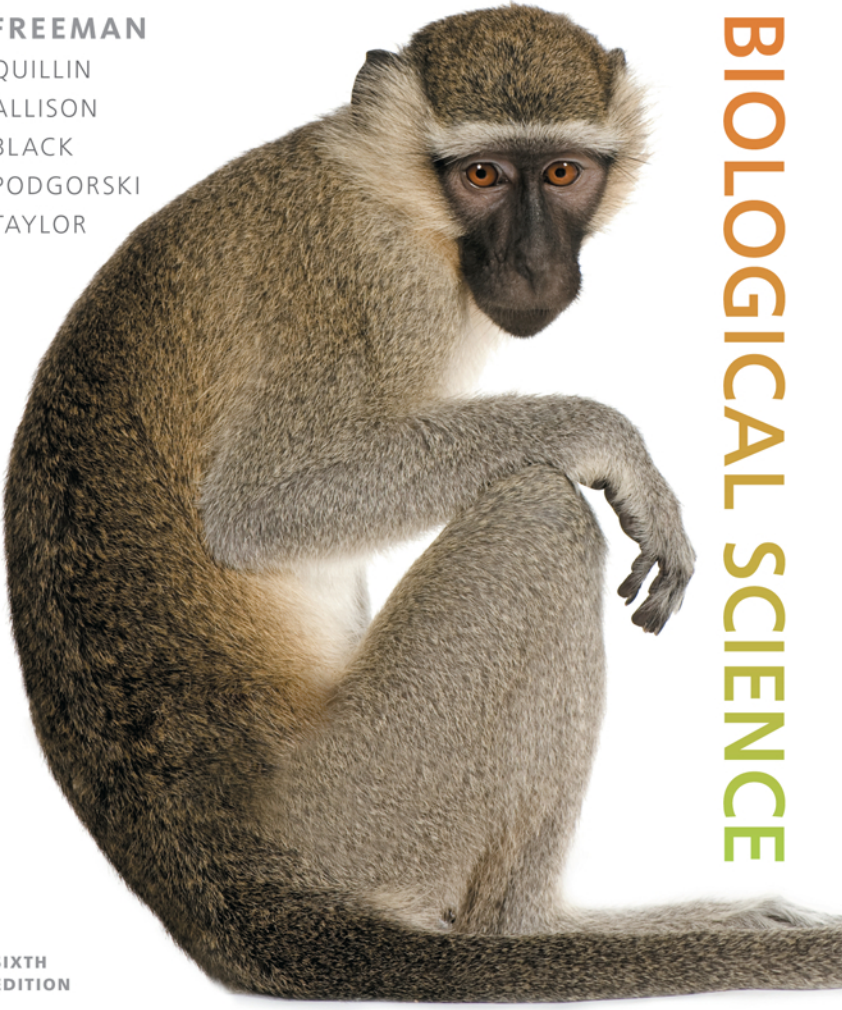
FREEMAN
QUILLIN
ALLISON
BLACK
PODGORSKI
TAYLOR

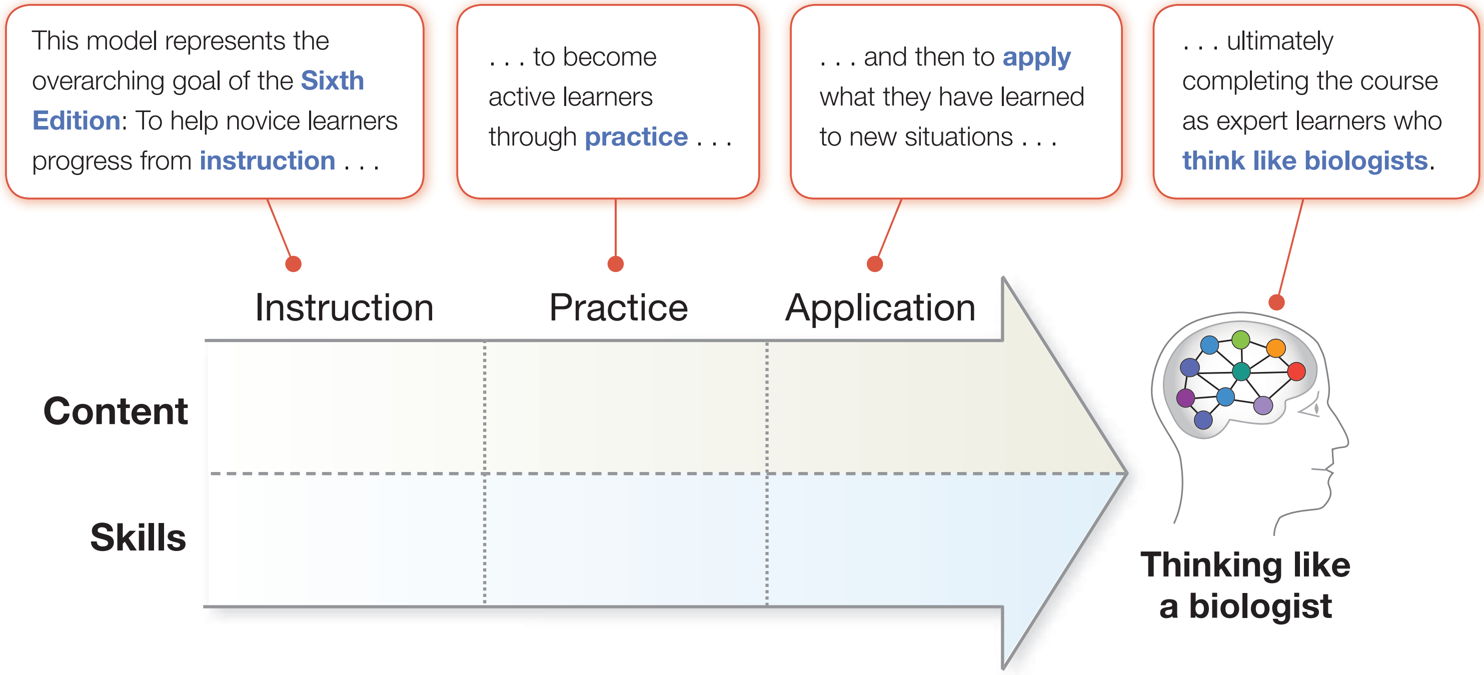
BIOLOGICAL SCIENCE



SIXTH EDITION

A Student-Centered Approach to the Study of Biology

Since its trailblazing First Edition, ***Biological Science*** has delivered numerous biology teaching innovations that emphasize higher-order thinking skills and conceptual understanding rather than an encyclopedic grasp of what is known about biology. With each edition, this approach has grown and improved to better help students make the shift from being novice learners to expert learners. Central to this shift is a student-centered approach that provides deep support for the learning of core content and the development of key skills that help students learn and practice biology.



On the pages that follow, we will show how the text and MasteringBiology resources work together to achieve this goal.

Develop a Conceptual Understanding of Biology

Unique Chapter-opening Roadmaps set the table for learning by visually grouping and organizing information to help students anticipate key ideas as well as recognize meaningful relationships and connections that are explored in the chapter that follows.

1 Biology and the Tree of Life

This vervet monkey baby is exploring its new world and learning how to find food and stay alive. It represents one of the key characteristics of life introduced in this chapter—replication.

In essence, biological science is the study of life. It searches for ideas and observations that unify our understanding of the diversity of life—from bacteria living in hot springs to humans and majestic sequoia trees.

The goals of this chapter are to introduce the nature of life and explore how biologists go about studying it. The chapter also introduces themes that will resonate throughout this book:

- Analyzing how organisms work at the molecular level.
- Understanding organisms in terms of their evolutionary history.
- Helping you learn to think like a biologist.

Let's begin with what may be the most fundamental question of all: What is life?

BIG PICTURE

This chapter is part of the Big Picture. See how on pages 16–17.

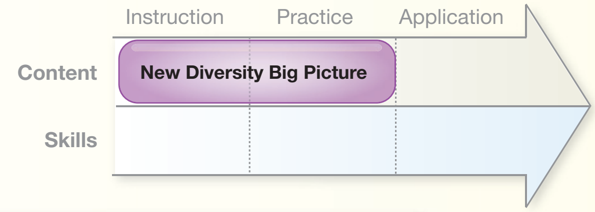
1

Each **Roadmap** begins with a statement of why the chapter topic is important.

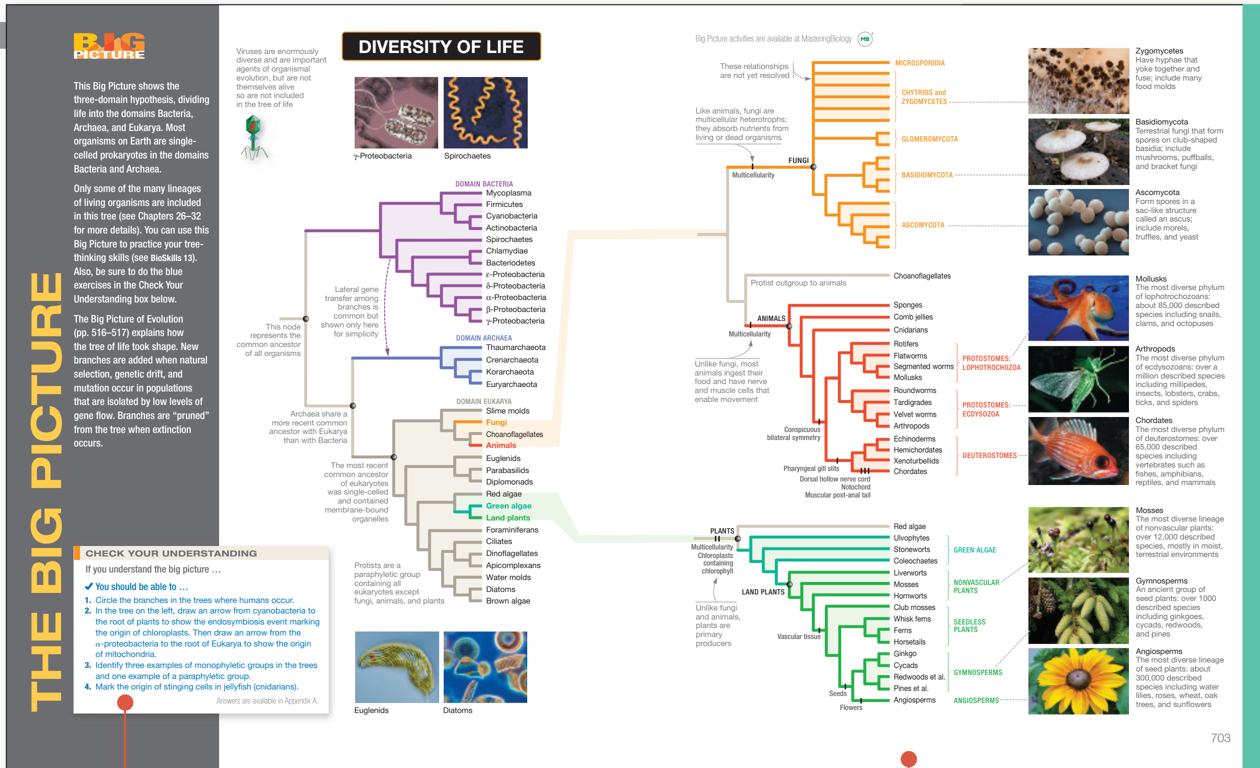
Key topics from each chapter are previewed, and related ideas are connected through **linking words**.

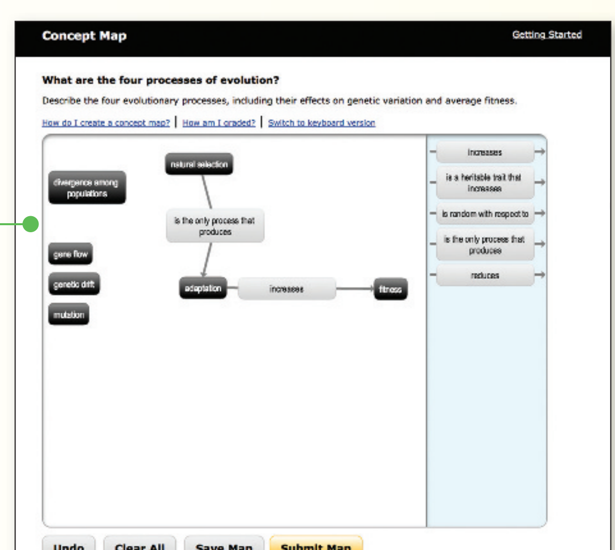
Chapter section numbers help students find key ideas easily in the chapter.

Big Picture Concept Maps are referenced on the opening page of related chapters, pointing students to summary pages that help them synthesize challenging topics.



Big Picture Concept Maps integrate visuals and words to help students synthesize information about challenging topics in biology that span multiple chapters and units.





"You should be able to…" activities

encourage students to analyze important patterns within each Big Picture concept map.

Big Picture topics include:

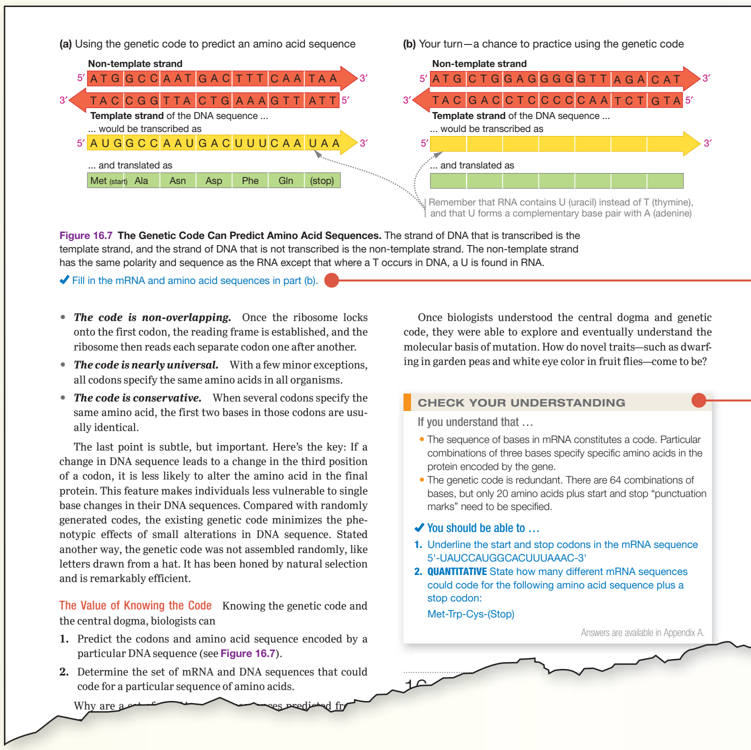
- Doing Biology, pp. 16–17
- The Chemistry of Life, pp. 140–141
- Energy for Life, pp. 232–233
- Genetic Information, pp. 396–397
- Evolution, pp. 516–517
- **NEW!** Diversity of Life, pp. 702–703
- Plant and Animal Form and Function, pp. 816–817
- Ecology, pp. 1162–1163

MasteringBiology®

Big Picture concept map tutorials are challenging, higher-level activities that require students to build their own concept map and to answer questions about the content. They are automatically graded to make it easy for professors to assign. New to the **Sixth Edition** are tutorials on diversity.

Engage in Scientific Inquiry and Active Problem-Solving

A wide variety of practice questions and exercises are designed to encourage readers to pause and test their understanding as they proceed through each chapter. All questions and exercises are highlighted in blue throughout the text.


(a) Using the genetic code to predict an amino acid sequence

(b) Your turn—a chance to practice using the genetic code

Figure 16.7 The Genetic Code Can Predict Amino Acid Sequences. The strand of DNA that is transcribed is the template strand, and the strand of DNA that is not transcribed is the non-template strand. The non-template strand has the same polarity and sequence as the RNA except that where a T occurs in DNA, a U is found in RNA.

✓ Fill in the mRNA and amino acid sequences in part (b).

- ***The code is non-overlapping.*** Once the ribosome locks onto the first codon, the reading frame is established, and the ribosome then reads each separate codon one after another.
- ***The code is nearly universal.*** With a few minor exceptions, all codons specify the same amino acids in all organisms.
- ***The code is conservative.*** When several codons specify the same amino acid, the first two bases in those codons are usually identical.

The last point is subtle, but important. Here's the key: If a change in DNA sequence leads to a change in the third position of a codon, it is less likely to alter the amino acid in the final protein. This feature makes individuals less vulnerable to single base changes in their DNA sequences. Compared with randomly generated codes, the existing genetic code minimizes the phenotypic effects of small alterations in DNA sequence. Stated another way, the genetic code was not assembled randomly, like letters drawn from a hat. It has been honed by natural selection and is remarkably efficient.

The Value of Knowing the Code Knowing the genetic code and the central dogma, biologists can

1. Predict the codons and amino acid sequence encoded by a particular DNA sequence (see **Figure 16.7**).
2. Determine the set of mRNA and DNA sequences that could code for a particular sequence of amino acids.

Why are a set of ... sequences predicted fr...

Once biologists understood the central dogma and genetic code, they were able to explore and eventually understand the molecular basis of mutation. How do novel traits—such as dwarfing in garden peas and white eye color in fruit flies—come to be?

CHECK YOUR UNDERSTANDING

If you understand that ...

- The sequence of bases in mRNA constitutes a code. Particular combinations of three bases specify specific amino acids in the protein encoded by the gene.
- The genetic code is redundant. There are 64 combinations of bases, but only 20 amino acids plus start and stop "punctuation marks" need to be specified.

✓ You should be able to ...

1. Underline the start and stop codons in the mRNA sequence 5'-UAUCCAUGGCACUUUAAAC-3'
2. **QUANTITATIVE** State how many different mRNA sequences could code for the following amino acid sequence plus a stop codon:
Met-Trp-Cys-(Stop)

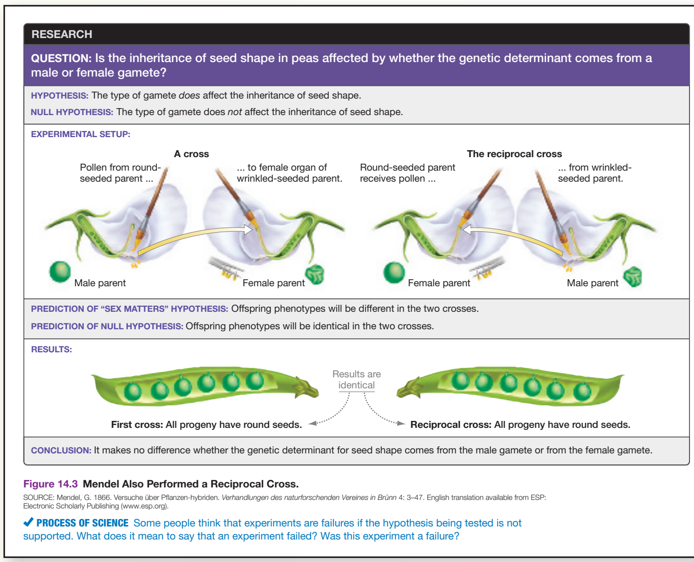
Answers are available in Appendix A.

Figure and table caption questions and exercises ask students to critically examine information in figures and tables.

Check Your Understanding activities ask students to work with important concepts in the chapter.

Research boxes teach students how we know what we know about biology by using current and classic research to model the observational and hypothesis-testing process of scientific discovery.

Each Research box concludes with a **question or exercise** that asks students to think critically about experimental design by predicting outcomes, analyzing the setup used to test a hypothesis, or interpreting data found in experimental results


RESEARCH

QUESTION: Is the inheritance of seed shape in peas affected by whether the genetic determinant comes from a male or female gamete?

HYPOTHESIS: The type of gamete *does* affect the inheritance of seed shape.

NULL HYPOTHESIS: The type of gamete does *not* affect the inheritance of seed shape.

EXPERIMENTAL SETUP:

PREDICTION OF "SEX MATTERS" HYPOTHESIS: Offspring phenotypes will be different in the two crosses.

PREDICTION OF NULL HYPOTHESIS: Offspring phenotypes will be identical in the two crosses.

RESULTS:

CONCLUSION: It makes no difference whether the genetic determinant for seed shape comes from the male gamete or from the female gamete.

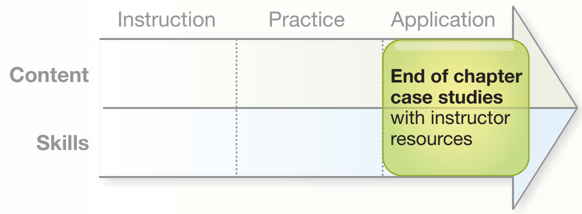
Figure 14.3 Mendel Also Performed a Reciprocal Cross.

SOURCE: Mendel, G. 1866. Versuche über Pflanzen-hybriden. *Verhandlungen des naturforschenden Vereines in Brünn* 4: 3–47. English translation available from ESP: Electronic Scholarly Publishing (www.esp.org).

✓ **PROCESS OF SCIENCE** Some people think that experiments are failures if the hypothesis being tested is not supported. What does it mean to say that an experiment failed? Was this experiment a failure?

MasteringBiology®

"Solve It" Tutorials engage learners in a multi-step investigation of a "mystery" or open question in which students must analyze real data.



Steps to Building Understanding

Each chapter ends with three groups of questions that build in difficulty

✔ TEST YOUR KNOWLEDGE

Begin by testing your basic knowledge of new information.

✔ TEST YOUR UNDERSTANDING

Once you're confident with the basics, demonstrate your deeper understanding of the material.

✔ TEST YOUR PROBLEM-SOLVING SKILLS

Work towards mastery of the content by answering questions that challenge you at the highest level of competency.

NEW! "Put It All Together" case studies appear at the end of every chapter and provide a brief summary of contemporary biology research in action. Each case study connects what students learn in class with current, real-world biology research questions. At least one question requires students to **analyze real data** or apply **quantitative skills**.

MasteringBiology®

NEW! Case study questions from the end of chapter are assignable in MasteringBiology.

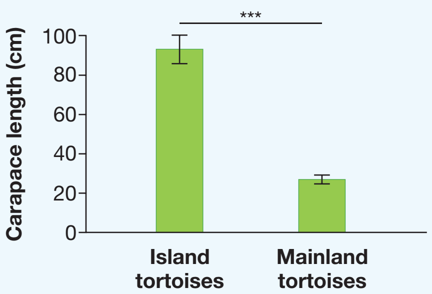
NEW! Classroom activity questions about the case study are available for clickers to help instructors easily incorporate the case studies into their classroom teaching.

✔ PUT IT ALL TOGETHER: Case Study

How does gigantism affect the physiology of animals?

Many species of animals on islands are larger than related species on the mainland. Scientists hypothesize that this phenomenon, called island gigantism, evolved in response to the scarcity of competitors and predators on islands. Reduced competition and predation allows species to exploit more resources and frees them from the need to hide in small refuges.

11. **QUANTITATIVE** The graph shown here compares the average carapace (shell) length of mainland and island tortoises. Summarize the results (*** means $P < 0.001$, see **BioSkills 3**), then use the data to predict whether the surface area/volume ratio is higher in mainland or island tortoises.



Source: Jaffe, A. L., G. J. Slater, and M. E. Alfaro. 2011. *Biology Letters* 7: 558–561.

12. Which tortoises, mainland or island, need to eat more food per gram of their body mass?

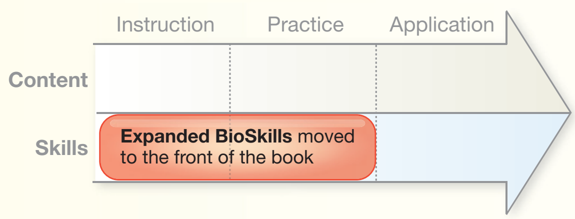
13. Which of the following might be a trade-off of gigantism experienced by giant island tortoises?
- **a.** They cool very rapidly during cold weather.
- **b.** It would be difficult to sustain their high mass-specific metabolic rates on a diet of plants alone.
- **c.** It could be more difficult to avoid thermally unfavorable conditions.
- **d.** They could hide from nonnative predators more easily.

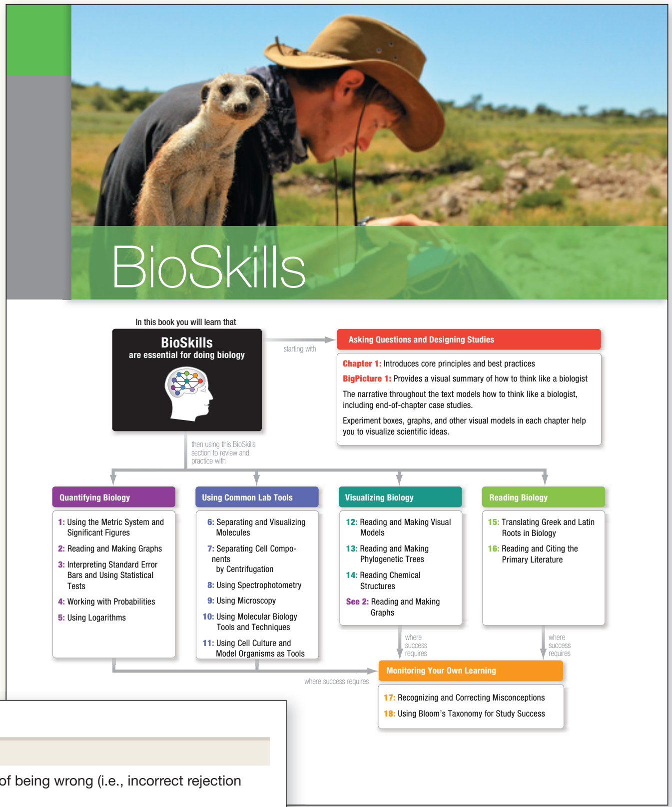
14. **CAUTION** True or false: The body temperatures of island tortoises always closely match the temperatures in their environments.

15. Suppose that a small mainland tortoise and a large island tortoise are placed in the same pen at a zoo. Which tortoise will be more poikilothermic, the small or large tortoise? Why?

16. **CAUTION** On a trip to the Galápagos Islands, you overhear a group of tourists refer to tortoises as "cold blooded." Explain why this word is not accurate to describe a giant tortoise.

Develop Skills for Success in Biology and Beyond…





NEW! Unique BioSkills reference section is now placed earlier in the text to draw attention to key skills students need to succeed in biology. Previously located in an appendix at the end of the text, this easy-to-find reference material now follows Chapter 1 to better support the development of skills throughout the course. Each BioSkill includes practice exercises.

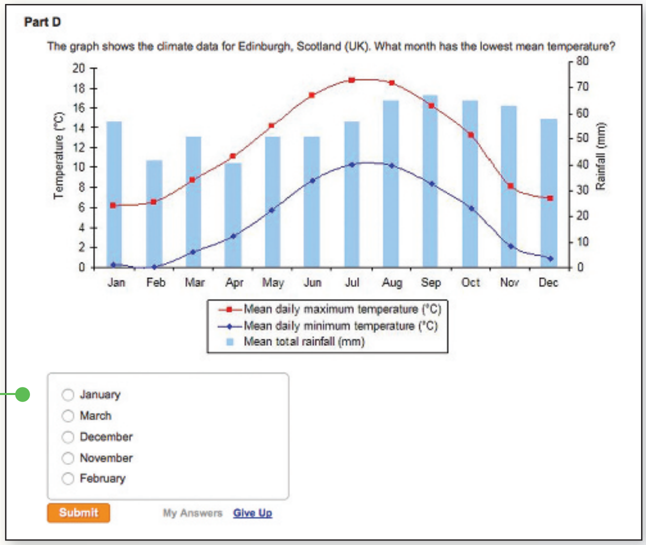
Table B3.1 Asterisk Rating System for *P* Values and Statistical Significance

P Value	Asterisk Rating	Statistical Significance Level	Meaning
$P > 0.05$	None	Not significant	Greater than a 1 in 20 chance of being wrong (i.e., incorrect rejection of the null hypothesis)
$P < 0.05$	*	Statistically significant	Less than a 1 in 20 chance of being wrong
$P < 0.01$	**	Statistically significant	Less than a 1 in 100 chance of being wrong
$P < 0.001$	***	Statistically significant	Less than a 1 in 1000 chance of being wrong

EXPANDED! BioSkill on Interpreting Standard Error Bars and Using Statistical Tests includes a new discussion of commonly used tests, such as chi square, t-test, and analysis of variance (ANOVA). A new section discusses interpreting *P* values and statistical significance.

MasteringBiology®

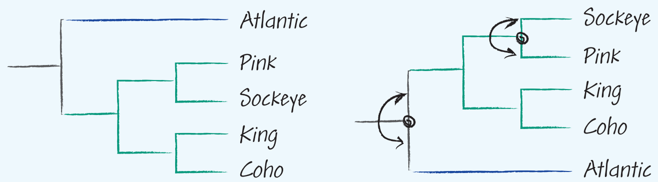
BioSkills review questions are available in the Study Area for self-paced learning and practice. Additional BioSkills questions in the item library are assignable for homework.



	Instruction	Practice	Application
Content	**Model-based reasoning boxes, videos, and aligned questions** added throughout book and in MasteringBiology		
Skills			

Making Models 25.1 Tips on Drawing Phylogenetic Trees

The closeness of taxon labels cannot be used to determine relationships among taxa. To understand why, you must view and draw trees as flexible models that can rotate at each node (like mobiles hanging from a ceiling) rather than as a static structures.



These trees have the same meaning.

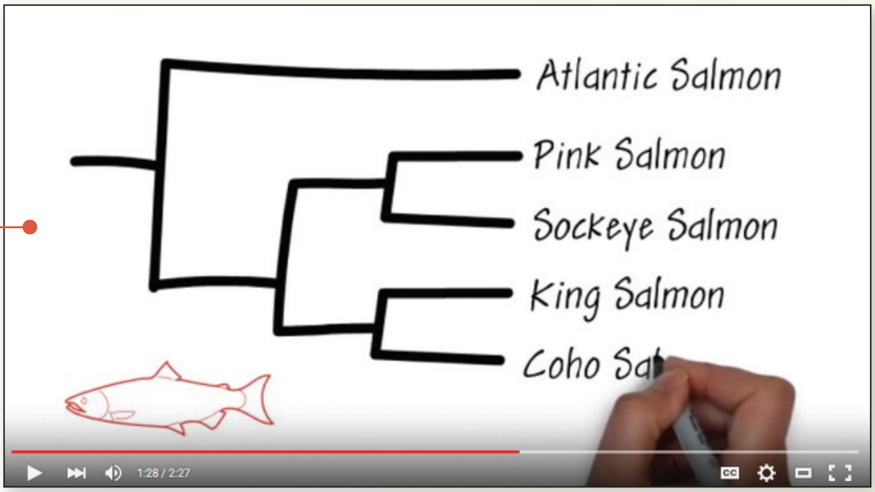
MODEL Draw one more "equivalent" tree with the same meaning as the two above, rotating one or more of the nodes.

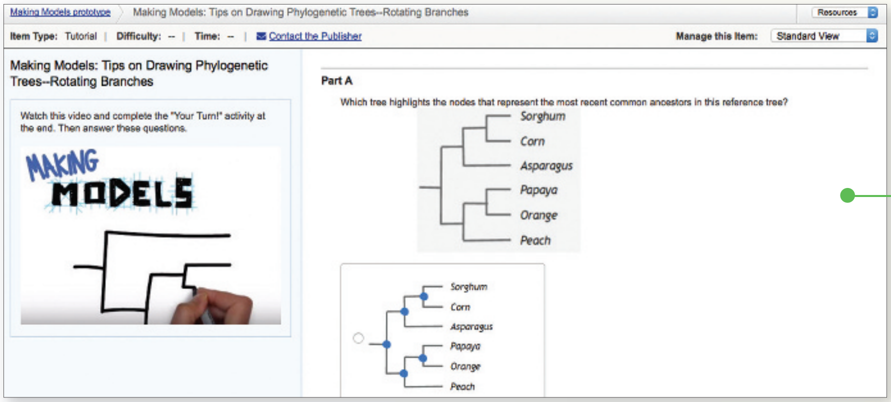
To see this model in action, go to https://goo.gl/mskc9S

NEW! Unique Making Models boxes appear at strategic points throughout chapters as a guide for developing a deeper understanding of biology concepts by interpreting and creating visual models.

Readers can access the videos via **QR codes**, through the eText, or in the Study Area of MasteringBiology.

NEW! Interactive whiteboard videos accompany each Making Models box to reinforce learning and to demonstrate how to build visual models.



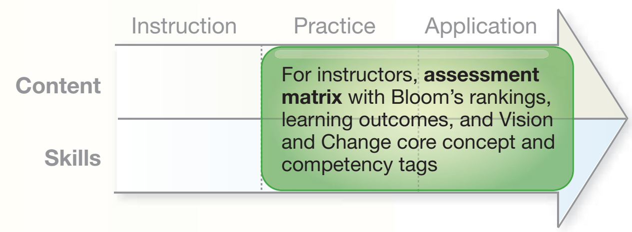


MasteringBiology®

NEW! Making Models activities are assignable for homework and include the whiteboard videos plus application questions that help in developing the skills of interpreting visual models.

For Instructors: Easily Align Assessment with Your Course Goals

Informed by current science education research and curriculum reform strategies, the Sixth Edition instructor resources provide a broad range of easy-to-use assessment options.



NEW! Chapter Assessment Grids help instructors quickly identify suitable assessment questions in the text according to learning outcomes, Bloom's taxonomy ranking, core concepts and core competencies discussed in the *Vision and Change in Undergraduate Biology Education* report, and, when applicable, common student misconceptions.

BLOOMS TAXONOMY RANKING

"Blue Thread" questions, including end-of-chapter problems, are ranked according to **Bloom's taxonomy** and are assignable in MasteringBiology.

LEARNING OUTCOMES

Each question is tagged to a publisher-provided **Learning Outcome**. Instructors may also track their own Learning Outcomes using MasteringBiology.

MISCONCEPTIONS

NEW! When applicable, **common student misconceptions** are addressed and identified with targeted questions.

VISION & CHANGE CORE CONCEPTS

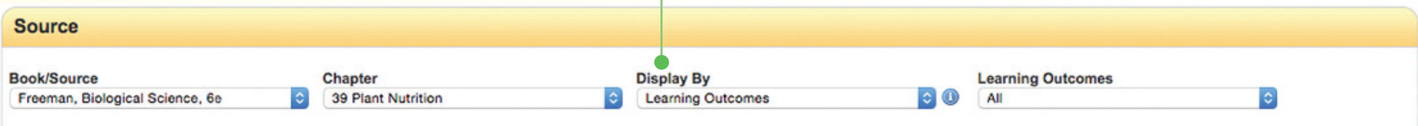
NEW! Each question that covers a **Core Concept** from the *Vision and Change in Undergraduate Biology Education* report is noted in the chapter assessment grid and in MasteringBiology.

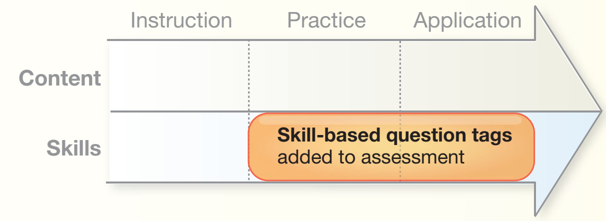
VISION & CHANGE CORE COMPETENCIES

NEW! Core Competencies from the *Vision and Change in Undergraduate Biology Education* report are indicated in the chapter assessment grid and in MasteringBiology.

MasteringBiology®

EXPANDED! Questions, activities, and tutorials are tagged by Bloom's ranking, Learning Outcome, and Vision and Change Core Concepts and Core Competencies.





An extensive selection of mid- and high-level assessment questions are provided throughout each chapter to help students learn, practice, and prepare for tests.

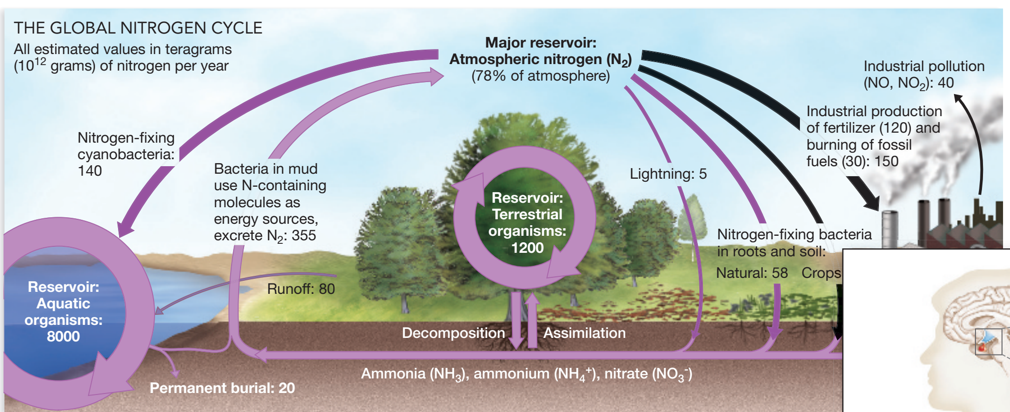


Figure 53.14 The Global Nitrogen Cycle. Nitrogen enters ecosystems as ammonia or nitrate via fixation from atmospheric nitrogen. It is exported in runoff and as nitrogen gas given off by bacteria that use nitrogen-containing compounds as an electron acceptor.

DATA: Fowler, D., et al. 2013. *Philosophical Transactions of the Royal Society B* 368 (1621): 20130165.

✔ **QUANTITATIVE** Calculate the percentage of total nitrogen fixation (all downward-pointing arrows) that is caused by human activities (black arrows).

NEW! Question labels call attention to questions that require **quantitative skills**, an understanding of the **process of science**, connecting biology and **society**, making **models**, and more.

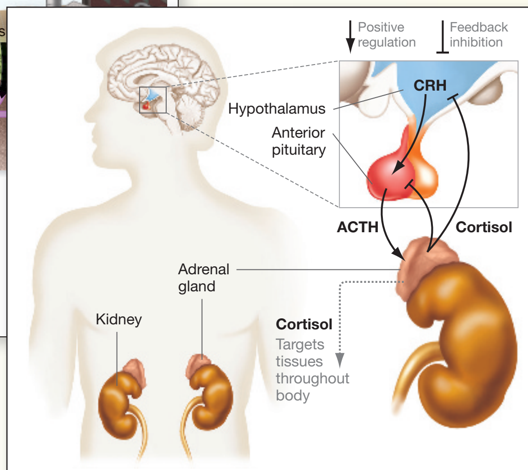


Figure 46.14 The Interaction between Cortisol, ACTH, and CRH Is an Example of Feedback Inhibition.

✔ **PROCESS OF SCIENCE** Use the figure to devise a test for adrenal failure in humans.

NEW! Caution questions address topics for which students often hold common misconceptions. Answers to Caution questions include information that addresses the misconception.

5. **CAUTION** According to data presented in this chapter, which one of the following statements is correct?
   a. When individuals change in response to challenges from the environment, their altered traits are passed on to offspring.
   b. Species are created independently of each other and do not change over time.
   c. Populations—not individuals—change when natural selection occurs.
   d. The traits of populations become more perfect over time.

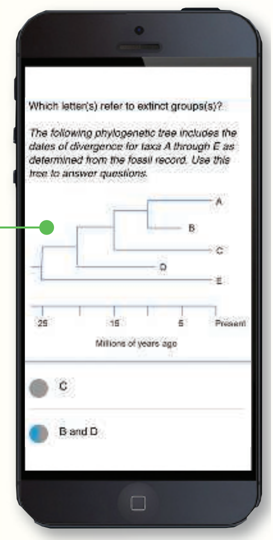
Succeed with MasteringBiology®

MasteringBiology is a powerful online learning and assessment system proven to improve results by engaging students before, during, and after class with a deep library of helpful activities. Mastering brings learning full circle by continuously adapting to each student and making learning more personal than ever—before, during, and after class.

Before Class

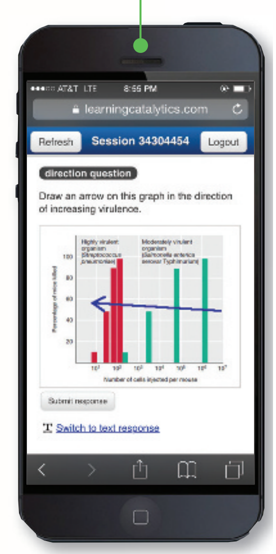
NEW! Dynamic Study Modules provide students with multiple sets of questions with extensive feedback so that they can test, learn, and retest until they achieve mastery of the textbook material.

NEW! More mobile-friendly Pre-class reading quizzes help students pinpoint concepts that they understand and concepts with which they need more help. By identifying topics that are most difficult for them, students are better prepared to ask questions and more likely to listen actively.



During Class

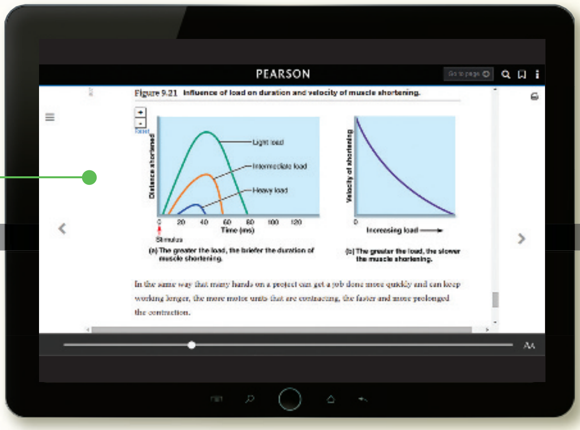
NEW! Learning Catalytics™ allows students to use their smartphone, tablet, or laptop to respond individually or in groups to questions in class. Visit learningcatalytics.com to learn more.



After Class

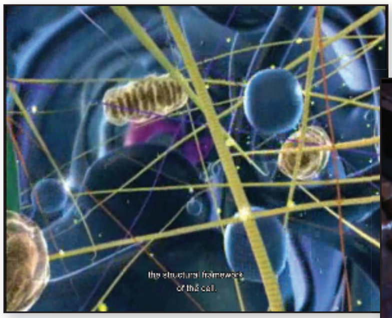
NEW! Optional Adaptive Follow-up Assignments are based on each student's performance on the original MasteringBiology assignment and provide additional questions and activities tailored to each student's needs.

Hundreds of self-paced tutorials and coaching activities provide students with individualized coaching with specific hints and feedback on the toughest topics in the course.

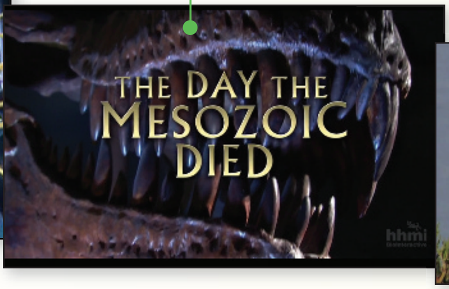


NEW! Pearson eText 2.0 integrates the text with videos and animations, in a format that adapts to the device being used. Features include student and instructor note-taking, highlighting, bookmarking, search, and hotlinked glossary.

MasteringBiology offers a wide variety of tutorials that can be assigned as homework. Examples include:



BioFlix® Tutorials use 3-D, movie-quality animations and coaching exercises to help students master tough topics outside of class. Animations can also be shown in class.



NEW! HHMI Short Films, documentary-quality movies from the Howard Hughes Medical Institute, engage students in topics from the discovery of the double helix to evolution, with assignable questions.

NEW! Galapagos Evolution Videos, filmed by Peter and Rosemary Grant, bring to life the dynamic evolutionary processes that impact Darwin's finches on Daphne Major Island.

INSTRUCTOR AND STUDENT RESOURCES

For Instructors

Instructor's Resource DVD Set
© 2017 | 0134255011 / 9780134255019
Everything you need for lectures is in one place, including video segments that demonstrate how to incorporate active-learning techniques into your own classroom, PowerPoint® Lecture Outlines, and over 300 additional animations.

Instructor's Guide (Download only)
Includes learning objectives, lecture outlines, vocabulary, active learning lecture activities, and clicker questions.

TestGen Test Bank (Download Only)
All of the exam questions in the Test Bank have been peer reviewed, providing questions that set the standard for quality and accuracy. Questions have been improved by evaluating user data from MasteringBiology. Test questions are ranked according to Bloom's taxonomy.

For Students

Study Guide by Warren Burggren et. al.
© 2017 | 0134254155 / 9780134254159
The Study Guide presents a breakdown of key biological concepts, difficult topics, and quizzes to help students prepare for exams.

Practicing Biology: A Student Workbook
© 2017 | 0134261941 / 9780134261942
This workbook provides a variety of hands-on activities such as mapping and modeling to suit different learning styles and help students discover which topics they need more help on. Students learn biology by doing biology.

BIOLOGICAL SCIENCE

Vervet monkey,
Chlorocebus pygerythrus

BIOLOGICAL SCIENCE

SIXTH EDITION

SCOTT FREEMAN
University of Washington

KIM QUILLIN
Salisbury University

LIZABETH ALLISON
College of William & Mary

MICHAEL BLACK
California Polytechnic State University in San Luis Obispo

GREG PODGORSKI
Utah State University

EMILY TAYLOR
California Polytechnic State University in San Luis Obispo

JEFF CARMICHAEL
University of North Dakota

PEARSON

Editor-in-Chief: Beth Wilbur
Senior Acquisitions Editor: Michael Gillespie
Project Managers: Mae Lum and Libby Reiser
Program Manager: Anna Amato
Senior Development Editor: Sonia DiVittorio
Development Editors: Stephanie Keep, Moira Lerner Nelson, Jennifer Angel, Mary Catherine Hager, Matt Lee, Mary Hill
Editorial Assistants: Josey Gist and Chloé Veylit
Instructor Media Project Managers: Eddie Lee and Chelsea Logan
Media Content Producers: Libby Reiser and Ziki Dekel
Executive Editorial Manager: Ginnie Simione Jutson
Program Management Team Lead: Michael Early
Project Management Team Lead: David Zielonka
Production Management: Integra
Copyeditor: Christianne Thillen
Proofreader: Pete Shanks
Compositor: Integra
Design Manager: Marilyn Perry
Interior and Cover Designer: tani hasegawa design
Illustrators: Imagineering Media Services
Rights & Permissions Project Managers: Donna Kalal and Timothy Nicholls
Rights & Permissions Management: Integra
Photo Researchers: Eric Schrader and Kristin Piljay
Manufacturing Buyer: Stacey Weinberger
Executive Marketing Manager: Lauren Harp
Front Cover Photo Credit: Eric Isselée/Fotolia
Title Page and Back Cover Credit: Eric Isselée/Shutterstock

Library of Congress Cataloging-in-Publication Data

Names: Allison, Lizabeth A.
Title: Biological science / Liz Allison [and five others].
Description: 6th edition. | Hoboken : Pearson Higher Education, [2017] | Includes index
Identifiers: LCCN 2015029612 | ISBN 9780321976499 | ISBN 0321976495
Subjects: LCSH: Biology.
Classification: LCC QH308.2 .F73 2017 | DDC 570—dc23
LC record available at http://lccn.loc.gov/2015029612

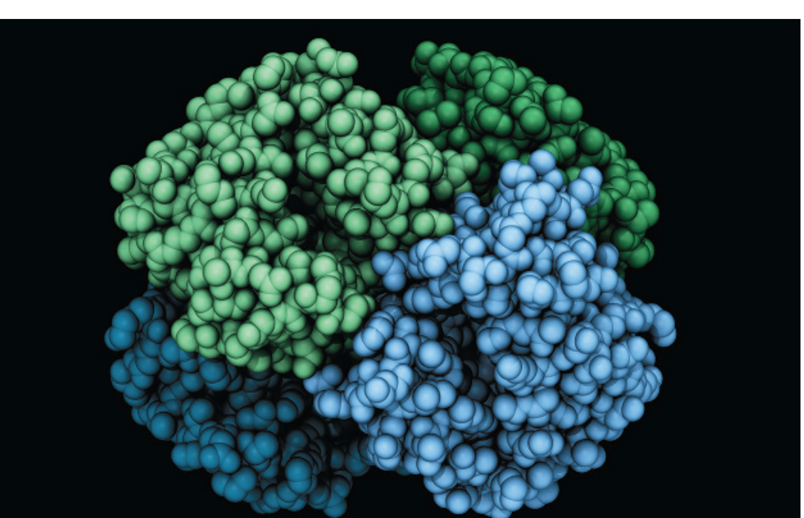
1 2 3 4 5 6 7 8 9 10—**V357**—18 17 16 15 14

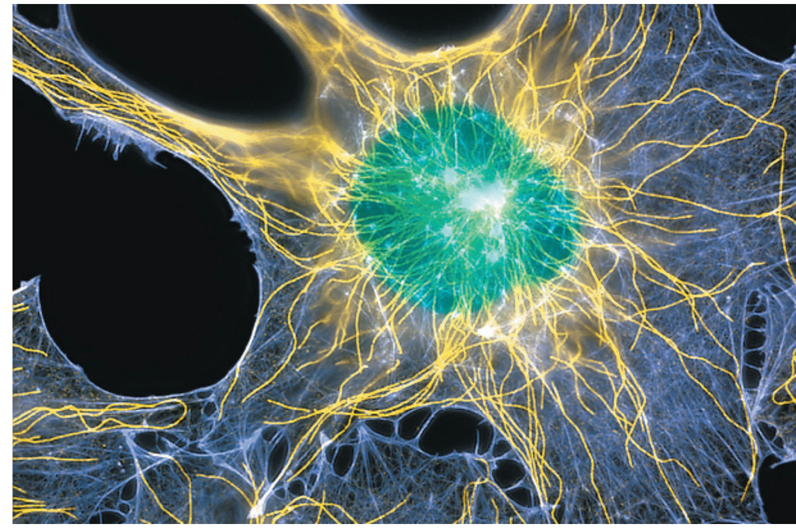
PEARSON

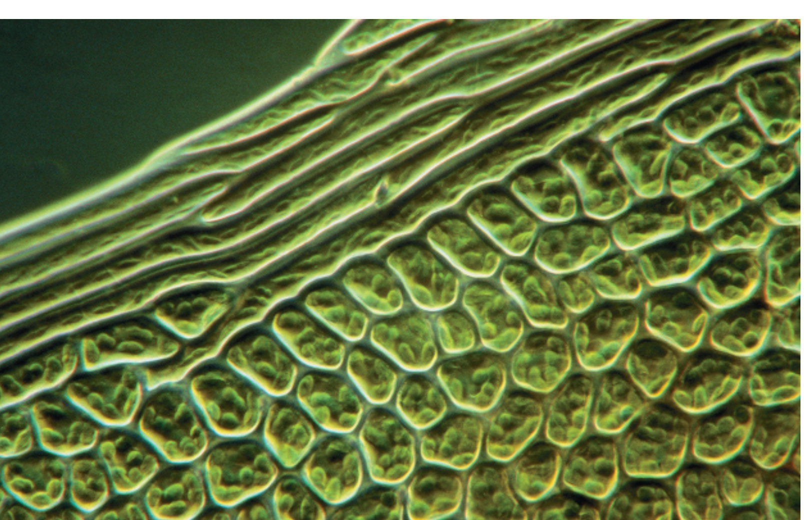
www.pearsonhighered.com

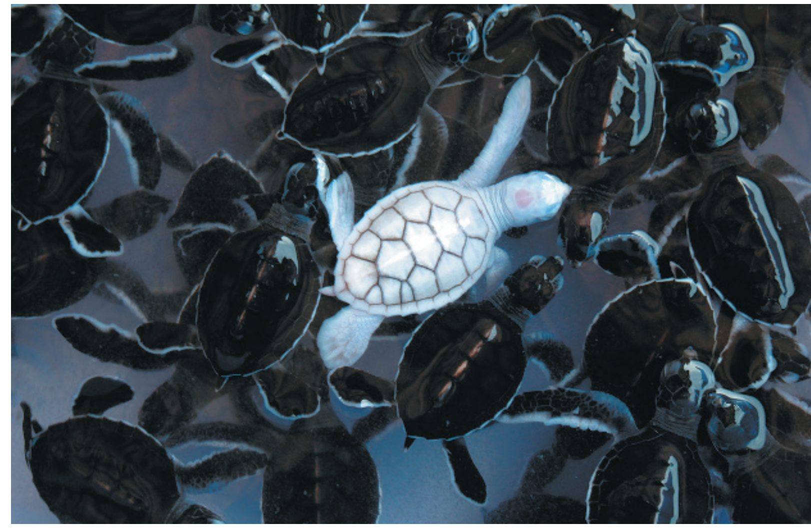
ISBN 10: 0-321-97649-5; ISBN 13: 978-0-321-97649-9 (Student edition)
ISBN 10: 0-134-24306-4; ISBN 13: 978-0-134-24306-1 (Books a la Carte edition)

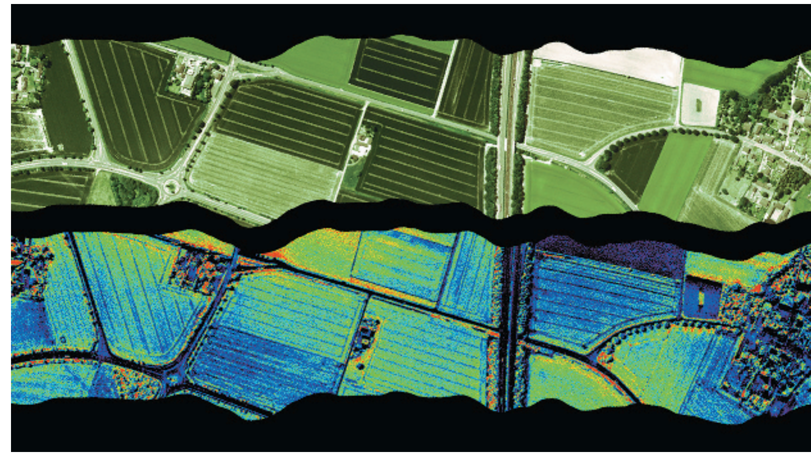
Detailed Contents











About the Authors

A Letter from Scott:

I started working on *Biological Science* in 1997 with a simple goal: To help change the way biology is taught. After just shy of 20,000 hours of work on four editions of this text, that goal still gets me out of bed in the morning. But instead of focusing my energies on textbook writing, I've decided to devote myself full-time to research on student learning and developing new courses for undergraduate and graduate students at the University of Washington.

I have passed the torch to an all-star cast of leading scientists and educators who have enthusiastically taught from, and contributed to, previous editions of *Biological Science*. The new team brings their passion, talent, and creativity to the book, with expertise that spans the breadth of the life sciences. Just as important, they work beautifully together because they think alike. They are driven by a shared concern for student learning, a commitment to the craft of writing, and a background in evidence-based teaching.

These pages provide a brief introduction to Liz Allison, Michael Black, Greg Podgorski, Kim Quillin, Jeff Carmichael, and Emily Taylor. As a group, they've built on the book's existing strengths and infused this edition with fresh energy, perspective, and ideas. I'm full of admiration for what they have accomplished, and excited about the impact this edition will have on biology students from all over the world.

—*Scott Freeman*

Scott Freeman received a Ph.D. in Zoology from the University of Washington and was subsequently awarded an Alfred P. Sloan Postdoctoral Fellowship in Molecular Evolution at Princeton University. He has done research in evolutionary biology on topics ranging from nest parasitism to the molecular systematics of the blackbird family and is coauthor, with Jon Herron, of the standard-setting undergraduate text *Evolutionary Analysis*. Scott is the recipient of a Distinguished Teaching Award from the University of Washington and is currently a Principal Lecturer in the UW Department of Biology, where he teaches introductory biology for majors, a writing-intensive course for majors called The Tree of Life, and a graduate seminar in college science teaching. Scott's current research focuses on how active learning affects student learning and academic performance.

Lizabeth A. Allison is Chancellor Professor of Biology at the College of William & Mary. She received her Ph.D. in Zoology from the University of Washington, specializing in molecular and cellular biology. Before coming to William & Mary, she spent eight years as a faculty member at the University of Canterbury in New Zealand. Liz teaches introductory biology for majors and upper-division molecular biology courses. She has mentored graduate students and more than 100 undergraduate research students, many of them coauthoring papers with her on intracellular trafficking of the thyroid hormone receptor in normal and cancer cells. The recipient of numerous awards, including a State Council for Higher Education in Virginia (SCHEV) Outstanding Faculty Award in 2009, Liz received one of the three inaugural Arts & Sciences Faculty Awards for Teaching Excellence in 2011, and a Plumeri Award for Faculty Excellence in 2012. In addition to her work on this text, she is author of *Fundamental Molecular Biology*, now in its second edition, with a third edition underway.
Lead Author; Chapter 1 and BioSkills
laalli@wm.edu

Michael Black received his Ph.D. in Microbiology & Immunology from Stanford University School of Medicine as a Howard Hughes Predoctoral Fellow. After graduation, he studied cell biology as a Burroughs Wellcome Postdoctoral Fellow at the MRC Laboratory of Molecular Biology in Cambridge, England. His current research focuses on the use of molecules to identify and track the transmission of microbes in the environment. Michael is a professor of Cell & Molecular Biology at California Polytechnic State University in San Luis Obispo, where he teaches introductory and advanced classes for majors in cell biology and microbiology. In addition to his teaching and research activities, Michael serves as the director of the Undergraduate Biotechnology Lab, where he works alongside undergraduate technicians to integrate research projects and inquiry-based activities into undergraduate classes.
Chapters 2–12, 33, and 48
mblack@calpoly.edu

Greg Podgorski received his Ph.D. in Molecular and Cellular Biology from Penn State University and has been a postdoctoral fellow at the Max Plank Institute for Biochemistry and Columbia University. His research interests are in biology education, developmental genetics, and computational biology. Greg's most recent work has been in mathematical modeling of how patterns of different cell types emerge during development and how tumors recruit new blood vessels in cancer. Greg has been teaching at Utah State University for more than 20 years in courses that include introductory biology for majors and for nonmajors, genetics, cell biology, developmental biology, and microbiology, and he has offered courses in nonmajors biology in Beijing and Hong Kong. He's won teaching awards at Utah State University and has been recognized by the National Academies as a Teaching Fellow and a Teaching Mentor.

Chapters 13–21

greg.podgorski@usu.edu

Jeff Carmichael received his B.S. in Biology from Slippery Rock University in Pennsylvania and his Ph.D. in Plant Biology from the University of Georgia. As an undergraduate student, he spent some time studying enzyme kinetics through a fellowship at Oak Ridge National Laboratory in Tennessee. His graduate work focused on sexual reproduction in an intriguing group of seed plants. He has been teaching and coordinating Introductory Biology at the University of North Dakota (UND) for more than 20 years. He also serves in the Office of Instructional Development where he helps other faculty members incorporate evidence-based best teaching practices in their courses. He has received excellence in teaching awards at UND and as a graduate student in Georgia. His revision of Unit 6 and part of Unit 5 of the Sixth Edition is his first foray into textbook writing.

Chapters 26–29 and 34–38

Jeffrey.Carmichael@und.edu

Kim Quillin received her B.A. in Biology at Oberlin College *summa cum laude* and her Ph.D. in Integrative Biology from the University of California, Berkeley as a National Science Foundation Graduate Fellow. Kim has worked in the trenches with Scott Freeman on every edition of *Biological Science*, starting with the ground-up development of the illustrations in the first edition in 1999 and expanding her role in each edition, always with the focus of helping students to think like biologists. Kim currently teaches introductory biology at Salisbury University, a member of the University System of Maryland, where she is actively involved in the ongoing student-centered reform of the concepts-and-methods course for biology majors. Her current research focuses on the scholarship of teaching and learning with an emphasis on visual model-based reasoning as a science process skill.

Chapters 22–25, 30–32, 49–54

kxquillin@salisbury.edu

Emily Taylor earned a B.A. in English at the University of California, Berkeley followed by a Ph.D. in Biological Sciences from Arizona State University, where she conducted research in the field of environmental physiology as a National Science Foundation Graduate Research Fellow. She is currently an associate professor of Biological Sciences at the California Polytechnic State University in San Luis Obispo. Her student-centered research program focuses on the endocrine and reproductive physiology of free-ranging reptiles, especially rattlesnakes. She teaches numerous undergraduate and graduate courses, including introductory biology, anatomy and physiology, endocrinology, and herpetology, and received the California Faculty Association's Distinguished Educator Award in 2010 and Cal Poly's Distinguished Teaching Award in 2012.

Chapters 39–47

etaylor@calpoly.edu

Preface to Instructors

From the very first edition, *Biological Science's* unique emphasis on the process of scientific discovery and guiding students to think like biologists has placed this book at the forefront of change in the way we teach biology. The Sixth Edition embraces this legacy and continues to exemplify the principles outlined in the recent *Vision and Change in Undergraduate Biology Education* report. As in previous editions, the cutting-edge biology in the Sixth Edition is pitched at the right level for introductory students, and is as accurate and as exciting as ever for instructors and students alike. New findings from education research continue to inform and inspire the coauthor team's thinking about *Biological Science*—we know more today than ever before about how students learn. These findings demand that we constantly look for new ways to increase student engagement in the learning process. Innovative features new to this edition offer students even more opportunities to actively apply concepts in new situations; evaluate experimental design, hypotheses, and data; synthesize results; and make and interpret models. For instructors, additional resources are provided to help align course activities and learning goals with their assessment strategies.

Core Values

In the Sixth Edition, the coauthor team has strived to extend the vision and maintain the core values of *Biological Science*—to provide a book and online resources for instructors who embrace the challenge of boosting students to higher levels of learning, and to provide a book that helps students each step of the way in learning to think like scientists, regardless of their starting point in the process. Dedicated instructors have high expectations of their students. The Sixth Edition provides tools to help students build their cognitive mastery in both biology content and transferrable skills—to learn at the level called for by the National Academy of Sciences, the Howard Hughes Medical Institute, the American Association of Medical Academies, and the National Science Foundation. Reports such as *Biology 2010, Scientific Foundations for Future Physicians*, and *Vision and Change* all place a premium on fundamental concepts and skills as well as connecting core ideas across all levels of biology.

What's New in This Edition

The Sixth Edition contains many new or expanded features, all of them designed to provide students with initial instruction in content and skills, followed by opportunities for lots of practice in applying knowledge and skills to new contexts. The ultimate goal is for students to learn to construct their own knowledge and think like biologists.

- **Relocated and Expanded BioSkills Section** Instructors recognize that biology students need to develop foundational science skills in addition to content knowledge. Since the Third Edition, *Biological Science* has provided a unique, robust set of materials and activities in an appendix to guide students who need extra help with the skills emphasized in the book. In the Sixth Edition, the BioSkills materials have been placed between Chapters 1 and 2 to emphasize their importance as a resource for success in doing biology, and to make it easier for students to access them throughout the course. The BioSkills are grouped within five broad categories depicted in a new opening road map: Quantifying Biology, Using Common Lab Tools, Visualizing Biology, Reading Biology, and Monitoring Your Own Learning. Four new BioSkills have been added: Using Spectrophotometry, Using Molecular Biology Tools and Techniques, Reading and Making Visual Models, and Recognizing and Correcting Misconceptions. Existing BioSkills have been updated to support new features in the Sixth Edition. For example, the explanation of statistical tests has been expanded, and *P* values are introduced to provide students with essential quantitative skills for interpreting data in the end-of-chapter case studies. BioSkills include practice questions, are cross-referenced throughout the text, and can be assigned online in MasteringBiology®.
- **Making Models Boxes** Reports like *Vision and Change* cite the importance of developing model-based reasoning skills. To help attain this goal, Making Models boxes have been added throughout the book to explicitly teach students how to use visual models to learn and do biology. Each Making Models box has three components: instruction in interpreting or creating a specific type of model, an example of that type of model, and an application question so that students can immediately practice their skills. In addition to the guidance in the text, online video versions are accessible via QR code so students can watch and interact with a dynamic presentation of modeling. Lastly, the video version is also included in an assignable MasteringBiology activity that tests students with higher-level questions.
- **Put It All Together Case Studies** The end-of-chapter question sets for every chapter now include a case study. Case studies briefly introduce contemporary biology research in action, followed by questions that ask students to apply the chapter's content and skills to the research topic. Instructor resources include clicker questions to give instructors the opportunity to use the case studies as discussion prompts in the classroom. A constant hallmark of this text is its emphasis on experimental evidence—on teaching how we know what we know. The case studies expand this emphasis, requiring students to evaluate real data and to see how ongoing scientific research is related to core biological ideas.
- **Big Picture on Biological Diversity** Introduced in the Fourth Edition, Big Picture concept maps integrate words and visuals to help students synthesize information about challenging topics

that span multiple chapters and units. In response to requests from instructors and students, a new Big Picture has been added on the Diversity of Life, illustrating the relationships among the major taxonomic groups in the tree of life.

- **Integrated Chapters** Three newly consolidated chapters reorganize and integrate information to better serve instructors and students. Chapter 20 (The Molecular Revolution: Biotechnology and Beyond) merges the most essential information on genome analysis that was previously discussed in separate chapters, while moving details of fundamental techniques to the BioSkills. Core material on the general principles of development, particularly those related to genetics and evolution, now forms the closing chapter of a streamlined unit on Gene Structure and Expression (Chapter 21). Content on plant and animal development has been moved from the former developmental biology unit to the respective reproduction and development chapters of the How Plants Work (Chapter 38) and How Animals Work (Chapter 47) units.
- **Skill-Based Question Tags** *Biological Science* has long emphasized skill development, and reports like *Vision and Change* also encourage this focus for introductory majors. To help students and instructors identify opportunities to practice key skills, questions are tagged to indicate the following: *Process of Science* questions explore the application of the scientific process; *Model* questions ask students to interpret or construct visual models; *Society* questions explore the relationship between science and society; *Quantitative* questions help students perform quantitative analysis and mathematical reasoning; and *Caution* questions address topics for which students often hold common misconceptions. Answers to *Caution* questions include information that addresses the misconception.
- **Detailed Assessment Matrix** At the beginning of the revision process, we thoroughly evaluated the assessment program and focused on revising it throughout the creation of the Sixth Edition. To aid our analysis, we looked at the question data collected in MasteringBiology, and we created an assessment matrix for each chapter that identifies how each question is related to learning outcomes, Bloom's level, common misconceptions, and *Vision and Change* core concepts and competencies. We hope the tool will assist instructors in selecting the most appropriate assessment items to align with the goals of their course.
- **Expanded Use of Summary Tables** The art program is further enhanced in this edition by additional illustrated summary tables that deliver content in a streamlined way and facilitate comparison and analysis by students. For example, the diversity boxes from the Fifth Edition's The Diversification of Life unit have been redesigned as photographic summary tables. These tables make subject areas more accessible to visual learners and reinforce a chapter's key concepts.

Hallmark Features of the Text

We are excited to introduce new features to the Sixth Edition. At the same time, we are committed to strengthening the hallmark features that make this book unique.

- **Road Maps** Starting with the Fifth Edition, each chapter opens with a concept map that visually groups and organizes information to help students anticipate key ideas as well as recognize meaningful relationships and connections among ideas. While the Road Maps help students look forward as they engage with a chapter, **Big Picture** concept maps integrate words and visuals to help students synthesize information about challenging topics that span multiple chapters or units. Together, these two features help students navigate chapter content and see the forest for the trees.
- **Opportunities for Practice** "Blue Thread" questions, integrated throughout the text, are designed to help students identify what they do and do not understand. The idea is that if students really understand a piece of information or a concept, they should be able to do something with it. As in the Fifth Edition, all questions in the text are assigned a Bloom's taxonomy level to help both students and instructors understand whether a question requires higher-order or lower-order cognitive skills.
  - **In-text "You Should Be Able To" questions** focus on topics and concepts that professors and students have identified as most key or difficult in each chapter.
  - **Caption questions and exercises** challenge students to examine the information in a figure or table critically—not just absorb it.
  - **Check Your Understanding boxes** present two to three tasks that students should be able to complete in order to demonstrate a mastery of summarized key ideas.
  - **End-of-chapter questions** are organized in three levels of increasing difficulty so students can build from lower- to higher-order cognitive levels of assessment.
- **Focus on Real Data** Students now have expanded opportunities to develop skills at working with real data from the primary literature. Sources of the data presented in Research Boxes, graphs, and end-of-chapter Case Studies are cited to model good practice for students and to provide a resource for students and instructors who wish to evaluate the original data more deeply.

Integration of Media

The textbook continues to be supported by MasteringBiology, the most powerful online homework, tutorial, and assessment system available. Tutorials follow the Socratic method, coaching students to the correct answer by offering feedback specific to a student's errors or misconceptions as well as supplying hints that students can access if they get stuck. Instructors can associate content with publisher-provided learning outcomes or create their own. Content highlights include the following:

- **Making Models Activities** Whiteboard videos—accessible online via QR code or the Study Area in MasteringBiology, bring the Making Models feature from the book to life to help students develop their visual modeling skills. The videos are also included in assignable activities that allow students to practice modeling and to apply their understanding to new situations.

- **Case Study Questions** Put It All Together Case Study questions are assignable in MasteringBiology. Additional clicker questions are also provided in instructor resources to facilitate classroom activities.
- **Solve It Tutorials** These activities allow students to act like scientists in simulated investigations. Each tutorial presents an interesting, real-world question that students will answer by analyzing and interpreting data.
- **Experimental Inquiry Tutorials** The call to teach students about the process of science has never been louder. To support such teaching, there are 10 interactive tutorials on classic scientific experiments—ranging from Meselson–Stahl on DNA replication to the Grants' work on Galápagos finches and Connell's work on competition. Students who use these tutorials should be better prepared to think critically about experimental design and evaluate the wider implications of the data—preparing them to do the work of real scientists in the future.
- **BioFlix® Animations and Tutorials** BioFlix are movie-quality, 3-D animations that focus on the most difficult core topics and are accompanied by in-depth, online tutorials that provide hints and feedback to guide student learning. Eighteen BioFlix animations and tutorials tackle topics such as meiosis, mitosis, DNA replication, photosynthesis, homeostasis, and the carbon cycle.
- **HHMI Short Films Activities** Documentary-quality movies from HHMI are available in MasteringBiology with assignable questions to make sure students understand key ideas.
- **Galápagos Evolution Video Activities** These incredible videos, filmed on the Galápagos Islands by Peter and Rosemary Grant, bring to life the dynamic evolutionary processes that have an impact on Darwin's finches on Daphne Major Island. Six videos explore important concepts and data from the Grants' field research, and assignable activities keep students focused on the important take-away points.
- **End-of-Chapter Questions** A broad range of end-of-chapter questions are available to assign in MasteringBiology.
- **Blue Thread Questions** Over 500 questions based on the Blue Thread questions in the textbook are assignable in MasteringBiology.
- **Big Picture Concept Map Tutorials** A new, more engaging concept mapping tool is the basis for highly interactive, challenging concept map activities based on the Big Picture figures in the textbook. Students build their own concept maps, which are auto-graded, and then answer questions to make sure they understand key ideas and make important connections.
- **BioSkills Activities** Activities based on the BioSkills content in the textbook are assignable in MasteringBiology, including activities to support the new BioSkills.
- **Reading Quiz Questions** Every chapter includes reading quiz questions that can be assigned to ensure students read the textbook and understand the basics. These quizzes are perfect as a pre-lecture assignment to get students into the content before class, allowing instructors to use class time more effectively.

Serving a Community of Teachers

All of us on the coauthor team are motivated by a deep commitment to students and to supporting the efforts of dedicated teachers. Our passion in life is doing and teaching biology. At various points along our diverse paths, we have been inspired by our own teachers when we were students, and now are inspired by our colleagues as we strive to become even better teacher-scholars. In the tradition of all previous editions of *Biological Science*, we have tried to infuse this textbook with the spirit and practice of evidence-based teaching. We welcome your comments, suggestions, and questions.

Many thanks for all you do for your students.

Content Highlights of the Sixth Edition

As discussed in the preface, a major focus of this revision is to introduce unique, innovative features designed to provide students with initial instruction in content and skills, as well as lots of practice in applying knowledge and skills to new contexts—with the ultimate goal of helping students learn to construct their own knowledge and think like biologists. As in each edition, to ensure that the content reflects the current state of science and is accurate, the author team has scrutinized every chapter to add new, relevant content, update descriptions when appropriate, and adjust the approach to certain topics to enhance student comprehension. New content emphasizes overarching themes—including how advances in understanding gene expression and genome structure inform all of biology, from development to evolution to physiology to ecology, and the profound impact of global climate change on life on Earth. In this section, some of the key content improvements to the textbook are highlighted.

Chapter 1 **Biology and the Tree of Life** New section titles emphasize the theme of five characteristics of life, within a framework of three unifying theories: the cell theory, the theory of evolution, and new coverage of the chromosome theory of inheritance. A brief introduction to the central dogma of molecular biology is added to provide students with a framework for understanding the connections between genes and phenotype early on in the book.

Chapter 2 **Water and Carbon: The Chemical Basis of Life** A more thorough explanation of chemical energy is included, covering the role of electronegativity, bond strength, and position of shared electrons with respect to the atomic nuclei. An expanded discussion addresses how molecular shape influences polarity and how changes in entropy are responsible for hydrophobic interactions between nonpolar molecules in a polar solvent.

Chapter 3 **Protein Structure and Function** The presentation of how electron sharing gives peptide bonds characteristics similar to double bonds is improved. Updated art more clearly illustrates how protein folding forms a substrate-specific active site in an enzyme. The introduction of prions is revised to describe how changes in protein structure may lead to cell death.

Chapter 4 **Nucleic Acids and the RNA World** The description of ATP hydrolysis is revised to avoid the common misconception that breaking phosphate bonds releases energy. The art and text are updated to present the geometry of nitrogenous bases relative to the sugar–phosphate backbone in double-stranded DNA. The role of hydrophobic interactions in shaping and stabilizing the DNA double helix is explained.

Chapter 5 **An Introduction to Carbohydrates** The impact of carbohydrate structure is emphasized by comparing the cleavage of maltose and lactose and exploring the basis of lactose intolerance that occurs in adults. The glycolipids and glycoproteins that serve as the ABO blood group antigens are introduced.

Chapter 6 **Lipids, Membranes, and the First Cells** Illustrations of fats and phospholipids are revised to emphasize similarity in structure. The description of osmosis is updated to include the effect of pressure on water transport and the concentration of solutes across a membrane at equilibrium.

Chapter 7 **Inside the Cell** Updated content highlights the differences in cell structure in eukaryotes, bacteria, and archaea. A revised description of receptor-mediated endocytosis, phagocytosis, and autophagy includes a new figure that illustrates how these pathways are involved in recycling components via lysosomes.

Chapter 8 **Energy and Enzymes: An Introduction to Metabolism** The introduction to potential and kinetic energy is expanded. The description of chemical energy is revised to focus on chemical bonds, support changes in Chapter 2, and address a common misconception that individual electrons carry energy. Illustrations of chemical bonds are updated to more accurately represent the correlation between bond length and chemical energy. The role of energetic coupling in converting endergonic reactions into exergonic reactions is clarified.

Chapter 9 **Cellular Respiration and Fermentation** Figures and text are updated to track the number of intermediates and products in each of the metabolic pathways. Redox potential is introduced as a measure of the ability of molecules to be reduced in redox reactions. The description of the fermentation pathways is expanded.

Chapter 10 **Photosynthesis** Greater emphasis is placed on the events responsible for converting the kinetic energy in light to potential energy stored in chemical bonds. Content is revised to address the misconceptions that the products of photosynthesis are used only to manufacture carbohydrates and that chloroplasts supply the ATP necessary for all other cellular functions. Figures and text are updated to more easily track the inputs and outputs in the photosynthetic reactions.

Chapter 11 **Cell–Cell Interactions** New content is added to the discussion of lipid-soluble signaling molecules and how second messengers in a signal transduction pathway can lead to many diverse cellular responses. A new quantitative question that addresses signal amplification is added. The discussion of the yeast pheromone response is expanded to draw connections between cell signaling and remodeling of the cell wall.

Chapter 12 **The Cell Cycle** Figures are updated to clearly distinguish differences between replicated and unreplicated chromosomes. New questions are added that address the application of a pulse–chase assay and common misconceptions associated with chromosome number during mitosis. New content is added covering the role of microtubules in chromosome movement and cell-cycle checkpoints.

Chapter 13 Meiosis Increased attention is paid to topics students are known to struggle with, such as the distinction between sister chromatids and homologous chromosomes, and the number of chromosomes and DNA molecules present in each daughter cell at the end of meiosis I compared with the end of meiosis II. The How Do Mistakes Occur? section is streamlined to focus on general themes of how aneuploidy arises during meiosis.

Chapter 14 Mendel and the Gene There is a sharper focus on challenging concepts, including the relationship between genotype and phenotype, the ability to consider phenotypes at levels that range from the molecular to the organismal, the meaning of dominance relationships, the significance of genetic mapping, and the importance of the chromosome theory of inheritance.

Chapter 15 DNA and the Gene: Synthesis and Repair Coverage is expanded on the Okazaki experiment and on the Nobel Prize–winning experiments of Greider and colleagues on telomeres and telomerase, so that students can more easily understand these investigations and their significance.

Chapter 16 How Genes Work Greater emphasis is placed on illustrating how the central dogma links genotype to phenotype. A stronger point is made that mutations can occur anywhere in the genome, not just in protein-coding sequences.

Chapter 17 Transcription, RNA Processing, and Translation New content helps students better understand polarity relationships among DNA, mRNA, and polypeptides. Three existing figures and one table are modified to improve clarity.

Chapter 18 Control of Gene Expression in Bacteria The discussion of the mechanism for glucose-mediated control of the *lac* operon is revised to highlight the continuing debate over the way catabolite repression works. The chapter is streamlined to allow students to focus on the fundamentals of how gene regulatory molecules control gene expression.

Chapter 19 Control of Gene Expression in Eukaryotes The material on control of translation is updated and reorganized, including a new example of global regulation of translation by mTor. Discussion of RNA interference is expanded, including a significantly modified figure showing how microRNAs are processed and how they function, and new discussion of how RNA interference can control chromatin condensation. The discussion of transcription initiation and the accompanying figure are updated.

Chapter 20 The Molecular Revolution: Biotechnology and Beyond Material previously spread across two chapters is merged to provide a more focused overview of major aims and techniques of genomics and related fields, including recent innovations such as CRISPR-Cas9 genome editing. Specific details of fundamental techniques are relocated to the BioSkills section for students and instructors who desire this level of coverage.

Chapter 21 Genes, Development, and Evolution Essential concepts previously spread across several chapters are brought together in this chapter, and it now links the Gene Structure and Expression unit to the Evolutionary Patterns and Processes unit by using molecular and cellular aspects of developmental biology as a bridge. New material on determination, induced pluripotent stem cells (iPS cells), and de-differentiation in cancer cells is included.

Chapter 22 Evolution by Natural Selection The historical introduction is simplified and illustrated in a new figure that compares different conceptual models of life's diversity. The homology section is updated to include developmental processes, and the three levels of homology are highlighted in a new summary table. More practice is provided in applying Darwin's postulates and reading phylogenetic trees. There is increased focus on overcoming common evolutionary misconceptions throughout the chapter. More plant examples are included. Focus on the ecological context of evolution is also increased.

Chapter 23 Evolutionary Processes The introduction to the Hardy–Weinberg principle is simplified and updated with some new examples. Increased attention is given to students' struggle to distinguish gene flow and genetic drift, and there are new follow-up questions. The summary table on evolutionary processes now includes icons to help students distinguish evolutionary processes, effect on genetic variation, and effect on fitness.

Chapter 24 Speciation New examples emphasize the origin of biodiversity, variation in rate of speciation, and biogeography, and illustrate the role of sexual selection and genetic mechanisms in speciation. Icons are now included in three summary tables to help students visualize mechanisms of reproductive isolation, species concepts, and outcomes of secondary contact between populations.

Chapter 25 Phylogenies and the History of Life The terms "microevolution" and "macroevolution" are now defined in the introduction. The phylogenetics section is updated to include more diverse examples. There is increased emphasis on avoiding common misconceptions in interpreting and drawing trees. The fossil review is reorganized into a photographic summary table. Dates in the history of life time line are updated. New evidence regarding causes of the end-Cretaceous extinction is introduced.

Chapter 26 Bacteria and Archaea New content is included on the role of endospores in the prokaryote life cycle, and recent studies on the human microbiome are highlighted. The section on themes in diversification is expanded to include mechanisms of gene transfer (e.g., transformation, transduction, and conjugation). Recent ideas that call into question the traditional three-domain tree of life hypothesis are presented.

Chapter 27 Protists Discussion of the role of endosymbiosis in the origin of mitochondria and chloroplasts is streamlined to focus on key concepts. The coverage of euglenids now includes a description of the flexible pellicle of this group, to underscore the point that most protist lineages are characterized by distinct microscopic features. Coverage of slime molds is expanded to include more on the structure and movement of plasmodial slime molds. Greater attention is paid to guiding students step-by-step through complex protist life cycles.

Chapter 28 Green Algae and Land Plants The updated discussion of the origin of plants now recognizes the conjugating algae (Zygnematophyceae) as one of the closest living relatives to land plants. Alternation of generations—the fundamental life cycle of all land plants—is now emphasized and presented with greater clarity.

Chapter 29 Fungi Content is updated to emphasize the important role of asexual spores (conidia) in the reproductive cycle of fungi. The unique relationship between a fungus and ants resulting in "zombie ants" is highlighted to illustrate the diversity of fungal lifestyles.

Chapter 30 An Introduction to Animals The chapter is updated to include insights gleaned from new genetic and developmental data, emphasizing that evolution is not a straightforward march from simple to complex.

Chapter 31 Protostome Animals The revised introduction is organized as a walk-through of a phylogeny to provide context from the previous chapter. Characteristics traditionally used to distinguish protostome development are deemphasized in light of recent research showing many exceptions. A new figure shows the phylogeny of arthropods, including insects within the Crustacea.

Chapter 32 Deuterostome Animals The echinoderm section has an increased emphasis on ecology and process of science, including Paine's keystone predator study. The invertebrate chordate section is expanded to include ascidians, thalaceans, and larvaceans. The key innovations section is revised and streamlined as a walk-through of the chordate phylogeny. The human evolution section is updated, including reference to new hominin species and an image of a Neanderthal woman.

Chapter 33 Viruses A new section on the role of viruses in shaping the evolution of organisms is introduced. A discussion of the SARS-CoV and MERS-CoV outbreaks is included to illustrate the international network of researchers that works to identify and control emerging viral infections. New content on how viruses impact society is included, along with new material covering recent discoveries on how the Ebola virus infects cells.

Chapter 34 Plant Form and Function The chapter is reorganized to discuss the structure and function of cells and tissues before placing them in the context of primary and secondary growth. Practice is provided on calculating and comparing the relationship between surface area and volume in different types of plant structures. Content on secondary growth is expanded to emphasize how trees make the transition from primary to secondary growth.

Chapter 35 Water and Sugar Transport in Plants The discussion of water potential and water movement is streamlined to bring key concepts into sharper focus. Recent work on the role of the SWEET genes in sugar transport is introduced.

Chapter 36 Plant Nutrition Discussion of parasitic plants is broadened and now includes dodder and ghost plants as examples.

Chapter 37 Plant Sensory Systems, Signals, and Responses The discussion of phototropins is streamlined to focus on key concepts. The role of phytochrome in circadian rhythms and etiolation is introduced. A summary table on key plant growth regulators is now illustrated with photographs to show the impact of hormones on plant growth and development.

Chapter 38 Plant Reproduction and Development The chapter is reorganized to merge essential information previously spread across several chapters and bring flowering plant reproduction and development together in a single, integrated story. Discussions of flower structure, pollination, fertilization, the formation of seeds and fruits, and embryogenesis are updated and streamlined. Coverage of vegetative development emphasizes the roles of apical meristems and genes involved in embryogenesis and leaf formation.

Chapter 39 Animal Form and Function The discussion of mammalian thermoregulation is moved into the section on homeostasis. In the introduction to animal tissue types, more explicit structure–function examples are given for each tissue type. The section on regulatory homeostasis is updated, and the idea that regulation and conformation are two ends of a spectrum is introduced. The expressions "warm-blooded" and "cold-blooded" are addressed to explain why these terms are problematic to use in biology. The section on countercurrent multipliers is simplified.

Chapter 40 Water and Electrolyte Balance in Animals The material on reabsorption in insect Malpighian tubules is streamlined. There is a discussion of how the vasa recta absorbs water and ions without disrupting the interstitial fluid gradient. A brief statement about how aldosterone functions in pH regulation of body fluids is added.

Chapter 41 Animal Nutrition The section on diabetes is expanded, and the importance of low cell glucose in addition to high blood glucose in untreated diabetes is stressed. A new figure addresses the relationship between obesity and type 2 diabetes.

Chapter 42 Gas Exchange and Circulation Oxygen–hemoglobin dissociation figures are redrawn more accurately, and new content helps students understand the meaning of a sigmoidal curve. The open circulatory system common to most invertebrates is illustrated with a new figure showing circulation in a spider.

Chapter 43 Animal Nervous Systems A new figure shows the relationships among sensory neurons, motor neurons, and interneurons. Review of material from earlier chapters on how ions are transported across membranes is streamlined. The discussion of the magnitude of action potentials and how action potentials propagate down an axon is clarified. Revisions emphasize that new action potentials are continuously generated along the entire length of an axon, addressing the misconception that a single action potential travels from one end to the other. Updated information is included on the hippocampus, the enteric nervous system, and the technique of optogenetics, a major breakthrough in neuroscience.

Chapter 44 Animal Sensory Systems The section on taste is updated to reflect new knowledge about the structure and function of gustation, and the likely existence of more than just five taste sensations. The role of mechanoreception in taste—by providing information about texture—is introduced. New content highlights one of the chapter's key ideas: Animals do not rely on senses independently and instead integrate information from multiple sensory modalities.

Chapter 45 Animal Movement A new figure shows examples of hydrostatic skeletons, endoskeletons, and exoskeletons. A brief section is added addressing the misconception that muscles grow by adding new cells during weight-lifting/training (in fact, the cells simply grow). A new section discusses the role of bone in calcium storage and the process of bone remodeling. Osteoblasts and osteoclasts are introduced, and osteoporosis is discussed briefly.

Chapter 46 Chemical Signals in Animals Content is rearranged to flow more logically: first introducing cell signaling, next discussing how hormones stimulate cells, then giving examples of what hormones can do, and finally describing how hormones are regulated overall. Discussion of the discovery of hormones is updated for historical accuracy and includes a new research box on Berthold's classic experiment on roosters, which shows that a chemical blood-borne messenger (later characterized as testosterone) can affect behavior and anatomy. Control of blood-glucose levels by insulin and glucagon is now used to illustrate how hormones maintain homeostasis.

Chapter 47 Animal Reproduction and Development Material previously spread across several chapters is merged to bring reproduction and development together to tell a single, integrated story. Coverage of fertilization is now integrated with egg development; coverage of cleavage, gastrulation, and organogenesis is combined into a new, descriptive section on embryonic development. New content covers formation of the central nervous system from the neural tube. The chapter now focuses more on the physiology of reproduction in mammals, but retains a comparative approach by including examples ranging from insects to marsupials.

Chapter 48 The Immune System in Animals Content is updated on the activation of B cells and allergens that are involved in mast-cell activation in allergic reactions. Coverage of the link between high levels of hygiene and the rising occurrence of allergies and autoimmune diseases in Westernized countries is expanded.

Chapter 49 An Introduction to Ecology The introduction is revised to clarify the relationship between traditional ecology and the study of human impacts. The niche concept is introduced as a tool to relate organisms to environmental conditions. The theory of plate tectonics and a figure showing continental drift are added to the section on biogeography. The Coriolis effect, prevailing winds, ocean gyres, and El Niño are added to the climate section. Information from the Fifth Edition's biome boxes is integrated into the text and included in new photographic summary tables on terrestrial and aquatic biomes.

Chapter 50 Behavioral Ecology The introduction includes increased emphasis on fitness trade-offs and variation among organisms in a population (population thinking). Section case studies are updated, including a new opportunity for students to practice with optimal foraging in bees, a new data graphic on sexual selection in *Anolis* lizards, and a new photo of monkeys engaged in reciprocal grooming. A new section addresses the misconception that individuals act for the good of the species.

Chapter 51 Population Ecology The mark–recapture Quantitative Methods box is expanded. The figure and discussion of the life-history continuum are expanded. The exponential growth section is revised for a clearer walk-through of the equations and more direct assistance with common misconceptions. A new photographic summary table of density-dependent factors is added. Human population content is updated. Applications to conservation are expanded.

Chapter 52 Community Ecology More plant examples are included. The case studies on species interactions are updated and clarified. The community structure section now begins with a discussion of how pairwise interactions combine to form webs of interactions, introducing the food web as an example. A discussion of bottom-up and top-down influences on community structure is now included.

Chapter 53 Ecosystems and Global Ecology Updates and clarifications are made throughout the chapter, particularly in the section on climate change, including updated data graphics. Nutrient-cycle figures are modified to distinguish natural and human-caused processes. A section on phosphorus cycling is added. The concept of tipping points is added, and the interaction of multiple variables is emphasized.

Chapter 54 Biodiversity and Conservation Biology Updates and clarifications are made throughout the chapter. A new figure contrasts resistance and resilience. A new data graphic emphasizes the resource intensity of beef. Overall, more emphasis is placed on the positive effects of conservation action, including a new full-page photographic summary table of conservation strategies.

Acknowledgments

Reviewers

The peer review system is the key to quality and clarity in science publishing. In addition to providing a filter, the investment that respected individuals make in vetting the material—catching errors or inconsistencies and making suggestions to improve the presentation—gives authors, editors, and readers confidence that the text meets rigorous professional standards.

Peer review plays the same role in textbook publishing. The time and care that this book's reviewers have invested is a tribute to their professional integrity, their scholarship, and their concern for the quality of teaching. Virtually every page in this edition has been revised and improved based on insights from the following individuals.

Claudio Aguilar, *Purdue University*
Marc Albrecht, *University of Nebraska*
Walid Al-Ghoul, *Chicago State University*
Göran Arnqvist, *Uppsala University, Sweden*
Andrea Aspbury, *Texas State University, San Marcos*
Christofer Bang, *Arizona State University*
Miriam Barlow, *University of California, Merced*
Mark Barsoum, *Davidson College*
Vernon Bauer, *Frances Marion University*
Erin Becker, *University of California, Davis*
Vagner Benedito, *West Virginia University*
Jonathon Bennett, *Towson University*
Aimee Bernard, *University of Colorado, Denver*
Ashok Bidwai, *West Virginia University*
Wendy Binder, *Loyola Marymount University*
Jaime Blair, *Franklin and Marshall College*
Michelle Boone, *Miami University, Ohio*
Mirjana Brockett, *Georgia Institute of Technology*
David Buchwalter, *North Carolina State University*
Romi Burks, *Southwestern University*
Patrick Cafferty, *Emory University*
Susan Capasso, *St. Vincent's College*
Dale Casamatta, *University of North Florida*
David Chambers, *Concord University*
Rebekah Chapman, *Georgia State University*
Sixue Chen, *University of Florida*
Kendra Cheruvelil, *Michigan State University*
Soochin Cho, *Creighton University*
Clark Coffman, *Iowa State University*
Rachel Cohen, *Minnesota State University, Mankato*
William Cohen, *University of Kentucky*
Ron Cooper, *University of California, Los Angeles*
David Coughlin, *Widener University*
Karen Curto, *University of Pittsburgh*
James Daly, *State University of New York at Purchase*
Suni Dharmasiri, *Texas State University, San Marcos*
Scott Dobrin, *University of Maine at Presque Isle*
Kevin Dixon, *Florida State University*
Peter Ducey, *SUNY Cortland*
David Featherstone, *University of Illinois at Chicago*
Jeffrey Firestone, *University of Maryland*
Sarah Firestone, *University of Maryland*
Kirsten Fisher, *California State University, Los Angeles*
Mark Flood, *Fairmont State University*
Cerrone Foster, *East Tennessee State University*
Caitlin Gabor, *Texas State University, San Marcos*
Theresa Geiman, *Loyola University Maryland*
Brian Gibbens, *University of Minnesota*
Matt Gilg, *University of North Florida*
Eva Gonzales, *Saint Louis University*
Tamar Goulet, *University of Mississippi*
Eric Green, *Salt Lake Community College*
Teshell K. Greene, *Virginia State University*
Kelly Grussendorf, *Minnesota State University, Mankato*
Nancy Guild, *University of Colorado, Boulder*
Kristin Hardy, *California Polytechnic State University, San Luis Obispo*
David Hanson, *University of New Mexico*
Christopher Haynes, *Shelton State Community College*
Donata Henry, *Tulane University*
Mar-Elise Hill, *Northern Arizona University*
Jennifer Holloway, *Faulkner State Community College*
Bernadette Holthuis, *University of Florida*
Kelly Howe, *University of New Mexico*
Deborah Hutchinson, *Seattle University*
Dianne Jennings, *Virginia Commonwealth University*
Luis Jimenez, *Bergen Community College*
Hua Jin, *University of Illinois at Chicago*
Heather Joesting, *Armstrong State University*
Greg Jones, *Santa Fe College*
Seth Jones, *University of Kentucky*
Pavan Kadandale, *University of California, Irvine*
Lou Kim, *Florida International University*
Samantha King, *University of North Carolina at Chapel Hill*
Arshad Khan, *University of Texas at El Paso*
Anton Komar, *Cleveland State University*
Margaret Kovach, *University of Tennessee at Chattanooga*
Patrick Krug, *California State University, Los Angeles*
Kim Lackey, *University of Alabama*
Michael LaMontagne, *Missouri State University*
Kirkwood Land, *University of the Pacific*
Jeanne Lawless, *Binghamton University*
Daewoo Lee, *Ohio University*
Brenda Leicht, *University of Iowa*
Craig Lending, *The College at Brockport*
Vicky Lentz, *SUNY Oneonta*
Tatyana Lobova, *Old Dominion University*
Cindy Malone, *California State University, Northridge*
Kathy Rath Marr, *Lakeland College*
Jennifer Metzler, *Ball State University*

Justin Meyer, *University of California, San Diego*
James Mickle, *North Carolina State University*
Allison Miller, *Saint Louis University*
Brooks Miner, *Ithaca College*
Chad Montgomery, *Truman State University*
Tsafrir Mor, *Arizona State University*
Deborah Muldavin, *Central New Mexico Community College*
Ross Nehm, *Stony Brook University*
Jennifer Osterhage, *University of Kentucky*
Robert Osuna, *SUNY Albany*
Karla Passalacqua, *Emory University*
Debra Pires, *University of California, Los Angeles*
Erin Questad, *California State Polytechnic University, Pomona*
Stacey Raimondi, *Elmhurst College*
Elizabeth Randolph, *Front Range Community College*
Marceau Ratard, *Delgado Community College*
Mark Reedy, *Creighton University*
Melissa Murray Reedy, *University of Illinois at Urbana-Champaign*
Larry G. Riley, *California State University, Fresno*
Laurel Roberts, *University of Pittsburgh*
Deborah Roess, *Colorado State University*
Anthony Rossi, *University of North Florida*
Tobili Sam-Yellowe, *Cleveland State University*
Thomas Sasek, *University of Louisiana at Monroe*
Leena Sawant, *Houston Community College*
Jennifer Scoggins, *Florida State University, Panama City*
Joan Sharp, *Simon Fraser University*
Gidi Shemer, *University of North Carolina at Chapel Hill*
Leah Sheridan, *Ohio University*
Girish C Shukla, *Cleveland State University*
Amanda Simons, *Framingham State University*
Chrissy Simmons, *Southern Illinois University, Edwardsville*
Denise Slayback-Barry, *Indiana University—Purdue University, Indianapolis*
Paul Small, *Eureka College*
Nancy Solomon, *Miami University, Ohio*
Chrissy Spencer, *Georgia Institute of Technology*
Joshua Springer, *Purdue University*
Robert Sterner, *University of Minnesota, Duluth*
Shannon Stevenson, *University of Minnesota, Duluth*
Tara Stoulig, *Southeastern Louisiana University*
Adam Summers, *University of Washington*
Billie Swalla, *University of Washington*
Zuzana Swigonova, *University of Pittsburgh*
Heather Thieringer, *Princeton University*
Mark Thogerson, *Grand Valley State University*
Alexandru Tomescu, *Humboldt State University*
Mike Twiner, *University of Michigan-Dearborn*
Melvin Tyree, *University of Alberta, Canada*
Catherine Ueckert, *Northern Arizona University*
John VandenBrooks, *Arizona State University*
Bina Vanmali, *Arizona State University*
Sebastián Vélez, *Worcester State University*
Audra Warren, *Faulkner State Community College*
Doris Watt, *Saint Mary's College*
Shuo Wei, *West Virginia University*
Dennis Welker, *Utah State University*
Kira Wennstrom, *Shoreline Community College*
Mark Westneat, *University of Chicago*
Allison Wiedemeier, *University of Louisiana at Monroe*
Robert Wise, *University of Wisconsin—Oshkosh*
Virginia White, *Riverside City College*
Jenn Yost, *California Polytechnic State University, San Luis Obispo*
Robert Yost, *Indiana University — Purdue University Indianapolis*
Ted Young, *University of Washington*
Brittany Ziegler, *Minnesota State University, Mankato*

Contributors

We are grateful for the hard work and creativity of the contributors who worked on an impressive array of print and online support materials.

Ana Araya-Anchetta, *Northern Arizona University*
Andrea Aspbury, *Texas State University, San Marcos*
Brian Bagatto, *University of Akron*
Jay Brewster, *Pepperdine University*
Warren Burggren, *University of North Texas*
Patrick Cafferty, *Emory University*
Tim Christensen, *East Carolina University*
David Coughlin, *Widener University*
Karen Curto, *University of Pittsburgh*
Candice Damiani, *University of Pittsburgh*
Clarissa Dirks, *The Evergreen State College*
Lisa Elfring, *University of Arizona*
Caitlin Gabor, *Texas State University, San Marcos*
Kathy Gillen, *Kenyon College*
Nancy Ann Guild, *University of Colorado, Boulder*
Jutta Heller, *University of Washington—Tacoma*
Laurel Hester, *Keuka College*
Mar-Elise Hill, *Northern Arizona University*
Mark Holbrook, *University of Iowa*
Kristine Kaiser, *Pomona College*
Jacob L. Kerby, *University of South Dakota*
Aric Krogstad, *Arizona State University*
Craig Lending, *SUNY Brockport*
Cindy Malone, *California State University, Northridge*
Jim Manser, *Harvey Mudd College*
Brad Mehrtens, *University of Illinois at Urbana—Champaign*
Jennifer Osterhage, *University of Kentucky*
Melissa Murray Reedy, *University of Illinois at Urbana—Champaign*
Ann Riedl, *Front Range Community College*
Anthony Rossi, *University of North Florida*
Christina T. Russin, *Northwestern University*
Joan Sharp, *Simon Fraser University*
Cara Shillington, *Eastern Michigan University*
Nancy Solomon, *Miami University*
Anna Soper, *University of Massachusetts Amherst*
Chrissy Spencer, *Georgia Institute of Technology*
Zuzana Swigonova, *University of Pittsburgh*
Catherine Ueckert, *Northern Arizona University*
Bina Vanmali, *Arizona State University*

We also offer a special thanks to Stephen Thomas of *Michigan State University* who brought the Making Models videos to life.

Book Team

Anyone who has been involved in a major production knows that many people work behind the scenes to make it all happen. The coauthor team is indebted to the many talented individuals who have made this book possible.

Astute comments by development editors Stephanie Keep, Moira Lerner Nelson, Jennifer Angel, Mary Catherine Hager, and Matt Lee vastly improved both the scientific accuracy and the clarity of writing on the revised manuscript.

The final version of the text was copyedited with mastery by Chris Thillen and expertly proofread by Pete Shanks. Art was rendered by Imagineering Media Services, while Eric Schrader and Kristen Piljay researched hundreds of new photographs for the Sixth Edition. The book's clean, innovative design was developed by Marilyn Perry and Tani Hasegawa. Text and art were skillfully set in the design by Integra.

Creating MasteringBiology® tutorials and activities requires a large team. Media content development was overseen by Tania Mlawer and Sarah Jensen. Libby Reiser and Ziki Dekel served as media producers, developing and coordinating new and revised media content. We also benefitted from the media guidance of Lee Ann Doctor, Laura Tommasi, Charles Hall, and Sarah Young-Dualan. Project Managers Eddie Lee and Chelsea Logan oversaw creation of the Instructor Resource DVD.

Pearson's talented sales reps, who listen to professors, advise the editorial staff, and get the book into students' hands, are supported by the boundless energy of Executive Marketing Manager Lauren Harp and Vice President of Marketing Christy Lesko. Marketing materials were produced by Jane Campbell.

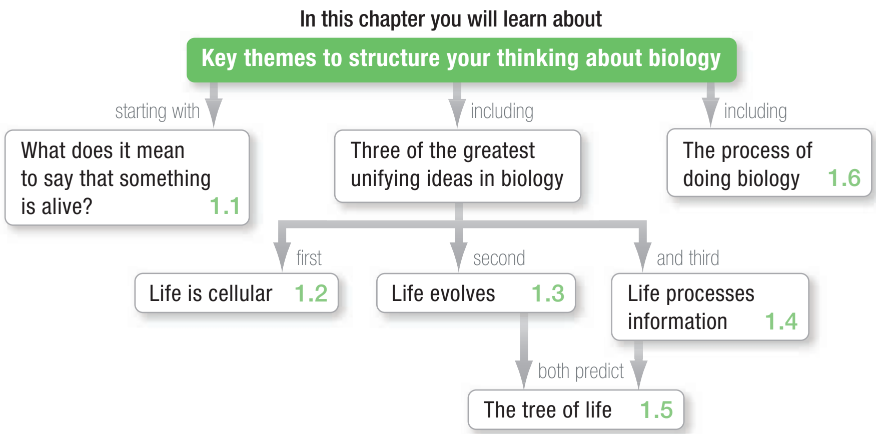
The vision and resources required to run this entire enterprise are the responsibility of Editor-in-Chief Beth Wilbur, who provided wise, inspirational, and focused leadership, and Adam Jaworski, Vice President of Pearson Science Editorial, who displays unwavering commitment to high-quality science publishing.

The editorial team was skillfully directed by Executive Editorial Manager Ginnie Simione Jutson during the early stages of the project. Program Manager Anna Amato's superb organizational skills and calm demeanor assured that all aspects of the process ran smoothly. Project Manager Mae Lum and Angel Chavez, Managing Editor of Integra, efficiently kept the mammoth project steadily rolling forward during production. Editorial Assistant Chloé Veylit gently but firmly kept all of us on track with deadlines and weekly conference calls. Development Editor Mary Hill worked magic to come up with visually aesthetic page layouts. Finally, we are deeply grateful for two key drivers of the Sixth Edition. Supervising Editor Sonia DiVittorio's remarkable vision and creativity; keen attention to detail, level, and clarity; and absolute insistence on excellence set the standard for us all. Senior Acquisitions Editor Michael Gillespie's unstoppable enthusiasm, invaluable skills at team building, upbeat attitude, and sharp intellect have energized and united the team while guiding the book through the hurdles to existence. The coauthor team gives many thanks to all these exceptional people for making the art and science of book writing a productive and exhilarating process.

This page intentionally left blank

1 Biology and the Tree of Life

This vervet monkey baby is exploring its new world and learning how to find food and stay alive. It represents one of the key characteristics of life introduced in this chapter—replication.



In essence, biological science is the study of life. It searches for ideas and observations that unify our understanding of the diversity of life—from bacteria living in hot springs to humans and majestic sequoia trees.

The goals of this chapter are to introduce the nature of life and explore how biologists go about studying it. The chapter also introduces themes that will resonate throughout this book:

- Analyzing how organisms work at the molecular level.
- Understanding organisms in terms of their evolutionary history.
- Helping you learn to think like a biologist.

Let's begin with what may be the most fundamental question of all: What is life?

BIG PICTURE

This chapter is part of the Big Picture. See how on pages 16–17.

1.1 What Does It Mean to Say That Something Is Alive?

An **organism** is a life-form—a living entity made up of one or more cells. Although there is no simple definition of life that is endorsed by all biologists, most agree that organisms share a suite of five fundamental characteristics. You can think of this text as one long exploration of these five traits.

- ***Cells*** Organisms are made up of membrane-bound units called **cells.** The membrane of a cell regulates the passage of materials between exterior and interior spaces.
- ***Replication*** One of the great biologists of the twentieth century, François Jacob, said that the "dream of a bacterium is to become two bacteria." Almost everything an organism does contributes to one goal: replicating itself.
- ***Evolution*** Organisms are the products of evolution, and their populations continue to evolve today.
- ***Information*** Organisms process hereditary, or genetic, information encoded in units called **genes.** Organisms also respond to information from the environment and adjust to maintain stable internal conditions. Right now, cells throughout your body are using information to make the molecules that keep you alive; your eyes and brain are decoding information on this page that will help you learn some biology, and if your room is too hot you might be sweating to cool off.
- ***Energy*** To stay alive and reproduce, organisms have to acquire and use energy. To give just two examples: plants absorb sunlight; animals ingest food.

Three of the greatest unifying ideas in all of science, which depend on the five characteristics just listed, laid the groundwork for modern biology: the cell theory, the theory of evolution, and the chromosome theory of inheritance. Formally, scientists define a **theory** as an explanation for a very general class of phenomena or observations that are supported by a wide body of evidence. Note that this definition contrasts sharply with the everyday usage of the word "theory," which often carries meanings such as "speculation" or "guess."

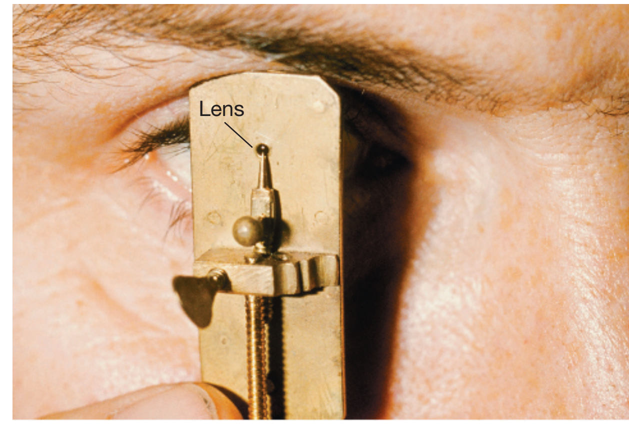
The cell theory, the theory of evolution, and the chromosome theory of inheritance address fundamental questions: What are organisms made of? Where do they come from? How is hereditary information transmitted from one generation to the next?

When these theories emerged in the mid-1800s, they revolutionized the way biologists think about the world. None of these insights came easily, however. The cell theory, for example, emerged after some 200 years of work. Let's examine some of the pivotal discoveries made along the way.

1.2 Life Is Cellular

In 1665 the Englishman Robert Hooke devised a crude microscope to examine the structure of cork (a bark tissue) from an oak tree. The instrument magnified objects to just 30× (30 times) their normal size, but it allowed Hooke to see something

(a) van Leeuwenhoek built his own microscopes—which, while small, were powerful. They allowed him to see, for example ...



(b) ... human blood cells (this modern photo was shot through one of van Leeuwenhoek's original microscopes).

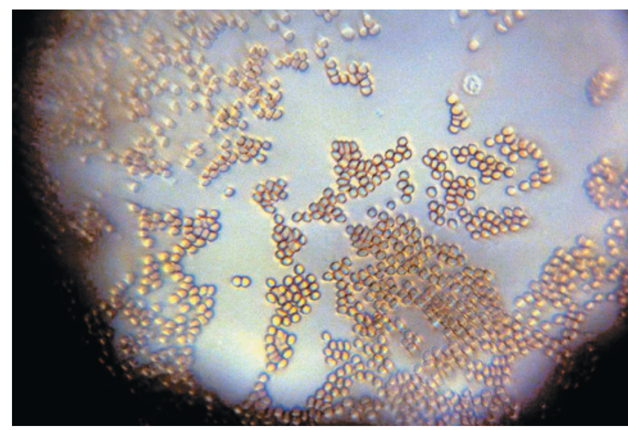


Figure 1.1 Van Leeuwenhoek's Microscope Made Cells Visible.

extraordinary. In the cork he observed small, pore-like compartments that were invisible to the naked eye. Hooke coined the term "cells" for these structures because he thought they resembled the cells inhabited by monks in a monastery.

Soon after Hooke published his results, the Dutch scientist Anton van Leeuwenhoek developed much more powerful microscopes, some capable of magnifications up to 300× (**Figure 1.1**). With these instruments, van Leeuwenhoek inspected samples of pond water and made the first observations of a dazzling collection of single-celled organisms that he called "animalcules."

In the 1670s an Italian researcher who was studying the leaves and stems of plants with a microscope concluded that plant tissues were composed of many individual cells. By the early 1800s, enough data had accumulated for a German biologist to claim that *all* organisms consist of cells. Did this claim hold up?

All Organisms Are Made of Cells

Advances in microscopy have made it possible to examine the amazing diversity and complexity of cells at higher and higher magnifications. Microscopes tens of thousands of times more powerful than van Leeuwenhoek's have revealed that cells are highly organized compartments separated from their environment by a membrane barrier. With these instruments, biologists have described over a million new species. The basic conclusion made in the 1800s remains intact: All organisms are made of cells.

The smallest organisms known today are bacteria that are barely 200 nanometers wide, or 200 *billionths* of a meter. (See BioSkills 1 to review the metric system.[1]) It would take 5000 of these organisms lined up side by side to span a millimeter. This is the distance between the smallest hash marks on a metric ruler. In contrast, sequoia trees can be over 100 meters tall, the equivalent of a 20-story building. Bacteria and sequoias are composed of the same fundamental building block, however—the cell. Bacteria consist of a single cell; sequoias are made up of trillions of cells.

The realization that all organisms are made of cells was fundamentally important, but it formed only the first part of the cell theory. In addition to understanding what organisms are made of, scientists wanted to understand how cells come to be.

Where Do Cells Come From?

In 1858, a German scientist named Rudolph Virchow proposed that all cells arise from cells already in existence. The complete **cell theory** builds on this concept: All organisms are made of cells, and all cells come from preexisting cells.

Two Hypotheses The cell theory was a direct challenge to the prevailing explanation of where cells come from, called spontaneous generation. In the mid-1800s, most biologists believed that organisms could arise spontaneously under certain conditions.

[1]BioSkills are located after Chapter 1. They focus on general skills that you'll use throughout this course. More than a few students have found them to be a lifesaver. Please use them!

The bacteria and fungi that spoil foods such as milk and wine were thought to appear in these nutrient-rich media of their own accord—springing to life from nonliving materials. In contrast, the cell theory maintained that cells do not arise spontaneously but are produced only when preexisting cells grow and divide. The all-cells-from-cells explanation was a **hypothesis:** a testable statement to explain a phenomenon or a set of observations.

Biologists usually use the word "theory" to refer to proposed explanations for broad patterns in nature and prefer hypothesis to refer to explanations for more tightly focused questions. A theory serves as a framework for developing new hypotheses.

An Experiment to Settle the Question Soon after Virchow's all-cells-from-cells hypothesis appeared in print, a French scientist named Louis Pasteur set out to test its predictions in an **experiment.** Experiments are a powerful scientific tool because they allow researchers to test the effect of a single, well-defined factor on a particular phenomenon. An experimental **prediction** describes a measurable or observable result that must be correct if a hypothesis is valid.

Pasteur wanted to determine whether organisms could arise spontaneously in a nutrient broth or whether they appear only when a broth is exposed to a source of preexisting cells. To address the question, he created two treatment groups that were identical in every respect but one: the factor being tested—in this case, a broth's exposure to preexisting cells.

Both treatments used glass flasks filled with the same amount of the same nutrient broth (Figure 1.2). Both flasks were boiled for the same amount of time to kill any existing organisms. After sterilization by boiling, however, any bacteria and fungi that cling to dust particles in the air could drop into the broth in the flask shown in Figure 1.2a because the neck of this flask was straight.

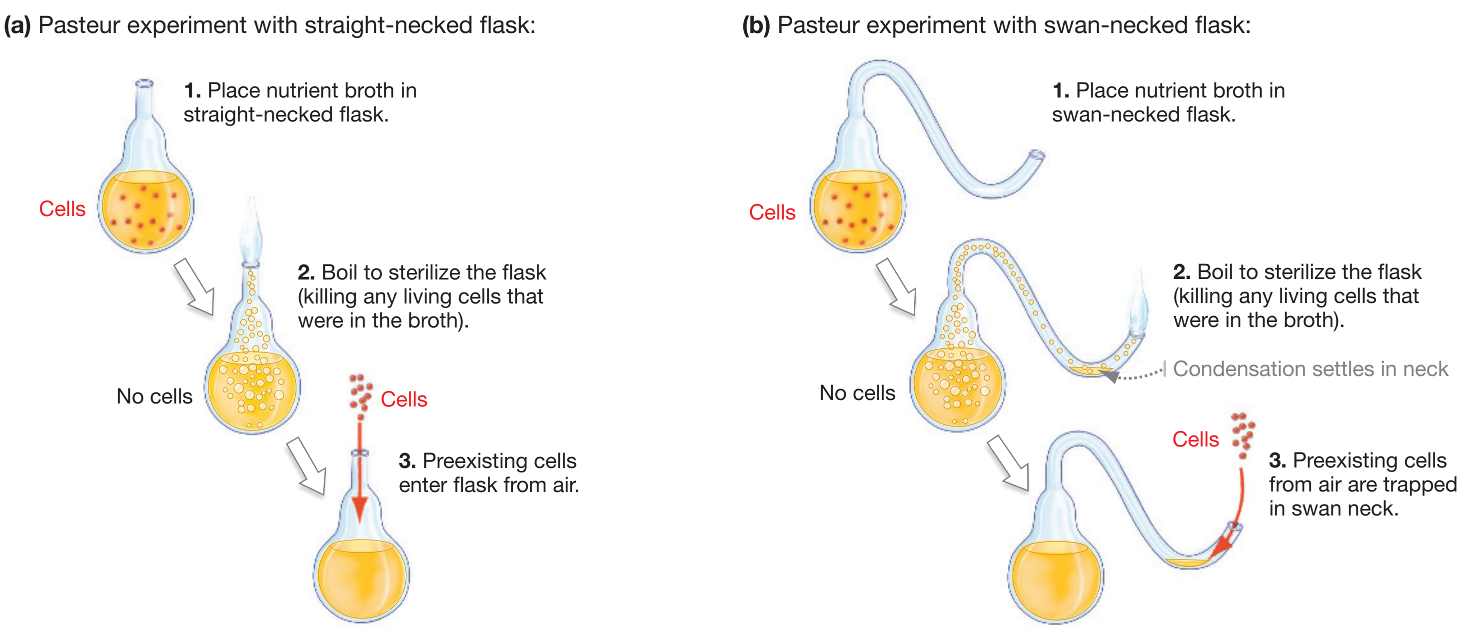


Figure 1.2 The Spontaneous Generation and All-Cells-from-Cells Hypotheses Were Tested Experimentally.

✔ **PROCESS OF SCIENCE** What problem would arise in interpreting these results if Pasteur had (1) put different types of broth in the two treatments, or (2) used a ceramic flask for one treatment and a glass flask for the other?

In contrast, in the flask with a long swan neck (Figure 1.2b), water would condense in the crook of the swan neck after boiling and this pool of water would trap any bacteria or fungi that entered on dust particles. Thus, the contents of the swan-necked flask were isolated from any source of preexisting cells even though they were still open to the air.

The spontaneous generation hypothesis predicted that cells would appear in both treatment groups. The all-cells-from-cells hypothesis predicted that cells would appear only in the treatment exposed to a source of preexisting cells.

And Pasteur's results? The broth in the straight-necked flask exposed to preexisting cells quickly filled with bacteria and fungi. This observation was important because it showed that the sterilization step had not altered the nutrient broth's capacity to support growth. The broth in the swan-necked flask remained sterile, however. Even when the flask was left standing for months, no organisms appeared in it. This result was inconsistent with the hypothesis of spontaneous generation.

Because Pasteur's data were so conclusive—meaning that there was no other reasonable explanation for them—the results persuaded most biologists that the all-cells-from-cells hypothesis was correct.

If all cells come from existing cells, where did the first cells come from? Biologists now have evidence that life arose from nonlife early in Earth's history, through a process called **chemical evolution.**

Life Replicates Through Cell Division

For life on Earth to continue to exist, cells must replicate. Most cells are capable of reproducing by dividing—in effect, by making a copy of themselves. As predicted by the cell theory, all the cells present in your body and in most other multicellular individuals are descended from preexisting cells, tracing back to a fertilized egg. A fertilized egg is a cell created by the fusion of sperm and egg—cells that formed in individuals of the previous generation.

New cells arise when preexisting cells split. In multicellular organisms they become specialized for particular functions by intricate processes. In this way, all the cells in a multicellular organism are connected by a common lineage. Is the tremendous diversity among organisms also related to common ancestry?

The second great founding idea in biology, published the same year as the all-cells-from-cells hypothesis, provided an answer. This was the realization, made independently by the English scientists Charles Darwin and Alfred Russel Wallace, that all the diverse **species**—all distinct, identifiable types of organisms—are connected by common ancestry.

1.3 Life Evolves

In 1858 short papers written separately by Darwin and Wallace were read to a small group of scientists attending a meeting of the Linnean Society of London. A year later, Darwin published a book that expanded on the idea summarized in those brief papers. The book was called *On the Origin of Species*. The first edition sold out in a day.

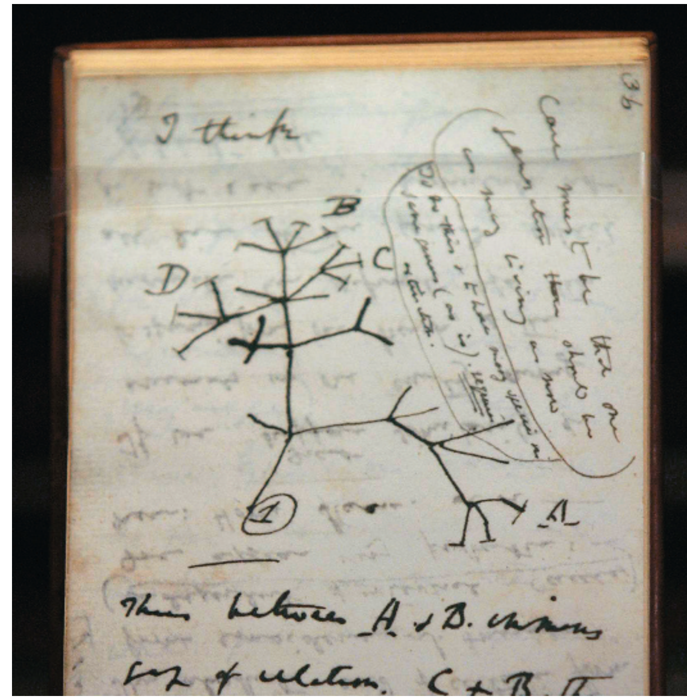


Figure 1.3 Sketch from Darwin's Notebook Dated 1837. Darwin wrote this in the notes that follow: "Thus genera would be formed. Bearing relation to ancient types with several extinct forms."

What Is Evolution?

Darwin and Wallace's theory made two important claims concerning patterns that exist in the natural world.

1. Species are related by common ancestry (**Figure 1.3**). This idea contrasted with the prevailing view in science at the time, which was that species represent independent entities created separately by a divine being.
2. The characteristics of species can be modified from generation to generation. Darwin called this process descent with modification. This claim argued against the popular view at the time that species do not change.

Evolution is a change in the characteristics of a population over time. A **population** is defined as a group of individuals of the same species living in the same area at the same time. To put it another way, species are related to one another and can change through time.

What Is Natural Selection?

Several other scientists had already come to the same conclusions as Darwin and Wallace about the relationships between species. The great insight by Darwin and Wallace was in proposing a process, called **natural selection,** that explains *how* evolution occurs.

Two Conditions of Natural Selection Natural selection occurs whenever two conditions are met.

1. Individuals within a population vary in characteristics that are **heritable**—meaning, traits that can be passed on to offspring.

2. In a particular environment, certain versions of these heritable traits help individuals survive better or reproduce more than do other versions.

If certain heritable traits lead to increased success in producing offspring, then those traits become more common in the population over time. In this way, the population's characteristics change as a result of natural selection acting on individuals. This is a key insight: Natural selection acts on individuals, but evolutionary change occurs in populations.

Evolution occurs when heritable variation leads to differential success in reproduction. Individual populations change through time in response to natural selection. But over the past several decades, biologists have also documented dozens of cases in which natural selection has caused populations of one species to diverge and form new species. This divergence process is called **speciation.**

Research on speciation has two important implications: All species come from preexisting species, and all species, past and present, trace their ancestry back to a single common ancestor.

Fitness and Adaptation

Darwin also introduced some new terminology to identify what happens during natural selection.

- In everyday English, "fitness" means "health and well-being." But in biology, **fitness** means "an individual's ability to produce viable offspring." Individuals with high fitness produce many surviving offspring.
- In everyday English, "adaptation" means that an individual is adjusting and changing to function in new circumstances. But in biology, an **adaptation** is a trait that increases the fitness of an individual in a particular environment.

Darwin and Wallace's ideas arose from their observations of nature. For example, in finches from the Galápagos Islands Darwin noted the remarkable variation in beak size and shape in species that otherwise appeared similar. He proposed that the birds on different islands in the chain were similar because they descended from a common ancestor—the finch populations that colonized different islands had changed through time and formed new species with distinct beaks.

Long-term studies by biologists over the past several decades have documented dramatic changes in a population of finches on one of the Galápagos Islands (you will learn more about this study in Chapter 22). When small, soft seeds were abundant there due to increased rainfall, finches with small, pointed beaks produced more offspring and had higher fitness than individuals with large, deep beaks. In this population and with this food source, a small, pointed beak was an adaptation that allowed certain individuals to thrive, and the incidence of finches with such beaks increased in the population.

Note that during this process, the beak shape of any individual finch did not change within its lifetime—the change occurred in the characteristics of the population over time. Darwin's finches continue to evolve today in response to changes in the environment.

Together, the cell theory and the theory of evolution provided the young science of biology with two central, unifying ideas:

1. The cell is the fundamental structural unit in all organisms.
2. All species are related by common ancestry and have changed over time in response to natural selection.

But what was the source of the heritable variation in traits? And how was information stored and transmitted from one generation to the next? The third unifying idea—the chromosome theory of inheritance—provided the foundation for biologists to answer these questions.

CHECK YOUR UNDERSTANDING

If you understand that …

- Natural selection occurs when heritable variation in certain traits leads to improved success in reproduction. Because individuals with these traits produce many offspring with the same traits, the traits increase in frequency and evolution occurs.
- Evolution is a change in the characteristics of a population over time.

✔ You should be able to …

Discuss the following statement: "Various species of Galápagos finches are adapted to their particular habitats."

Answers are available in Appendix A.

1.4 Life Processes Information

After Walter Sutton and Theodor Boveri proposed the **chromosome theory of inheritance** in 1902, the pieces of the genetic puzzle began to fall into place. The key point? Inside cells, hereditary or genetic information is encoded in genes, the units located on chromosomes.

But it wasn't until experiments were carried out in the 1950s that biologists figured out the molecular nature of the genetic material—a **chromosome** consists of a molecule of **deoxyribonucleic acid,** or **DNA.** To sum up, DNA is the heredity material. Genes consist of specific segments of DNA that code for products in the cell.

The Central Dogma

In what is considered one of the greatest scientific breakthroughs of biology, James Watson and Francis Crick proposed that DNA is a double-stranded helix (Figure 1.4). Crucial insights that led to this model came from structural analyses performed by Rosalind Franklin in Maurice Wilkins' laboratory.

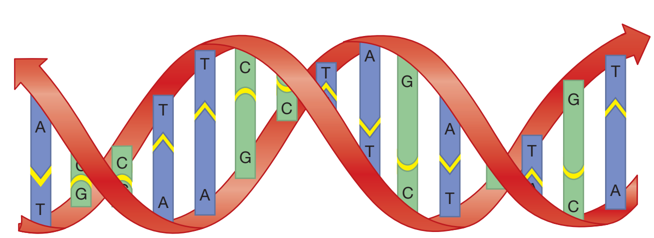


Figure 1.4 DNA Is a Double Helix.

Each strand of the **double helix** is made up of varying sequences of four different kinds of building blocks. In terms of structure, on each strand of the helix the building blocks of DNA are connected one to another linearly. In terms of function, they are like letters of the alphabet—the four different kinds of molecular building blocks are symbolized by the letters A, T, C, and G. A sequence of this letter code is like the sequence of letters in a word—it has meaning. In this way, DNA carries, or encodes, the information required for an organism's growth and reproduction.

The two strands of the double helix are joined by connections between the building blocks that occur only between certain letters: A always pairs with T, and C always pairs with G (see Figure 1.4). This pairing is key: DNA can be copied, and the information encoded in the DNA is faithfully preserved. The pairs are arranged much like the rungs on a ladder, with the strands acting as the sides of the ladder.

How is this information transmitted? The **central dogma**—first articulated by Crick—describes the flow of information in cells. In this context, the term "dogma" means a framework for understanding. Put simply, DNA codes for RNA, which codes for proteins (**Figure 1.5**).

Molecular machinery in cells makes a copy of a particular gene's information in the form of a closely related molecule called **ribonucleic acid,** or **RNA.** RNA molecules carry out a number of specialized functions in cells. For example, molecular machinery reads a messenger RNA molecule to determine what building blocks to use to make a **protein.** Proteins are crucial to most tasks required for a cell to exist, from forming structural components to promoting the chemical reactions that sustain life.

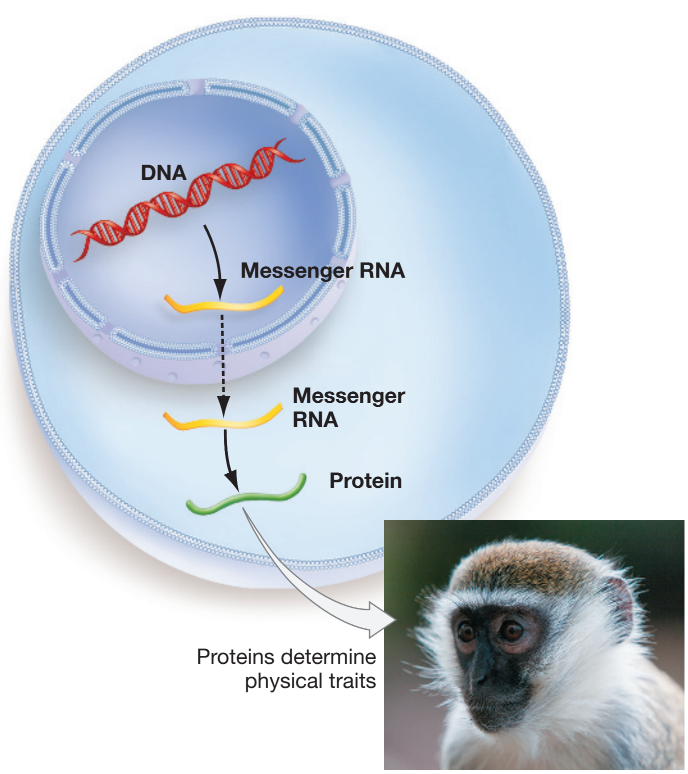


Figure 1.5 The Central Dogma Describes the Flow of Genetic Information. Genetic information flows from DNA to RNA to proteins. Differences in DNA sequences may lead to different physical traits.

Understanding the structure of DNA provided insight into how genetic information is passed from cell to cell or from one organism to its offspring. Making a copy of DNA in a cell is a highly accurate process, but mistakes can occur. What happens when a mistake is made? Differences in DNA sequences may lead to differences in the sequence of building blocks of proteins.

The implications are profound: The outward appearance of an organism is a product of the proteins produced by its molecular machinery, so differences in DNA sequences might lead to a difference, for example, in finch beak size and shape, or in the length of a giraffe's neck. At the level of individuals, such changes might increase or decrease fitness. At the population level, changes in sequence lead to the heritable variations that underlie the diversity of life and make evolution possible.

Life Requires Energy

The chemical reactions that sustain the diversity of life take place inside cells. Transmitting genetic information, and the other work carried out by cells, requires energy. Organisms—whether single-celled or multicellular—are capable of living in a wide array of environments because they vary in cell structure and how they acquire and use energy.

Organisms have two fundamental nutritional needs—acquiring chemical energy in the form of a molecule called **ATP** (or **adenosine triphosphate**) and obtaining molecules that can be used as building blocks for the synthesis of DNA, RNA, proteins, the cell membrane, and other large, complex compounds required by the cell. How organisms do this—whether acquiring energy from the sun or through chemical compounds—is central to the tremendous diversification of life after it first arose on Earth.

1.5 The Tree of Life

The theory of evolution by natural selection predicts that biologists should be able to construct a **tree of life**—a family tree of organisms. If life on Earth arose just once, then such a diagram would describe the genealogical relationships between species with a single, ancestral species at its base. Has this task been accomplished? If the tree of life exists, what does it look like?

Using Molecules to Understand the Tree of Life

One of the great breakthroughs in research on the tree of life occurred when American biologist Carl Woese (pronounced *woze*) and colleagues began analyzing the molecular components of organisms as a way to understand their evolutionary relationships. Their goal was to understand the **phylogeny** of all organisms—their actual genealogical relationships. Translated literally, "phylogeny" means "tribe-source."

To understand which organisms are closely versus distantly related, Woese and co-workers needed to study a molecule found in all organisms. They selected an RNA molecule, an essential part of the machinery that all cells use to grow and reproduce. The researchers based their initial work on the sequence of building blocks observed in this RNA molecule. At the time it was not yet possible to easily analyze DNA sequences. With advances in technology, biologists now use DNA sequences to investigate phylogenetic relationships.

Analyzing Genetic Variation Why might DNA (or RNA) be useful for understanding the relationships between organisms? The answer is that the sequence of building blocks in DNA is a trait that can change during the course of evolution. Although a gene may code for an RNA or protein molecule that performs the same function in all organisms, the corresponding DNA sequence is not identical among species.

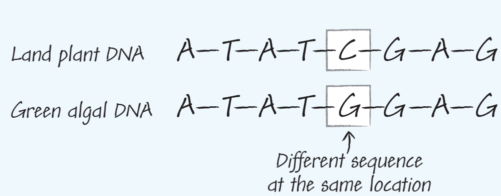
How is such genetic variation analyzed? Recall that the building blocks in DNA are symbolized by the letters A, T, C, and G. Biologists use this letter code to depict DNA sequences (**Making Models 1.1**). In land plants, for example, a section of DNA might start with the sequence A-T-A-T-**C**-G-A-G. In green algae, which are closely related to land plants, the same section of the molecule might contain A-T-A-T-**G**-G-A-G. But in brown algae, which are not closely related to green algae or to land plants, the same part of the molecule might consist of A-**A**-A-T-**G**-G-A-**C**.

The next step in analyzing genetic variation is to consider what the similarities and differences in the sequences imply about relationships between species. The goal is to produce a diagram that describes the phylogeny of the organisms being compared.

A diagram that depicts evolutionary history in this way is called a **phylogenetic tree.** (For help in learning how to read a phylogenetic tree, see **BioSkills 13**.) Just as a family tree shows relationships between individuals, a phylogenetic tree shows relationships between species. On a phylogenetic tree, branches that share a recent common ancestor—that is, an ancestral population—represent species that are closely related; branches that don't share recent common ancestors represent species that are more distantly related.

Making Models 1.1 Tips on Drawing DNA Sequences

In models focused on the information content in DNA, structural details can be left out and the double-stranded DNA double helix simplified to show the letter code on one strand only. Sequences can then be compared for similarities and differences.



MODEL Suppose that in the same section of DNA, molds and other fungi have the sequence A-T-A-T-G-G-A-C. Draw a model that compares the sequences. Do fungi appear to be more closely related to green algae or to land plants? Explain your logic.

To see this model in action, go to https://goo.gl/rXkXrM

The Tree of Life Estimated from Genetic Data To construct a phylogenetic tree, such as the one shown in **Figure 1.6**, researchers use sophisticated computer programs to find the arrangement of branches that is most consistent with the similarities and differences observed in the genetic data.

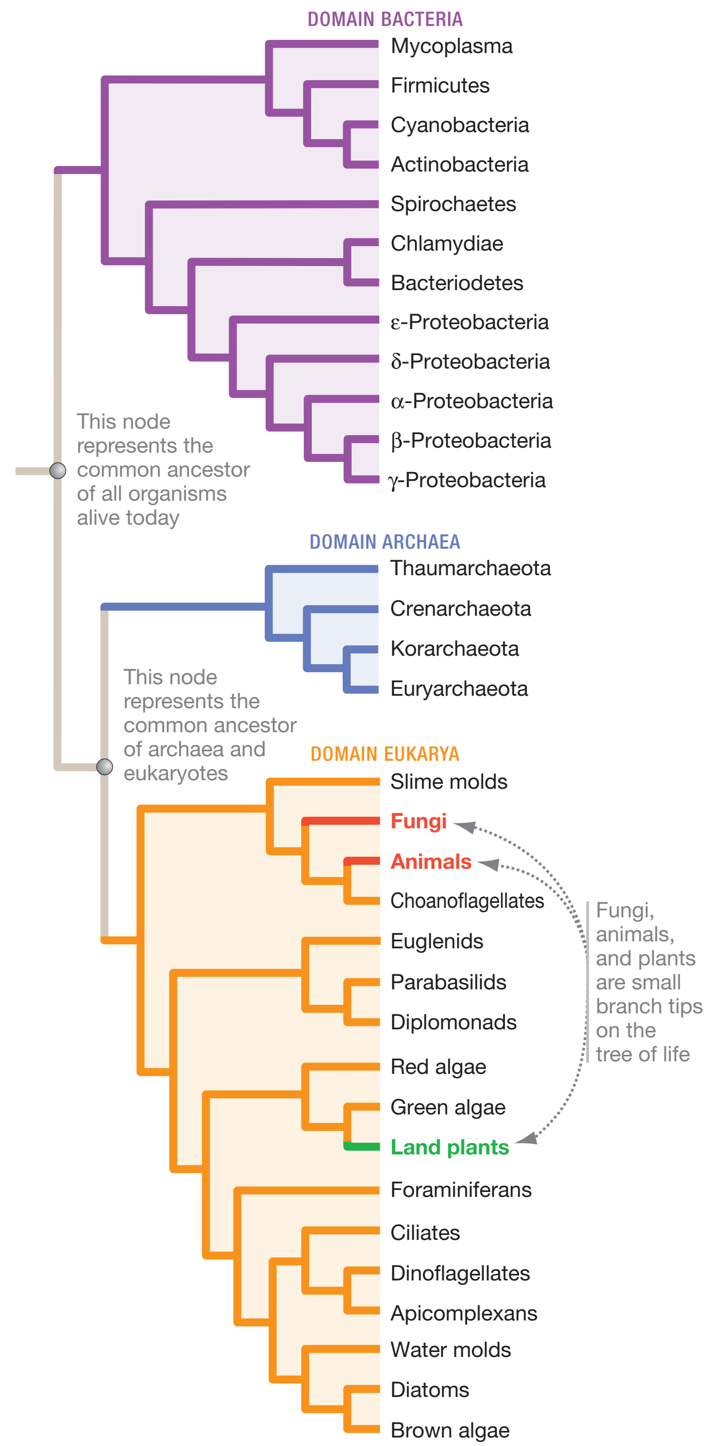


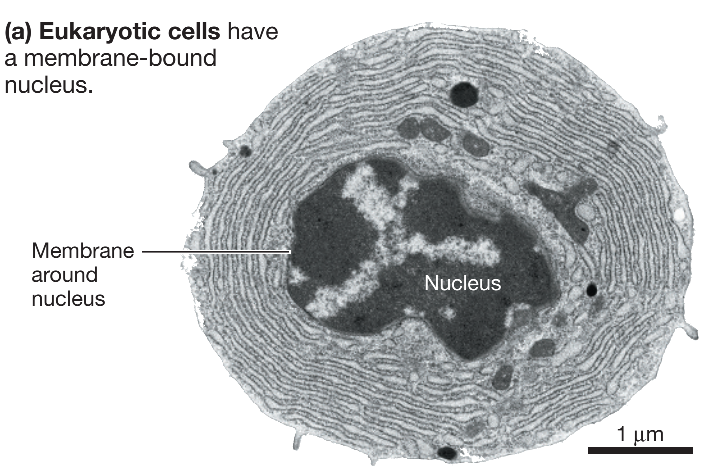
Figure 1.6 The Tree of Life Was Produced by Comparing Genetic Sequence Data. The three domains of life revealed by the analysis are labeled. Common names are given for lineages in the domains Bacteria and Eukarya. Phyla names are given for lineages in the domain Archaea, because most of them have no common names.

Because this tree includes such a diverse array of species, it is often called the universal tree, or the tree of life. Notice that the tree's main node is the common ancestor (ancestral population) of all living organisms. Researchers who study the origin of life propose that the tree's root extends even further back to the "*l*ast *u*niversal *c*ommon *a*ncestor" of cells, or **LUCA.**

The tree of life implied by genetic sequence data established that there are three fundamental groups or lineages of organisms: **(1)** the Bacteria, **(2)** the Archaea, and **(3)** the Eukarya. In all **eukaryotes** (literally, "true kernel"), cells have a prominent component called the nucleus (**Figure 1.7a**). Because the vast majority of bacterial and archaeal cells lack a nucleus, they are referred to as **prokaryotes** (literally, "before-kernel"; see **Figure 1.7b**). The vast majority of bacteria and archaea are unicellular ("one-celled"); many eukaryotes are multicellular ("many-celled").

When results based on genetic data were first published, biologists were astonished. For example:

- Prior to Woese's work and follow-up studies, biologists thought that the most fundamental division among organisms was between prokaryotes and eukaryotes. The Archaea were virtually unknown—much less recognized as a major and highly distinctive branch on the tree of life.
- Fungi were thought to be closely related to plants. Instead, they are actually much more closely related to animals.



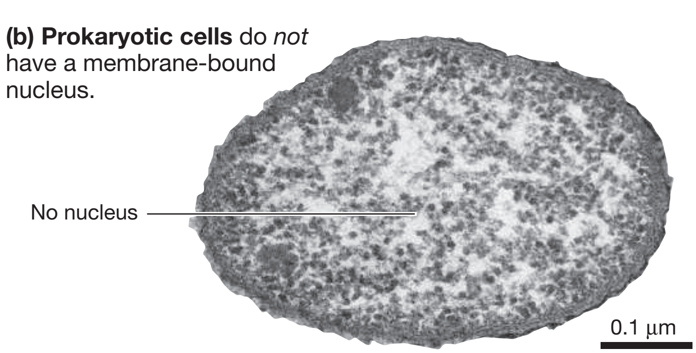


Figure 1.7 Eukaryotic and Prokaryotic Cells Differ in Structure.

✔ **QUANTITATIVE** How many times larger is the eukaryotic cell in this figure than the prokaryotic cell? (Hint: Study the scale bars.)

- Traditional approaches for classifying organisms—including the system of five kingdoms divided into various classes, orders, and families that you may have learned in high school—are inaccurate in many cases, because they do not reflect the actual evolutionary history of the organisms involved.

The Tree of Life Is a Work in Progress Just as researching your family tree can help you understand who you are and where you came from, so the tree of life helps biologists understand the relationships between organisms and the history of species. The discovery of the Archaea and the accurate placement of lineages such as the fungi qualify as exciting breakthroughs in our understanding of evolutionary history and life's diversity.

Work on the tree of life continues at a furious pace, however, and the location of certain branches on the tree is hotly debated. As databases expand and as techniques for analyzing data improve, the shape of the tree of life will undoubtedly change. Our understanding of the tree of life, like our understanding of every other topic in biological science, is dynamic.

How Should We Name Branches on the Tree of Life?

In science, the effort to name and classify organisms is called **taxonomy.** Any named group is called a **taxon** (plural: **taxa**). Currently, biologists are working to create a taxonomy, or naming system, that accurately reflects the phylogeny of organisms. Based on the tree of life, Woese proposed a new taxonomic category called the **domain.** He designated the Bacteria, Archaea, and Eukarya as the three domains of life.

Biologists often use the term **phylum** (plural: **phyla**) to refer to major lineages within each domain. Although the designation is somewhat arbitrary, each phylum is considered a major branch on the tree of life. Within the lineage called animals, biologists currently name 30–35 phyla—each of which is distinguished by distinctive aspects of its body structure as well as by distinctive gene sequences. For example, the mollusks (clams, squid, octopuses) constitute a phylum, as do chordates (the vertebrates and their close relatives).

Because the tree of life is so new, though, naming systems are still being worked out. For example, recent genetic data have fueled an ongoing debate about whether there are only two domains of life: Bacteria as one domain, and the rest of life the other. One thing that hasn't changed for centuries, however, is the naming system for individual species.

Scientific (Latin) Names In 1735, a Swedish botanist named Carolus Linnaeus established a system for naming species that is still in use today. Linnaeus created a two-part name unique to each type of organism.

- ***Genus*** The first part indicates the organism's **genus** (plural: **genera**). A genus is made up of a closely related group of species. For example, Linnaeus put humans in the genus *Homo*. Although humans are the only living species in this genus, at least six extinct organisms, all of which walked upright and made extensive use of tools, were later also assigned to *Homo*.

- ***Species*** The second term in the two-part name identifies the organism's species. Linnaeus gave humans the species name *sapiens*. A species name is always preceded by its genus.

An organism's genus and species designation is called its **scientific name** or Latin name. Scientific names are always italicized. Genus names are always capitalized, but species names are not—as in *Homo sapiens*.

Linnaeus maintained that different types of organisms should not be given the same genus and species names. Other species may be assigned to the genus *Homo* (from the Latin for "man"), and members of other genera may be named *sapiens* (from the Latin for "wise" or "knowing"), but only humans are named *Homo sapiens*. Each scientific name is unique.

Scientific Names Are Often Descriptive Scientific names and terms are often based on Latin or Greek word roots that are descriptive. For example, consider the yeast *Saccharomyces cerevisiae*. *Saccharomyces* is aptly named—the domesticated strains of yeast used in commercial baking and brewing are often fed sugar (Greek root *saccharo*), and yeast is a fungus (Greek root *myces*). The species name of this organism, *cerevisiae*, is Latin for "beer." Loosely translated, then, the scientific name of brewer's yeast means "sugar-fungus for beer."

Scientific names and terms often seem daunting at first glance. So, most biologists find it extremely helpful to memorize some of the common Latin and Greek roots. To aid you in this process, new terms in this text are often accompanied by a translation of their Latin or Greek word roots in parentheses. (A glossary of common root words with translations and examples is also provided in BioSkills 15.)

CHECK YOUR UNDERSTANDING

If you understand that …

- A phylogenetic tree shows the evolutionary relationships between species.
- To infer where species belong on a phylogenetic tree, biologists examine their genetic and other characteristics. Closely related species should have similar characteristics, while less closely related species should be less similar.

✔ You should be able to …

Examine the following DNA sequences and determine which two species would be closest on a phylogenetic tree.

Species A: A A C T A G C G C G A T

Species B: A A C T A G C G C C A T

Species C: T T C T A G C G G T A T

Answers are available in Appendix A.

1.6 Doing Biology

This chapter has introduced some of the great ideas in biology. The development of the cell theory, the theory of evolution, and the chromosome theory of inheritance provided cornerstones when the science was young. The central dogma explained the flow of information from DNA to physical traits of an organism, and the more recent insights of the tree of life have revolutionized our understanding of life's diversity.

These three unifying ideas are considered great because they explain fundamental aspects of nature, and because they have consistently been shown to be correct. They are considered correct because they have withstood extensive testing.

How do biologists go about testing their ideas? Before answering this question, let's step back a bit and consider the types of questions that researchers can and cannot ask.

The Nature of Science

Biologists ask questions about organisms, just as physicists and chemists ask questions about the physical world or geologists ask questions about Earth's history and the processes that shape landforms. No matter what their field, all scientists ask questions that can be answered by observing or measuring things—by collecting data. Conversely, scientists cannot address questions that can't be answered by observing or measuring things.

This distinction is important. It is at the root of continuing controversies about teaching evolution in publicly funded schools. In the United States and in Turkey, in particular, some Christian and Islamic leaders have been particularly successful in pushing their claim that evolution and religious faith are in conflict. Even though the theory of evolution is considered one of the most successful and best-substantiated ideas in the history of science, they object to teaching it.

The vast majority of biologists and many religious leaders reject this claim; they see no conflict between evolution and religious faith. Their view is that science and religion are compatible because they address different types of questions.

- Science is about formulating hypotheses and finding evidence that supports or conflicts with those hypotheses.
- Religious faith addresses questions that cannot be answered by data. The questions addressed by the world's great religions focus on why we exist and how we should live.

So how do biologists go about answering questions? After formulating hypotheses, biologists perform studies that yield experimental data or descriptive data, such as observing a behavior, characterizing a structure within a cell by microscopy, or sequencing DNA. Let's consider two examples of this process.

Why Do Giraffes Have Long Necks? An Introduction to Hypothesis Testing

If you were asked why giraffes have long necks, you might say based on your observations that long necks enable giraffes to reach food that is unavailable to other mammals. This hypothesis is expressed in African folktales and has traditionally been accepted by many biologists. The food competition hypothesis is so plausible, in fact, that for decades no one thought to test it.

In the mid-1990s, however, Robert Simmons and Lue Scheepers assembled data suggesting that the food competition hypothesis is only part of the story. Their analysis supports an alternative hypothesis: Long necks allow giraffes to use their heads as effective weapons for battering their opponents, and longer-necked giraffes have a competitive advantage in fights.