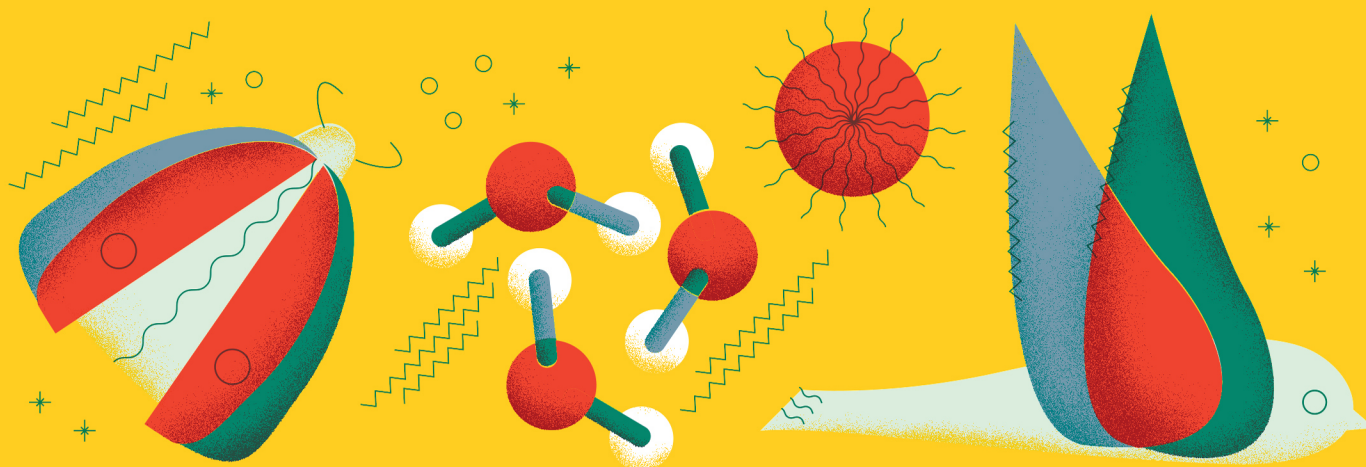


Anne Houtman ◦ Megan Scudellari ◦ Cindy Malone



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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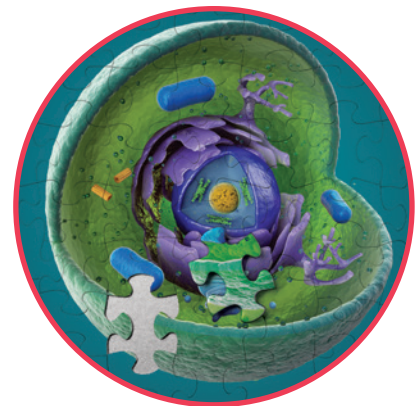
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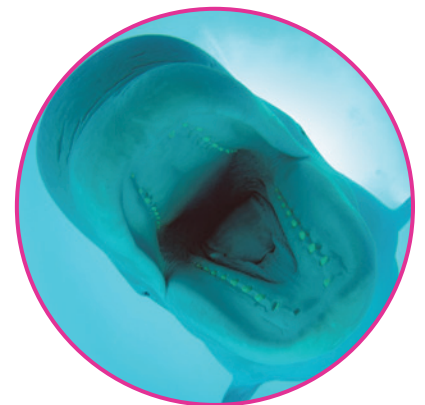
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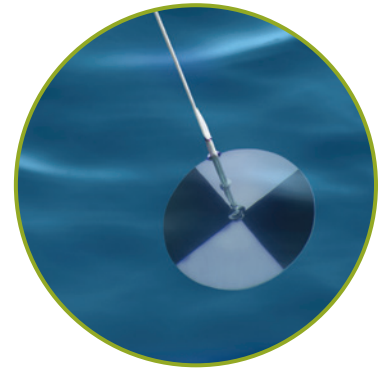
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About the Authors



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.



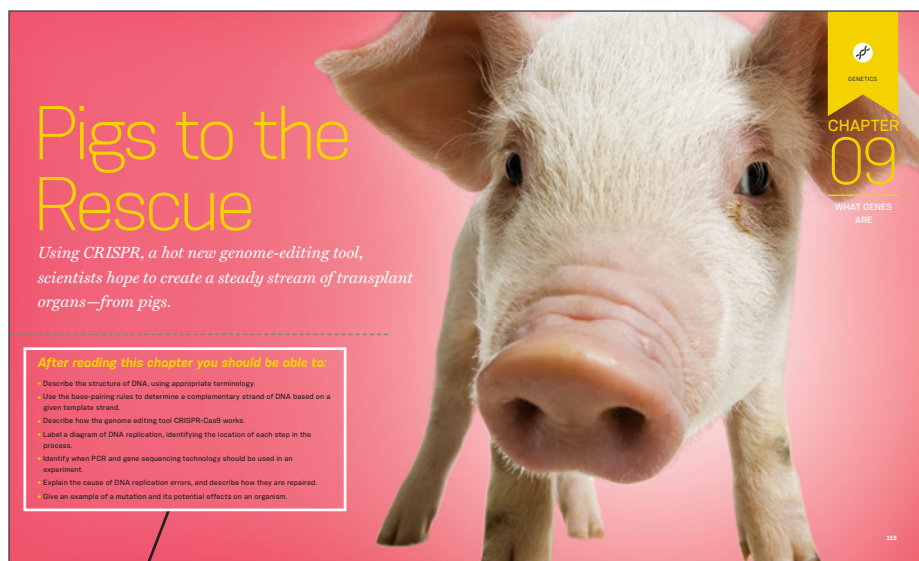
Chapter 19: Growth of Populations—Zika-Busting Mosquitoes

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

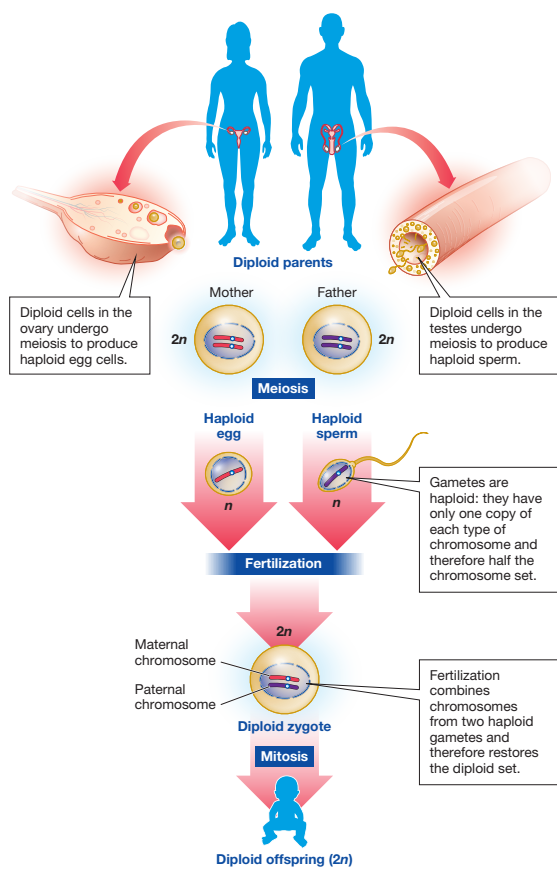
Michael Hellberg (right) is an evolutionary biologist at Louisiana State University who studies how species evolve in marine environments. Carlos Prada (left) was a graduate student in Hellberg's lab, and is now a postdoctoral researcher at Penn State studying how organisms cope with changes in the environment.



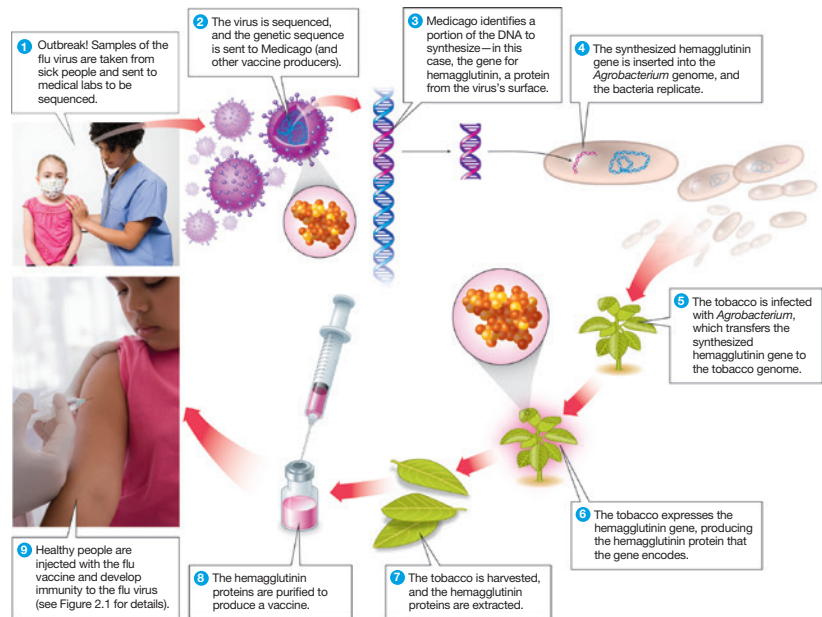
XU XING

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.



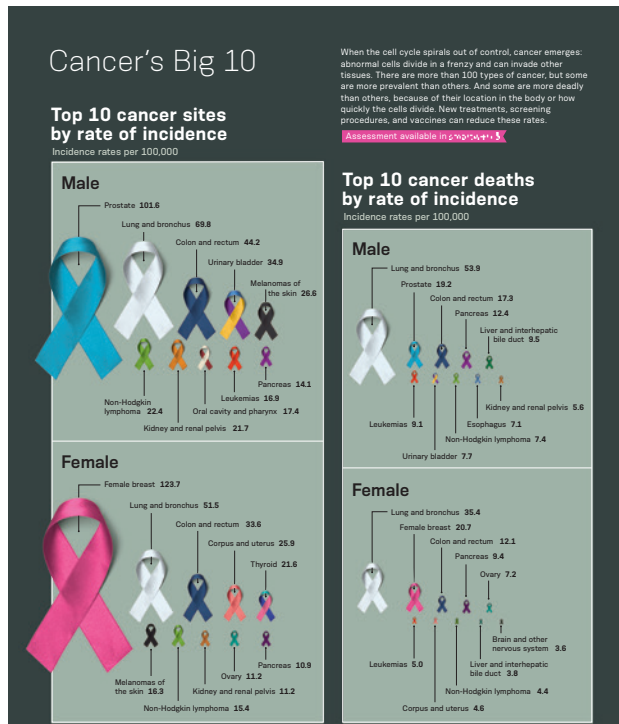
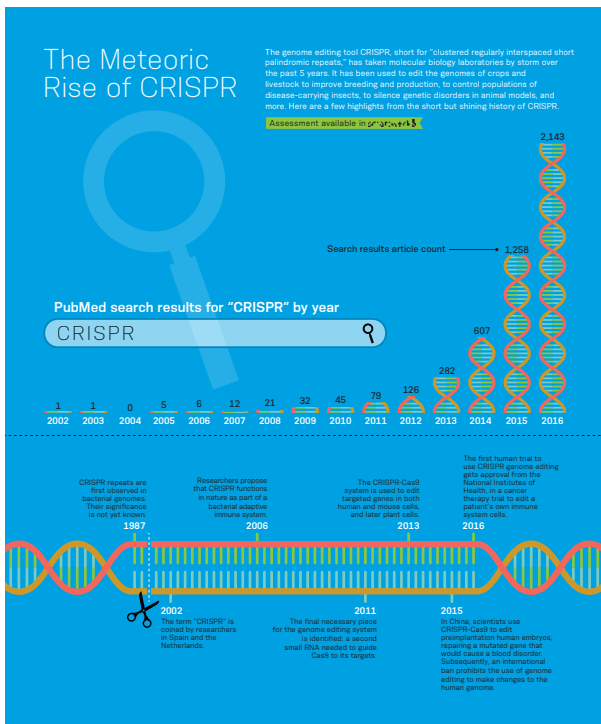
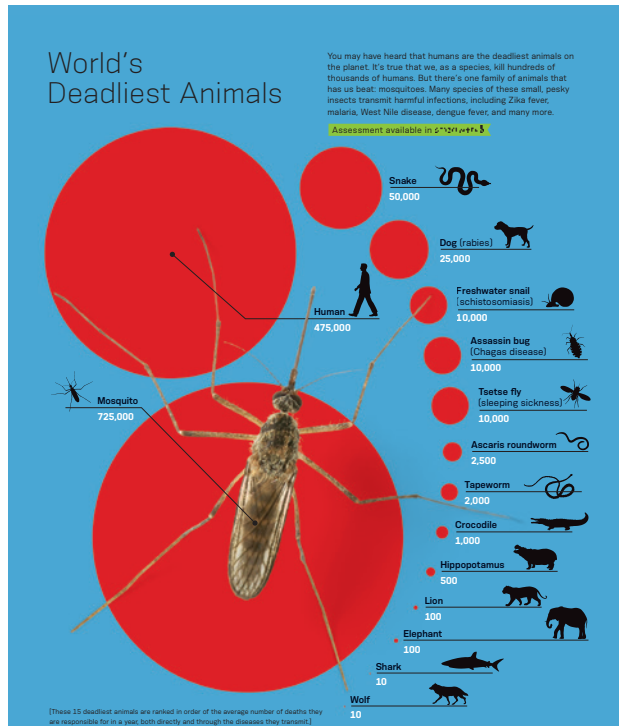
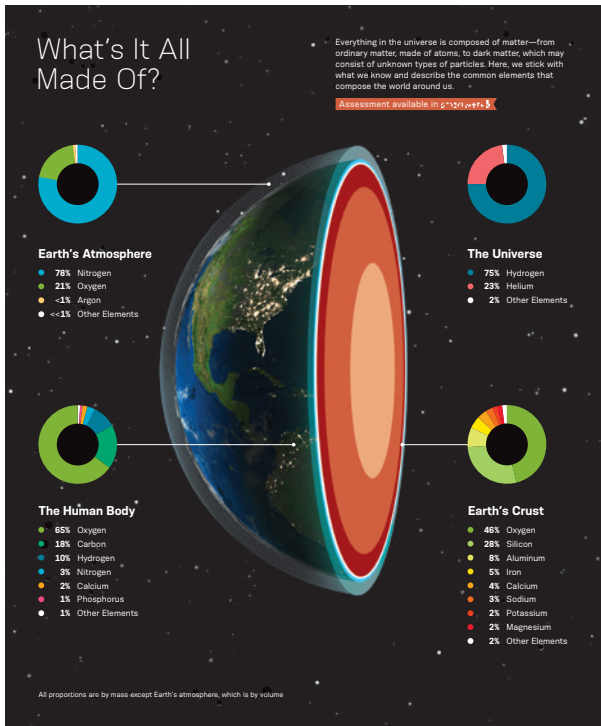
Most **figures** in the book are accompanied by three questions that promote understanding and encourage engagement with the visual content. Answers are provided at the back of the book, making the questions a useful self-study tool.



- Q1:** 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?

- 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).



REVIEWING THE SCIENCE


- Natural selection for inherited traits occurs in those common patterns: directional, stabilizing, and disruptive.
- Directional selection:** individuals at one phenotypic extreme of a given genetic trait have an advantage over all others in the population.
- Stabilizing selection:** individuals with intermediate phenotypes have an advantage over those with the extreme phenotypes.
- Disruptive selection:** individuals with either extreme phenotype have an advantage over those with an intermediate phenotype.
- Convergent evolution:** a dietary related genotype that does not require common ancestral enzyme similar structures in response to similar environmental challenges.
- All mechanisms of evolution depend on the genetic variation provided by new alleles created by **mutation**.

THE QUESTIONS

The Basics

- The founder effect is a type of **genetic drift** (gene flow) in which individuals in a small group of a large population establish a **new distinct population / are the only survivors** and then reproduce.

223 • CHAPTER 12 Mechanisms of Evolution



REVIEWING THE SCIENCE

- Genes are composed of **DNA**, which consists of two parallel strands of repeating units called **nucleotides** twisted into a **double helix**.
- The four nucleotides of DNA contain the bases adenine (A), cytosine (C), guanine (G), and thymine (T). The nucleotides exhibit **complementary base-pairing** according to **base-pairing rules**: A can pair only with T and C can pair only with G.
- DNA is wrapped around **nucleosomes**, forming **nucleosomes**. These nucleosome structures can further compact the DNA by coiling around themselves to form a **chromatin fiber**. Chromatin fibers further coil around themselves to form chromosomes.
- The **CRISPR-Cas9** editing system is composed of two pieces of **CRNA** designed to form base pairs at precise locations in a gene. This DNA-RNA interaction enables the Cas9 protein to cut the DNA at the site where they efficiently cut the DNA, resulting in a gene deletion after some repair processes take place. Additional genetic manipulations are required to generate a gene insertion.
- DNA replication** occurs in all living organisms prior to mitosis. The double helix unwinds, and the two strands break apart. Each strand of DNA serves as a template from which a new strand is copied. **DNA polymerase** builds each new strand of DNA using **nucleotides** located near the **origin of replication**.
- The polymerase chain reaction, or PCR**, is a laboratory technique to amplify the DNA from a small initial amount to millions of copies. Amplified DNA can then be sequenced to examine specific genes or mutations.
- DNA is subject to damage by physical, chemical, and biological agents, and errors in DNA replication are common. DNA polymerase "proofreads" the DNA during replication and corrects most mistakes. Repair proteins are a backup repair mechanism and correct any errors that DNA polymerase misses.
- A change to the sequence of bases in an organism's DNA is called a **mutation**. Three types of mismatch mutations can alter a gene's DNA sequence: **substitutions, insertions, and deletions**. If only a single base is altered, it is a **point mutation**.



THE BASICS

The Basics


- DNA replication results in:
 - two DNA molecules—one with two old strands, and one with two new strands.
 - two DNA molecules, each of which has two new strands.
 - two DNA molecules, each of which has one old strand and one new strand.
 - none of the above.
- The DNA of cells is damaged:
 - thousands of times per day.
 - by collisions with other molecules, chemical accidents, and radiation.
 - not every day and only by radiation.
 - both a and b.
- The DNA of different species differs in the:
 - sequence of bases.
 - complementary base-pairing.
 - number of nucleotide strands.
 - location of the sugar-phosphate portion of the DNA molecule.
- Mutation:
 - can produce new alleles.
 - can be harmful, beneficial, or neutral.
 - is a change in an organism's DNA sequence.
 - all of the above.
- Link each term with the correct definition:
 - NUCLEOTIDE**: The complementary bases joined by hydrogen bonds.
 - BASE PAIR**: The nitrogen-containing component of a nucleotide; there are four variants of this component.
 - DNA MOLECULE**: A strand of nucleotides linked together by covalent bonds between a sugar and a phosphate; two strands are linked by hydrogen bonds between complementary bases.
 - BASE**: A phosphate, a sugar, and a nitrogen-containing base.

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Try Something New

- The silver fox (see "The New Family Pet?" on page 127) belongs to the same species as the red fox (*Vulpes vulpes*). Two silver foxes always breed true for silver offspring. A silver fox bred to a red fox will produce either all red offspring or, occasionally, half red and half silver offspring. Red foxes bred together usually produce all red offspring, but they occasionally produce silver offspring in the ratio of 3 red to 1 silver. (Hint: Chew Punnett squares showing these predicted results.) Which of the following statements is/are consistent with the information provided here about inheritance of coat color in foxes subject? [Select all that apply.]
 - Red foxes are all homozygous.
 - Silver foxes are all homozygous.
 - Red is dominant to silver.
 - Some red foxes are homozygous and some are heterozygous.
 - Some red foxes are homozygous and some are heterozygous.
- In your garden you grow Big Boy (round) and Roma (oval) tomatoes. You love the taste of Big Boy, but you think it's easier to slice Roma tomatoes. You decide to cross-pollinate a Big Boy and a Roma to see whether you can create a new strain of "King Boy." In the first generation, all of the tomatoes are round. How would you explain this result? What would your next cross be? Write out the cross in a Punnett square, using parental genotypes. What proportion of the next generation, if any, would be oval?
- For several hundred years, goldfish have been selectively bred in China and Japan for body color and shape, tail shape, bulging eyes, and even fussy head growths.
 - Imagine that you have a tank of pie-shop goldfish and have just introduced a couple of black moor goldfish, hoping that you will breed. When the eggs laid by the black moor female (P generation) hatch and the young goldfish begin to develop, you are excited to see that they are orange. How would you explain this result in terms of the inheritance of body color in goldfish? What breeding experiment could you conduct to test your hypothesis?
 - In 2003, a large team of researchers including Elaine Ostrander and Gordon Luik published the results of its research on coat inheritance in dogs. The study began by focusing on dachshunds and Portuguese water dogs, but then widened to more than 80 breeds. The scientists were able to explain 55 percent of the variation in dog coat types with just two alleles at each of three genes, each inherited independently of the other. These genes coded for hair length (L/l), wire or curl in the coat (W/w), and the presence of "furnishings" (F/f), which are the mousethail and eyebrows often seen in wire-haired dogs (see photo). Long-haired dogs carry two copies of the long-hair allele, which is recessive to the short-hair allele. Dogs with furnishings can be either homozygous or heterozygous for the furnishings allele, dogs without furnishings are homozygous for the no-furnishings allele.
 - At the hair length and furnishings genes, what is the genotype of a long-haired dog without furnishings?
 - At the hair length and furnishings genes, what are all the possible genotypes of a short-haired dog with furnishings?
 - Create a Punnett square of two dogs heterozygous for hair length and furnishings. What is the offspring phenotype ratio for those two traits?

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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."

REVIEWING THE SCIENCE

- Unlike natural selection, _____ is not related to an individual's ability to survive and may result in offspring that are less well adapted to survive in a particular environment.
 - genetic drift
 - sexual selection
 - directional selection
 - convergent evolution
- Which of the following statements about convergent evolution is true?
 - It demonstrates how similar environments can lead to different physical structures.
 - It demonstrates that similar environments can lead to the same physical structures.
 - It demonstrates that similarity of structures is due to descent from a common ancestor.
 - It demonstrates that similarity of structures is due to random chance.
- Evolution is most accurately described as a change in allele frequencies in _____ over time.
 - an individual
 - a species
 - a population
 - a community


Challenge Yourself

- In a population, which individuals are most likely to survive and reproduce?
 - The individuals that are the most different from the others in the population.
 - The individuals that are best adapted to the environment.
 - The largest individuals in the group.
 - The individuals that can catch the most prey.
- A study of a population of the goldenrod willowherb finds that large individuals consistently survive and reproduce at a higher rate than small or medium-sized individuals. Assuming that a linear phenotypic trait, the most likely evolutionary mechanism at work here is:
 - disruptive selection.
 - directional selection.
 - stabilizing selection.
 - natural selection, but it is not possible to tell whether it is disruptive, directional, or stabilizing.
- Explain how, because of sexual selection, an individual might be very successful at surviving (natural selection), but not pass on genes to the next generation.
 - In the garden shed belonging to one of the text's authors, stabilizing selection has occurred over the past 20 years in the house mice, *Mus musculus*. Which of the following scenarios is an example of stabilizing selection?
 - Small and medium-sized mice cannot reach the seed shelf in the shed and therefore are at a disadvantage for feeding food to their offspring and reproducing as well as large mice.
 - Small mice cannot reach the seed shelf, and large mice are easily seen by hawks circling above. Medium-sized mice therefore survive and reproduce better than both small and large mice.
 - Small mice can easily reach the yard to the vegetable garden, and large mice can easily reach the seed shelf. Medium-sized mice have trouble with the seed shelf and are seen by hawks in the yard. Small and large mice survive and reproduce much better than medium-sized mice.
 - All of these are examples of stabilizing selection.
 - None of these are examples of stabilizing selection.

LEVELING UP

- What do you think?** One way to prevent a small population of a plant or animal species from going extinct is to deliberately introduce some individuals from a large population of the same species into the smaller population. In terms of the evolutionary mechanisms discussed in this chapter, what are the potential benefits and drawbacks of transferring individuals from one population to another? Do you think biologists and conservationists should take such actions?
- Write Now biology: mechanisms of evolution** This assignment reviews the mechanisms of evolution through five selected short stories from *Welcome to the Monkey House* by Kurt Vonnegut Jr. Answer the questions associated with each story.
 - "Harrison Bergeron"** What message is this story trying to send? Cite examples from the story that make this clear. Cite examples from the evolution of this chapter.**"Welcome to the Monkey House"** Is this story an example of sexual selection? Why or why not? Cite examples from the story and from the chapter to support your thinking.**"The Eighth Queen"** If technology could provide such an instrument, how would it affect the evolution of humans? What about the evolution of other species on Earth?**"Already We Were"** Relate this story to some of the mechanisms of evolution from this chapter as you can. Cite examples from the story and the chapter to support your thinking.**"Tomorrow and Tomorrow and Tomorrow"** Do you think the new types of drugs are a good or bad thing? Where would you draw the line on technology's ability to extend life? How would drugs like these affect the natural selection and evolution of humans? What about the evolution of other species on Earth?

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Battling Resistance • 239

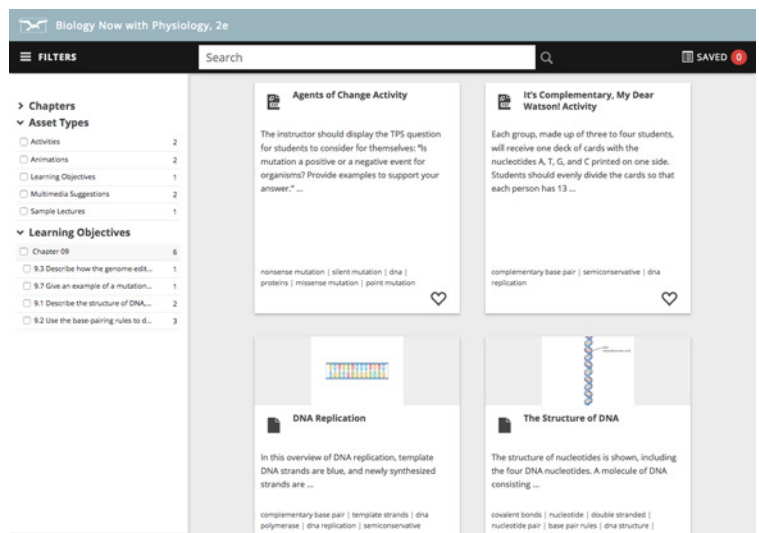
Powerful resources for teaching and assessment



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.



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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.



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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.

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Reviewers

Second Edition

Anne Artz, Preuss School, UC San Diego

Allan Ayella, McPherson College

Erin Baumgartner, Western Oregon
University

Joydeep Bhattacharjee, University of
Louisiana, Monroe

Rebecca Brewer, Troy High School

Victoria Can, Columbia College Chicago

Lisa Carloye, Washington State University,
Pullman

Michelle Cawthorn, Georgia Southern
University

Craig Clifford, Northeastern State
University

Beth Collins, Iowa Central Community College
Julie Constable, California State University, Fresno
Gregory A. Dahlem, Northern Kentucky University
Danielle M. DuCharme, Waubesa Community College
Robert Ewy, SUNY Potsdam
Clayton Faivor, Ellsworth Community School
Michael Fleming, California State University, Stanislaus
Kathy Gallucci, Elon University
Kris Gates, Pikes Peak Community College
Heather Giebink, Pennsylvania State University
Candace Glendening, University of Redlands
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Meshagae Hunte-Brown, Drexel University
Douglas P. Jensen, Converse College
Ragupathy Kannan, University of Arkansas–Fort Smith
Julia Khodor, Bridgewater State University
Jennifer Kloock, Garces Memorial High School
Karen L. Koster, University of South Dakota
Dana Robert Kurpius, Elgin Community College
Joanne Manaster, University of Illinois
Mark Manteuffel, St. Louis Community College
Jill Maroo, University of Northern Iowa
Tsitsi McPherson, SUNY Oneonta
Kiran Misra, Edinboro University of Pennsylvania
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Lori Nicholas, New York University
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Christopher J. Osovitz, University of South Florida
Christopher Parker, Texas Wesleyan University
Brian K. Paulson, California University of Pennsylvania
Carolina Perez-Heydrich, Meredith College
Thomas J. Peri, Notre Dame Preparatory School

Kelly Norton Pipes, Wilkes Early College High School
Gordon Plague, SUNY Potsdam
Benjamin Predmore, University of South Florida
Jodie Ramsey, Highland High School
Logan Randolph, Polk State College
Debra A. Rinne, Seminole State College of Florida
Michael L. Rutledge, Middle Tennessee State University
Celine Santiago Bass, Kaplan University
Steve Schwendemann, Iowa Central Community College
Sonja Stampfler, Kellogg Community College
Jennifer Sunderman Broo, Saint Ursula Academy
J. D. Swanson, Salve Regina University
Heidi Tarus, Colby Community College
Larchinee Turner, Central Carolina Technical College
Ron Vanderveer, Eastern Florida State College
Calli A. Versagli, Saint Mary's College
Mark E. Walvoord, University of Oklahoma
Lisa Weasel, Portland State University
Derek Weber, Raritan Valley Community College
Danielle Werts, Golden Valley High School
Elizabeth Wright, Athenian School
Steve Yuza, Neosho County Community College

First Edition

Joseph Ahlander, Northeastern State University
Stephen F. Baron, Bridgewater College
David Bass, University of Central Oklahoma
Erin Baumgartner, Western Oregon University
Cindy Bida, Henry Ford Community College
Charlotte Borgeson, University of Nevada, Reno
Bruno Borsari, Winona State University
Ben Brammell, Eastern Kentucky University
Christopher Butler, University of Central Oklahoma
Stella Capoccia, Montana Tech

Kelly Cartwright, College of Lake County
 Emma Castro, Victor Valley College
 Michelle Cawthorn, Georgia Southern
 University
 Jeannie Chari, College of the Canyons
 Jianguo Chen, Claflin University
 Beth Collins, Iowa Central Community
 College
 Angela Costanzo, Hawai'i Pacific
 University
 James B. Courtright, Marquette University
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 Community College
 Julie Ehresmann, Iowa Central
 Community College
 Laurie L. Foster, Grand Rapids
 Community College
 Teresa Golden, Southeastern Oklahoma
 State University
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 Tonia Hermon, Norfolk State University
 Glenda Hill, El Paso Community College
 Vicki J. Huffman, Potomac State College,
 West Virginia University
 Carl Johansson, Fresno City College
 Victoria Johnson, San Jose State University
 Anthony Jones, Tallahassee Community
 College
 Hinrich Kaiser, Victor Valley College
 Vedham Karpakakunjaram, Montgomery
 College
 Dauna Koval, Bellevue College
 Maria Kretzmann, Glendale Community
 College
 MaryLynne LaMantia, Golden West
 College
 Brenda Leady, University of Toledo
 Lisa Maranto, Prince George's Community
 College
 Roy B. Mason, Mt. San Jacinto College
 Gabrielle L. McLemore, Morgan State
 University
 Paige Mettler-Cherry, Lindenwood
 University
 Rachel Mintell, Manchester Community
 College
 Kiran Misra, Edinboro University of
 Pennsylvania

Lori Nicholas, New York University
 Louise Mary Nolan, Middlesex Community
 College
 Fran Norflus, Clayton State University
 Brian Paulson, California University of
 Pennsylvania
 Carolina Perez-Heydrich, Meredith College
 Ashley Ramer, University of Akron
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 Tim Revell, Mt. San Antonio College
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 Kathreen Ruckstuhl, University of Calgary
 Michael L. Rutledge, Middle Tennessee
 State University
 Brian Sato, UC Irvine
 Malcolm D. Schug, University of North
 Carolina at Greensboro
 Craig M. Scott, Clarion University of
 Pennsylvania
 J. Michael Sellers, University of Southern
 Mississippi
 Marieken Shaner, University of New
 Mexico
 David Sheldon, St. Clair County
 Community College
 Jack Shurley, Idaho State University
 Daniel Sigmon, Alamance Community
 College
 Molly E. Smith, South Georgia State
 College, Waycross
 Lisa Spring, Central Piedmont Community
 College
 Steven R. Strain, Slippery Rock University
 of Pennsylvania
 Jeffrey L. Travis, SUNY Albany
 Suzanne Wakim, Butte College
 Mark E. Walvoord, University of Oklahoma
 Sherman Ward, Virginia State University
 Lisa Weasel, Portland State University
 Jennifer Wiatrowski, Pasco-Hernando
 State College
 Rachel Wiechman, West Liberty University
 Bethany Williams, California State
 University, Fullerton
 Satya M. Witt, University of New Mexico
 Donald A. Yee, University of Southern
 Mississippi

Focus Group Participants

Michelle Cawthorn, Georgia Southern University
Marc Dal Ponte, Lake Land College
Kathy Gallucci, Elon University
Tamar Goulet, University of Mississippi
Sharon Gusky, Northwestern Connecticut Community College
Krista Henderson, California State University, Fullerton
Tara Jo Holmberg, Northwestern Connecticut Community College
Brenda Hunzinger, Lake Land College
Jennifer Katcher, Pima Community College
Cynthia Kay-Nishiyama, California State University, Northridge
Kathleen Kresge, Northampton Community College
Sharon Lee-Bond, Northampton Community College
Suzanne Long, Monroe Community College
Boriana Marintcheva, Bridgewater State University
Roy B. Mason, Mt. San Jacinto College
Gwen Miller, Collin College
Kimo Morris, Santa Ana College
Fran Norflus, Clayton State University
Tiffany Randall, John Tyler Community College
Gail Rowe, La Roche College
J. Michael Sellers, University of Southern Mississippi
Uma Singh, Valencia College
Patti Smith, Valencia College
Bethany Stone, University of Missouri
Willetta Toole-Simms, Azusa Pacific University
Bethany Williams, California State University, Fullerton

Class Test Participants

Bruno Borsari, Winona State University
Jessica Brzyski, Georgia Southern University
Beth Collins, Iowa Central Community College

Christopher Collumb, College of Southern Nevada
Jennifer Cooper, University of Akron
Julie Ehresmann, Iowa Central Community College
Michael Fleming, California State University, Stanislaus
Susan Holecheck, Arizona State University
Dauna Koval, Bellevue College
Kiran Misra, Edinboro University of Pennsylvania
Marcelo Pires, Saddleback College
Michael L. Rutledge, Middle Tennessee State University
Jack Shurley, Idaho State University
Uma Singh, Valencia College
Paul Verrell, Washington State University
Daniel Wetzel, Georgia Southern University
Rachel Wiechman, West Liberty University

Instructor and Student Resource Contributors

Holly Ahern, SUNY Adirondack
Steven Christenson, Brigham Young University-Idaho
Beth Collins, Iowa Central Community College
Julie Ehresmann, Iowa Central Community College
Jenny Gernhart, Iowa Central Community College
Julie Harless, Lone Star College
Janet Harouse, New York University
Vedham Karpakakunjaram, Montgomery College
Dauna Koval, Bellevue College
Brenda Leady, University of Toledo
Boriana Marintcheva, Bridgewater State University
Paige Mettler-Cherry, Lindenwood University
Lori Nicholas, New York University
Christopher Osovitz, University of South Florida
Tiffany Randall, John Tyler Community College
Lori Rose, Sam Houston State University
Suzanne Wakim, Butte College
Bethany Williams, California State University, Fullerton

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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.

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.



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.

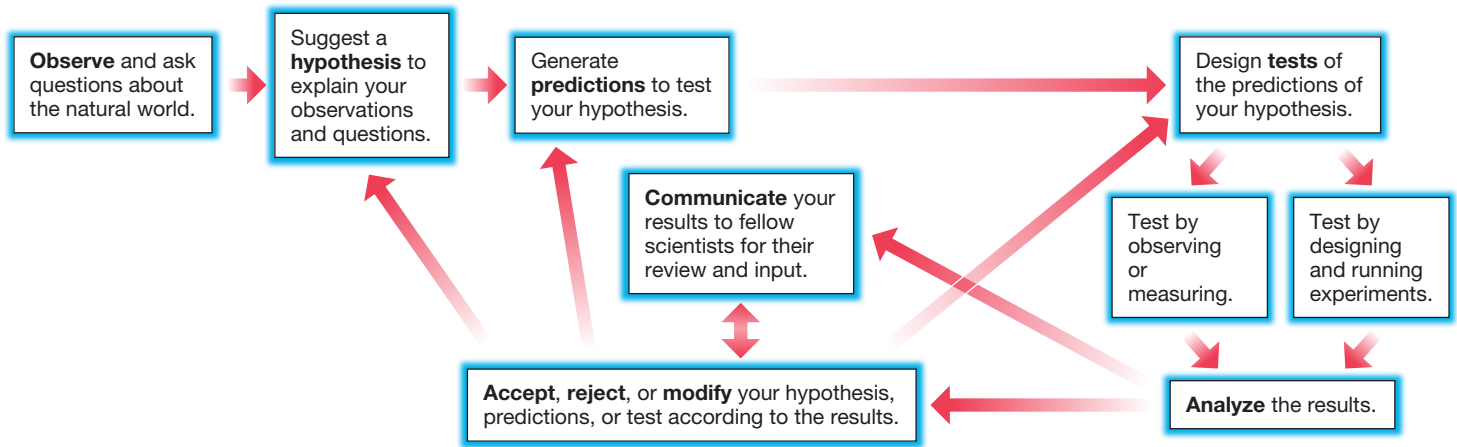



Figure 1.1

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.”

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.



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?

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

Melissa Behr, formerly with the New York Department of Health, is now a doctor of veterinary medicine at South Dakota State University. She conducts research on the pathology and biology of bats and teaches at the UW veterinary school.

