book.

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Perhaps most of all, we are indebted to the many scientists and individuals who shared their time and stories for these chapters. To the men and women we interviewed for this book, we cannot thank you enough. Your stories will inspire the next generation of biologists.

Biology Now

with Physiology

Caves of Death

Scientists scramble to identify a mysterious scourge decimating bat populations.

After reading this chapter you should be able to:

- Caption a diagram of the scientific method, identifying each step in the process.
- Develop a hypothesis from a given observation and suggest one or more predictions based on that hypothesis.
- Design an experiment using appropriate variables, treatments, and controls.
- Give specific examples of a scientific fact and a scientific theory.
- Create a graphic showing the levels of biological organization.
- Determine whether something is living or nonliving based on the characteristics of living things.

SCIENCE

CHAPTER 01

THE NATURE OF SCIENCE

Every spring for 30 years, Alan Hicks laced up his hiking boots, packed his camera, and set out to count bats in caves in upstate New York. A biologist with the New York State Department of Environmental Conservation, Hicks leads one of the few efforts in the country to collect annual data on bat populations. Since 1980, he had never missed the annual cave trip—until March 17, 2007.

"That day, of all days in my entire career, I stayed at my desk," recalls Hicks, who had remained behind to write a report for his supervisor. A couple of hours after his crew left to inspect some local caves, 15 miles from the Albany office, Hicks's cell phone rang.

"Hey, Al. Something weird is going on here," said a nervous voice. "We've got dead bats. Everywhere."

The line went quiet. "What are we talking here?" asked Hicks. "Hundreds of dead bats?"

"No," said the voice. "Thousands."

At first, Hicks conjectured that the bats had died in a flood, which had happened in that particular cave before. But the next day, a young volunteer who had been out with the team told Hicks to check his e-mail. The volunteer had sent him a picture taken the day before of eight little brown bats (*Myotis lucifugus*) hanging from a cave outcropping. Each one had a fuzzy white nose. This was a surprise because little brown bats do not have white noses.

Hicks e-mailed the picture to every bat researcher he knew. The fuzzy white material looked like a fungus, but there was no previous record of a fungus killing bats. As scientist after scientist looked at the picture, they all replied the same way: "What is that?" Hicks resolved to find out what was killing the bats and whether the white fuzz was involved.

Why was Hicks so interested in saving the bats? And why should any of us care, apart from valuing the preservation of all of Earth's creatures? For one thing, bats help us by devouring insects that would otherwise destroy agricultural crops and forests (see "Bug Zappers" on page 15). And mosquitoes, which bats eat, are the world's most deadly animal to humans: through malaria transmissions, mosquitoes kill hundreds of thousands of people each year.

ALAN HICKS

Alan Hicks is a retired bat specialist who began the investigation of a mysterious bat illness while working for the New York Department of Environmental Conservation.

As a biologist, Hicks took a scientific view of the world—logical, striving for objectivity, and valuing evidence over other ways of discovering the truth. **Science** is a body of knowledge about the natural world, but it is much more than just a mountain of data. Science is an evidence-based process for acquiring that knowledge.

- Science deals with the natural world, which can be detected, observed, and measured.
- Science is based on evidence that can be demonstrated through observations and/or experiments.
- Science is subject to independent validation and peer review.
- Science is open to challenge by anyone at any time on the basis of evidence.
- Science is a self-correcting enterprise.

To gather knowledge, Hicks would apply the **scientific method** (**Figure 1.1**). The scientific method is not a set recipe that scientists follow in a rigid manner. Instead, the term is meant to capture the core logic of how science works. Some people prefer to speak of the **process of science** rather than the scientific method. Whatever we call it, the practices that produce scientific knowledge can be applied across a broad range of disciplines—including bat biology.

Keep in mind that, as powerful as the scientific method is, it is restricted to seeking natural causes to explain the workings of our world. There are other areas of inquiry that science cannot address. The scientific method cannot tell us what is morally right or wrong. For example, science can inform us about the differences between humans and other animals, but it cannot identify the morally correct way to act on that information. Science also cannot speak to the existence of God or any other supernatural being. Nor can it tell us what is beautiful or ugly, which poems are most lyrical, or which paintings are most inspiring. So, although science exists comfortably alongside different belief systems—religious, political, and personal—it cannot answer all questions.

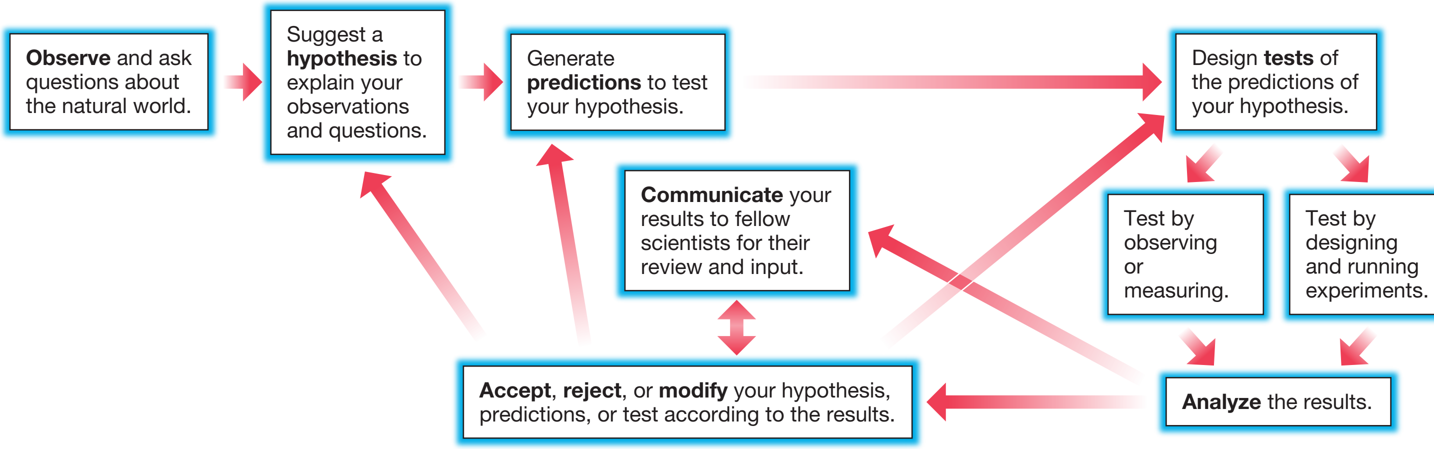

Figure 1.1

The scientific method

The scientific method is a logical process that helps us learn more about the natural world.

Q1: **What were the original observation and question of the scientists studying the sick bats?**

Q2: **At what point in the scientific method would a scientist decide on the methods she should use to test her hypothesis?**

Q3: **How might you explain the scientific method to someone who complains that "scientists are always changing their minds; how can we trust what they say?"**

But science is the best way to answer questions about the natural world. The first two steps of the scientific method are to *gather observations* and *form a hypothesis*. Hicks didn't waste a moment of time before applying the scientific method to the question of the white fuzz. Bats were dying. "Bats are part of the planet and vital members of the ecosystem," says Hicks. "They play an important role in the environment in which we live."

Bat Crazy

On March 18, the day after the first dead bats were discovered, Hicks entered the cave to make observations—a key part of the scientific process. An **observation** is a description, measurement, or record of any object or phenomenon. Hicks's team observed that the sick bats had not only white noses, but also depleted fat reserves, meaning that the bats did not have enough stored energy to get through the winter. The bats also had white fuzz on their wings with scarred and dying wing tissue, and they were behaving abnormally, waking up early from hibernation and leaving the cave when it was still too cold outside to hunt.

Hicks's team also observed that the illness cut across species—many different types of bats were getting sick—and the bats exhibited a high rate of death: in some cases, up to 97 percent of infected bats died. Hicks and others began to call the illness white-nose syndrome (WNS). They still didn't know what caused the syndrome, but its characteristics led them to the assumption that the cause was a living organism (see "The Characteristics of Living Organisms" on page 6).

"For the first few years, we were just sleuthing," says Paul Cryan, a research biologist with the U.S. Geological Survey (USGS), and one of the scientists who received the original e-mailed picture from Hicks. From that first picture, Cryan was involved in trying to pinpoint the cause. "We were trying to understand something that had never happened before in a group of animals that was poorly understood."

In the caves, Hicks began collecting dead bats and sending them to laboratories around the nation. In those labs, technicians scraped samples from the bats' noses and wings, rubbed the samples into petri dishes (shallow glass or plastic plates containing a nutrient solution used to grow microorganisms), and watched to see whether the white fuzz would grow. Time after time, many different types of bacteria and fungi grew on the dishes, speckling them with dots of different-colored colonies, but none of the samples were unusual. Nothing special or dangerous appeared to be present on the bats.

One researcher, a young microbiologist named David Blehert, decided to try something different. Blehert worked at the USGS National Wildlife Health Center in Madison, Wisconsin. In December 2007, Hicks called Blehert. Blehert listened carefully as Hicks described how WNS was spreading. "He said, 'We have a major problem on our hands,'" recalls Blehert. "It turns out he was 100 percent right."

Hicks described to Blehert the conditions under which the bats lived during hibernation—caves in upstate New York, where the temperature was often between 30°F and 50°F. Blehert realized that most of the laboratories, including his, were trying to grow the samples

The Characteristics of Living Organisms

All living things share certain features that characterize life.

1. *They are composed of one or more cells.* The **cell** is the smallest and most basic unit of life; all organisms are made of one or more cells. Larger organisms are made up of many different kinds of specialized cells and are known as *multicellular organisms.*
2. *They reproduce autonomously using DNA.* All living organisms are able to **reproduce**, to make new individuals like themselves. **DNA** is the genetic material that transfers information from parents to offspring. A segment of DNA that codes for a distinct genetic characteristic is called a *gene*. Life, no matter how simple or how complex, uses this inherited genetic code to direct the structure, function, and behavior of every cell.
3. *They obtain energy from the environment to support metabolism.* All organisms need **energy** to survive. Organisms use a wide variety of methods to capture this energy from their environment. The capture, storage, and use of energy by living organisms is known as *metabolism.*
4. *They sense the environment and respond to it.* Living organisms **sense** many aspects of their external environment, from the direction of sunlight to the presence of food and mates. All organisms gather information about the environment by sensing it, and then respond appropriately.
5. *They maintain a constant internal environment.* Living organisms sense and respond to not only the external environment, but also their internal conditions. All organisms maintain constant internal conditions—a process known as **homeostasis**.
6. *They can evolve as groups.* **Evolution** is a change in the genetic characteristics of a group of organisms over generations. When a characteristic becomes more or less common across generations, evolution has occurred within the group.

	Rock	Virus	Fungus	Plant	Animal
Composed of one or more cells	✗	✗	✓	✓	✓
Autonomously reproduce themselves	✗	✗	✓	✓	✓
Obtain energy from their environment	✗	✗	✓	✓	✓
Sense their environment and respond to it	✗	✗	✓	✓	✓
Maintain a constant internal environment (homeostasis)	✗	✗	✓	✓	✓
Can evolve as groups	✗	✓	✓	✓	✓
Living	✗	?	✓	✓	✓

from the bats at room temperature—a method conducive to the growth of many fungi. But in the caves, any living thing would have to grow at cold temperatures, so Blehert and his technicians took samples from dead bats, put them on petri dishes, and placed the dishes in the fridge.

At the same time, Melissa Behr, an animal disease specialist at the New York State Health Department, accompanied Hicks on a trip to a local cave (**Figure 1.2**). Behr swabbed a sample of the white fuzz directly from a bat in the cave, immediately spread it onto a glass slide, and looked at it under a microscope. A unique fungus was on the plate. The fungus was visible in little white fuzzy patches of cells, and up close, the individual spores of the fungus appeared crescent-shaped—different from all the other "normal" microbes growing on the bats' skin, and different from any fungus known to the researchers.

But Behr's single observation wasn't enough evidence to convince anyone that the strange-looking fungus was the cause of WNS. To be of use in science, an observation must be repeatable, preferably by multiple techniques. Independent observers should be able to see or detect the same object or phenomenon, at least some of the time.

In this case, Blehert was able to reproduce Behr's results by an independent technique. After letting his plates sit in the fridge for a few weeks, Blehert removed them and observed white patches of the same strange, crescent-shaped fungal spores. "OK, we now have in laboratory culture what Melissa captured when she collected white material in the caves," thought Blehert. "We've got it."

Figure 1.2

Preparing to enter the bat cave

Scientists suit up to collect more observations on the infected bats and the environmental conditions in the bats' roosting cave.

Q1: Which step(s) in the scientific method does this photograph illustrate?

Q2: What types of environmental data might the researchers have collected?

Q3: Why do you think the researchers are wearing protective gear?

Prove Me Wrong

In science, just as in everyday life, observations lead to questions, and questions lead to potential explanations. For example, if you flip on a light switch but the light does not turn on, you wonder why, and then you look for an explanation: Is the lamp plugged in? Has the lightbulb burned out? You then identify one of these explanations as the most likely hypothesis for why the light did not turn on.

A scientific **hypothesis** (plural "hypotheses") is an informed, logical, and plausible explanation for observations of the natural world. From the start, Hicks hypothesized that a new, cold-loving fungus was the primary cause of death in the bats. After observing the unique crescent-shaped fungal spores, Behr and Blehert agreed with this hypothesis. "It was the simplest

DAVID BLEHERT

A microbiologist and branch chief of the Wildlife Disease Diagnostic Laboratories at the National Wildlife Health Center, David Blehert studies a variety of fungal and bacterial pathogens that are harmful to bats, humans, and other species.

solution," says Blehert. "We had bats with a white fungus that nobody had ever seen before growing on them, so that was the most likely thing that was doing it."

But other scientists disagreed. A fungus itself is rarely deadly to a mammal; more often, a fungus causes an annoying, but not lethal, skin infection or is a secondary response after an animal gets sick from a viral or bacterial infection. So scientists proposed other hypotheses for the cause of WNS. Some suggested the fungus was a secondary effect of an underlying condition, such as a viral infection. Others hypothesized that an environmental contaminant, such as a pesticide, was the cause of death. "There were so many different hypotheses," says Cryan. "But that's what is beautiful about the scientific process. You observe as much as you can, and from those observations you can form multiple hypotheses. Science doesn't proceed by just landing on the right hypothesis the first time."

One of the joys, and challenges, of the scientific method is that after scientists suggest competing hypotheses, they then test their own hypotheses against those of others. A scientific hypothesis must be constructed in such a way that it is potentially **falsifiable**, or refutable. In other words, it must make predictions that can be clearly determined to be true or false, right or wrong (**Figure 1.3**). A well-constructed hypothesis is precise enough to make predictions that can be expressed as "if . . . then" statements.

For example, *if* WNS is caused by a transmissible fungus, *then* healthy bats that hibernate in contact with affected bats should develop the condition. *If* the fungus is secondary to an underlying condition, *then* the infection will occur in bats only after the primary underlying condition is present. *If* an environmental contaminant is the cause, *then* bats with WNS symptoms will have elevated levels of that contaminant in their blood or on their skin.

In each "if . . . then" case, it is possible to design tests able to demonstrate that a prediction is right or wrong. Although predictions can be shown to be true or false, the same is not true of hypotheses. Hypotheses can be *supported*, but no amount of testing can *prove* a hypothesis is correct with complete certainty (**Figure 1.4**).

The reason a hypothesis cannot be proved is that there might be another factor, unmeasured or unobserved, that explains why the prediction is true. For example, consider the first prediction stated in the previous paragraph—that healthy bats hibernating in contact with affected bats will develop WNS. If this is true, the reason might be that the healthy bats were infected by a fungus from their neighbor, supporting the hypothesis that the disease is caused by a transmissible fungus. Alternatively, related bats may tend to hibernate together in the same cave, and the disease, or at least vulnerability to the disease, might be genetically based. The hypothesis that the disease is fungal is *supported* but not *proved* by the correctness of this prediction.

Blehert set out to test the hypothesis that he, Behr, and Hicks had put forward—that a unique, cold-loving fungus was the primary cause of death in the bats. One can test a hypothesis through observational studies or experimental studies. Blehert's first study was observational. Observational studies can be purely **descriptive**—reporting information (**data**) about what is found in nature. Observational studies can also be **analytical**—looking for (analyzing)

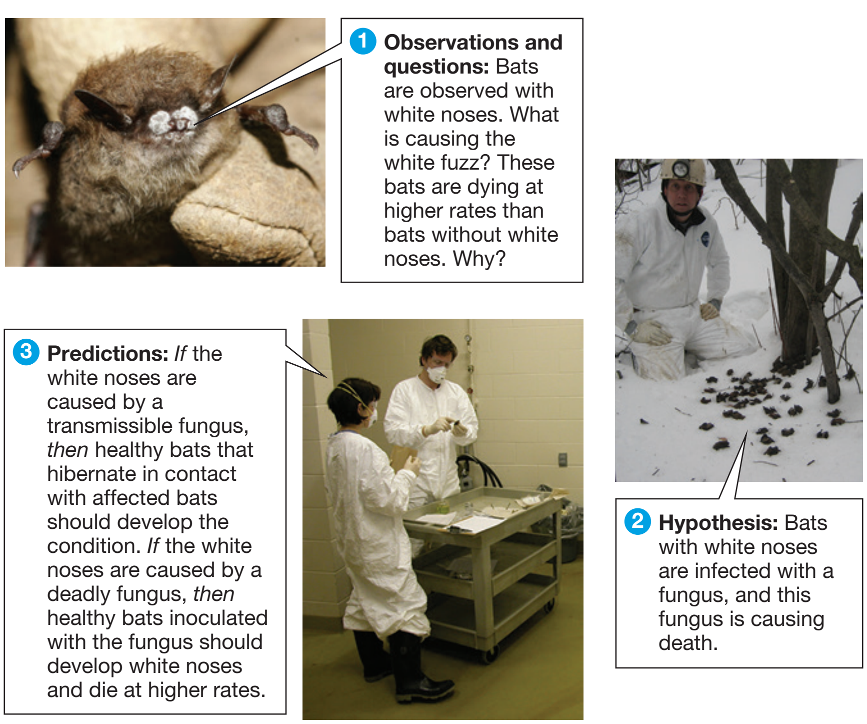

Figure 1.3

From observation to hypothesis to testable prediction

Figure 1.4

Hypotheses are supported or not supported, but never proved

Although the claim of scientifically confirmed mildness in this vintage advertisement for cigarettes seems ridiculous, "science" is still used to sell products today. Most Americans see thousands of advertisements every day, and many of these make "scientific" claims that are exaggerated or inaccurate.

Q1: **State the hypothesis that this advertisement is claiming was scientifically tested.**

Q2: **State a prediction that comes from this hypothesis. Is it testable? Why or why not?**

Q3: **Explain in your own words why the hypothesis cannot be "proved."**

patterns in the data and addressing how or why those patterns came to exist. The tools of **statistics**—a branch of mathematics that can quantify the reliability of data—help scientists determine how well those patterns support a hypothesis. Observational studies usually rely on both descriptive and analytical methods to test predictions made by a hypothesis.

In 2009, Blehert, Behr, and Hicks published a scientific paper in which they described the results from inspecting 117 dead bats. They identified microscopic damage caused by a specific kind of fungus in 105 of the bats, and isolated and identified the fungus from a subset of 10 of them. It was a type of cold-loving fungus belonging to a group of fungi called *Geomyces*. They named this new species *Geomyces destructans*.

Their observational study revealed a correlation between white fungus on the noses of bats and bat illness and death. Observational studies suggest possible causes for a phenomenon, but they do not establish a cause-effect relationship. To demonstrate that the fungus was actually causing the illness—and not just correlated with it—Blehert designed and conducted an experiment. Testing scientific hypotheses often involves both observational and experimental approaches (**Figure 1.5**).

Catching the Culprit

An **experiment** is a repeatable manipulation of one or more aspects of the natural world. Blehert's experiment was to take healthy bats into his laboratory and expose them to the fungus. Like analytical observational studies, experimental studies use statistics to determine whether the experimental results support or refute the hypothesis being tested.

In studying nature, whether through observations, experiments, or both, scientists focus on **variables**, characteristics of any object or individual organism that can change. In a scientific experiment, a researcher typically manipulates

MELISSA BEHR

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