Brooker | Widmaier | Graham | Stiling

BIOLOGY

Second Edition

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BIOLOGY, SECOND EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 DOW / DOW 1 0 9 8 7 6 5 4 3 2 1 0

ISBN 978–0–07–353221–9
MHID 0–07–353221–5

Vice President & Editor-in-Chief: *Marty Lange*
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(USE) Cover Image: *Crystal Jellyfish (Aequorea victoria), ©Gary Kavanagh*
Senior Photo Research Coordinator: *John C. Leland*
Photo Research: *Pronk & Associates*
Compositor: *Lachina Publishing Services*
Typeface: *9.5/12 Slimbach*
Printer: *R. R. Donnelley*

Library of Congress Cataloging-in-Publication Data

Biology / Robert J. Brooker ... [et al.]. -- 2nd ed.
p. cm.
Includes index.
ISBN 978–0–07–353221–9 — ISBN 0–07–353221–5 (hard copy : alk. paper) 1. Biology. I. Brooker, Robert J.
QH308.2.B564445 2011
570--dc22

2009023209

www.mhhe.com

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About the Authors

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Rob Brooker (Ph.D., Yale University) received his B.A. in biology at Wittenberg University in 1978. At Harvard, he studied the lactose permease, the product of the *lacY* gene of the *lac* operon. He continues working on transporters at the University of Minnesota, where he is a Professor in the Department of Genetics, Cell Biology, and Development and has an active research laboratory. At the University of Minnesota, Dr. Brooker teaches undergraduate courses in biology, genetics, and cell biology. In addition to many other publications, he has written three editions of the undergraduate genetics text *Genetics: Analysis & Principles*, McGraw-Hill, copyright 2009.

Eric P. Widmaier

Eric Widmaier received his Ph.D. in 1984 in endocrinology from the University of California at San Francisco. His research is focused on the control of body mass and metabolism in mammals, the hormonal correlates of obesity, and the effects of high-fat diets on intestinal cell function. Dr. Widmaier is currently Professor of Biology at Boston University, where he recently received the university's highest honor for excellence in teaching. Among other publications, he is a coauthor of *Vander's Human Physiology: The Mechanisms of Body Function,* 11th edition, published by McGraw-Hill, copyright 2008.

Linda E. Graham

Linda Graham received her Ph.D. in botany from the University of Michigan, Ann Arbor. Her research explores the evolutionary origin of land-adapted plants, focusing on their cell and molecular biology as well as ecological interactions. Dr. Graham is now Professor of Botany at the University of Wisconsin–Madison. She teaches undergraduate courses in biology and plant biology. She is the coauthor of, among other publications, *Algae*, copyright 2000, a major's textbook on algal biology, and *Plant Biology*, copyright 2006, both published by Prentice Hall/ Pearson.

Left to right: Eric Widmaier, Linda Graham, Peter Stiling, and Rob Brooker

Peter D. Stiling

Peter Stiling obtained his Ph.D. from University College, Cardiff, Wales, in 1979. Subsequently, he became a postdoc at Florida State University and later spent 2 years as a lecturer at the University of the West Indies, Trinidad. During this time, he began photographing and writing about butterflies and other insects, which led to publication of several books on local insects. Dr. Stiling is currently a Professor of Biology at the University of South Florida at Tampa. He teaches graduate and undergraduate courses in ecology and environmental science as well as introductory biology. He has published many scientific papers and is the author of *Ecology: Global Insights and Investigations*, soon to be published by McGraw-Hill. Dr. Stiling's research interests include plant-insect relationships, parasite-host relationships, biological control, restoration ecology, and the effects of elevated carbon dioxide levels on plant herbivore interactions.

The authors are grateful for the help, support,
and patience of their families, friends, and students,
Deb, Dan, Nate, and Sarah Brooker,
Maria, Rick, and Carrie Widmaier,
Jim, Michael, and Melissa Graham, and
Jacqui, Zoe, Leah, and Jenna Stiling.

Improving Biology Education: We Listened to You

A Step Ahead

A Step Ahead describes what we set out to accomplish with this second-edition textbook. As authors and educators, we know your goal is to ensure your students are prepared for the future—their future course work, lab experiences, and careers in the sciences. Building a strong foundation in biology will put your students a step ahead on this path.

The illustrations are outstanding and better than in most textbooks. They are clear, eye-catching, and compactly illustrate the important features without the cluttering that so often accompanies diagrams. The essential features can be seen and understood at a glance.

Harold Heatwole, North Carolina State University

Through our classroom experiences and research work, we became inspired by the prospect that the first edition of *Biology* could move biology education forward. We are confident that this new edition of *Biology* is a step ahead because we listened to you. Based on our own experience and our discussions with educators and students, we continue to concentrate our efforts on these crucial areas:

- Experimentation and the process of science
- Modern content
- Evolutionary perspective
- Emphasis on visuals
- Accuracy and consistency
- Critical thinking
- Media—active teaching and learning with technology

Continued feedback from instructors using this textbook has been extremely valuable in refining the presentation of the material. Likewise, we have used the textbook in our own classrooms. This hands-on experience has provided much insight regarding areas for improvement. Our textbook continues to be comprehensive and cutting-edge, featuring an evolutionary focus and an emphasis on scientific inquiry.

This is an excellent textbook for biology majors, and the students should keep the book as a future reference. The thoughts flow very well from one topic to the next.

Gary Walker, Youngstown State University

The first edition of *Biology* was truly innovative in its visual program, and with the second edition it remains a step ahead. In watching students study as well as in extensive interviews, it is clear that students rely heavily on the artwork as their primary study tool. As you will see when you scan through our book, the illustrations have been crafted with the student's perspective in mind. They are very easy to follow, particularly those that have multiple steps, and have very complete explanations of key concepts. We have taken the approach that students should be able to look at the figures and understand the key concepts, without having to glance back and forth between the text and art. Many figures contain text boxes that explain what the illustration is showing. In those figures with multiple steps, the boxes are numbered and thereby guide the students through biological processes.

A Step Ahead in Serving Teachers and Learners

To accurately and thoroughly cover a course as wide ranging as biology, we felt it was essential that our team reflect the diversity of the field. We saw an opportunity to reach students at an early stage in their education and provide their biology training with a solid and up-to-date foundation.We have worked to balance coverage of classic research with recent discoveries that extend biological concepts in surprising new directions or that forge new concepts. Some new discoveries were selected because they highlight scientific controversies, showing students that we don't have all the answers yet. There is still a lot of work for new generations of biologists. With this in mind, we've also spotlighted discoveries made by diverse people doing research in different countries to illustrate the global nature of modern biological science.

As active teachers and writers, one of the great joys of this process for us is that we have been able to meet many more educators and students during the creation of this textbook. It is humbling to see the level of dedication our peers bring to their teaching. Likewise, it is encouraging to see the energy and enthusiasm so many students bring to their studies. We hope this book and its media package will serve to aid both faculty and students in meeting the challenges of this dynamic and exciting course. For us, this remains a work in progress, and we encourage you to let us know what you think of our efforts and what we can do to serve you better.

Rob Brooker, Eric Widmaier, Linda Graham, Peter Stiling

CHANGES TO THIS EDITION

The author team is dedicated to producing the most engaging and current textbook that is available for undergraduate students who are majoring in biology. We want our students to be inspired by the field of biology and to become critical thinkers. To this end, we have made the following changes throughout the entire book.

- Each chapter in the second edition begins with an interesting story or a set of observations that will capture the students' interests as they begin to read a chapter.
- To help students test their knowledge and critical-thinking skills, we have increased the number of Concept check questions that are associated with the figure legends and revised many of the questions at the end of each chapter so they are at a higher level in Bloom's taxonomy. An answer key for the questions is now provided in an appendix at the end of the book.
- To further help students appreciate the scientific process, the Feature Investigation in each chapter now includes three new elements: a Conclusion, the original journal citation for the experiment, and questions that are directly related to the experiment.
- Many photographs and micrographs have been enlarged or replaced with better images.
- The presentation of the material has been refined by dividing some of the chapters into smaller sections and by the editing of complex sentences.

With regard to the scientific content in the textbook, the author team has worked with hundreds of faculty reviewers to refine the first edition and to update the content so that our students are exposed to the most cutting-edge material. Some of the key changes that have occurred are summarized below.

Chemistry Unit

- **Chapter 2. The Chemical Basis of Life I: Atoms, Molecules, and Water:** This stage-setting chapter now introduces the concepts of matter and energy, chemical equilibrium, condensation/hydrolysis reactions, and expands upon the properties of water (for example, introducing such concepts as specific heat). The nature and importance of radioisotopes in biology and medicine has also been expanded and clarified, along with a new photo of a whole-body PET scan of a person with cancer.
- **Chapter 3. The Chemical Basis of Life II: Organic Molecules:** Enzymes are now defined in this early chapter. A new figure has been added that reinforces and elaborates upon the mechanism and importance of dehydration and hydrolysis reactions, which were first introduced in Chapter 2. This figure includes the principles of polymer formation and breakdown. Carbohydrates, lipids, proteins, and nucleic acids have been reorganized into distinct major headings for sharper focus.

Cell Unit

- **Chapter 4. General Features of Cells:** You will find improved illustrations of the cytoskeleton and new content regarding the origin of peroxisomes. The chapter has a new section on Protein Sorting to Organelles and ends with a new section called System Biology of Cells: A Summary, which summarizes the content of Chapter 4 from a systems biology perspective.
- **Chapter 5. Membrane Structure, Synthesis, and Transport:** This chapter has a new section on the Synthesis of Membrane Components in Eukaryotic Cells. In this section, you will find a description of how cells make phospholipids, a critical topic that is often neglected.
- **Chapter 6. An Introduction to Energy, Enzymes, and Metabolism:** Based on reviewer comments, this newly created chapter splits the material that was originally in Chapter 7 of the first edition. Chapter 6 provides an introduction to energy, enzymes, and metabolism. It includes added material on ribozymes and a novel section at the end of the chapter that describes the important topic of how cells recycle the building blocks of their organic macromolecules.
- **Chapter 7. Cellular Respiration, Fermentation, and Secondary Metabolism:** In the second edition, Chapter 7 is now divided into three sections: Cellular Respiration in the Presence of Oxygen, Anaerobic Respiration and Fermentation, and Secondary Metabolism.
- **Chapter 8. Photosynthesis:** The discussion of the light-dependent reactions is now divided into two sections: Reactions that Harness Light Energy and Molecular Features of Photosystems.
- **Chapter 9. Cell Communication:** Two sections that were in the first edition on Cellular Receptors and Signal Transduction and the Cellular Response have been streamlined and simplified. A new section called Apoptosis: Programmed Cell Death has been added, which includes a pioneering Feature Investigation that describes how apoptosis was originally discovered.
- **Chapter 10. Multicellularity:** The figures in this chapter have been greatly improved with a greater emphasis on orientation diagrams that help students visualize where an event is occurring in the cell or in a multicellular organism.

Genetics Unit

- **Chapter 11. Nucleic Acid Structure, DNA Replication, and Chromosome Structure:** The section on Chromosome Structure has been moved from Chapter 15 in the first edition to this chapter so that the main molecular features of the genetic material are contained within a single chapter. To help students grasp the major concepts, the topic of DNA replication has been split into two sections: Overview of DNA Replication and Molecular Mechanism of DNA Replication.
- **Chapter 12. Gene Expression at the Molecular Level:** Several topics in this chapter have been streamlined to make it easier for students to grasp the big picture of gene expression.
- **Chapter 13. Gene Regulation:** Topics in gene regulation, such as micro RNAs, have been updated.
- **Chapter 14. Mutation, DNA Repair, and Cancer:** Information regarding the effects of oncogenes has been

modified so that students can appreciate how mutations in particular oncogenes and tumor suppressor genes promote cancer.

- **Chapter 15. The Eukaryotic Cell Cycle, Mitosis, and Meiosis:** This chapter now begins with a section on the eukaryotic cell cycle, which was in Chapter 9 of the first edition. This new organization allows students to connect how the cell cycle is related to mitosis and meiosis. Also, a new Genomes and Proteomes Connection on cytokinesis has been added, which explains new information on how cells divide.
- **Chapter 16. Simple Patterns of Inheritance:** To make the topics stand out better for students, this chapter has been subdivided into six sections: Mendel's Laws of Inheritance, The Chromosome Theory of Inheritance, Pedigree Analysis of Human Traits, Sex Chromosomes and X-Linked Inheritance Patterns, Variations in Inheritance Patterns and Their Molecular Basis, and Genetics and Probability.
- **Chapter 17. Complex Patterns of Inheritance:** The coverage of X inactivation, genomic imprinting, and maternal effect genes has been streamlined to focus on their impacts on phenotypes.
- **Chapter 18. Genetics of Viruses and Bacteria:** In response to reviewers of the first edition, this chapter now begins with viruses. The topics of viroids and prions are set apart in their own section. Also, the information regarding bacterial genetics comes at the end of the chapter and is divided into two sections on Genetic Properties of Bacteria and on Gene Transfer Between Bacteria.
- **Chapter 19. Developmental Genetics:** Invertebrate development has been streamlined to focus on the major themes of development. The topic of stem cells has been updated with new information regarding their importance in development and their potential uses in medicine.
- **Chapter 20. Genetic Technology:** New changes to this chapter include an improved figure on polymerase chain reaction (PCR) and new information regarding the engineering of Bt crops in agriculture.
- **Chapter 21. Genomes, Proteomes, and Bioinformatics:** This chapter has been updated with the newest information regarding genome sequences. Students are introduced to the NCBI website, and a collaborative problem at the end of the chapter asks the students to identify a mystery gene sequence using the BLAST program.

Evolution Unit

- **Chapter 22. The Origin and History of Life:** The topic of fossils has been separated into its own section. The second edition has some new information regarding ideas about how polymers can be formed abiotically in an aqueous setting. The role of oxygen has been expanded.
- **Chapter 23. An Introduction to Evolution:** To help the students make connections between genes and traits, newly discovered examples, such as the role of allelic differences in the *Igf2* gene among dog breeds, have been added.
- **Chapter 24. Population Genetics:** To bring the topics into sharper focus, this chapter is now subdivided into five sections: Genes in Populations, Natural Selection, Sexual Selection, Genetic Drift, and Migration and Nonrandom Mating. The important topic of single nucleotide polymorphisms is highlighted near the beginning of the chapter along with its connection to personalized medicine.
- **Chapter 25. Origin of Species and Macroevolution:** The topic of species concepts has been updated with an emphasis on the general lineage concept. Sympatric speciation has been divided into three subtopics: Polyploidy, Adaptation to Local Environments, and Sexual Selection.
- **Chapter 26. Taxonomy and Systematics:** The chapter begins with a modern description of taxonomy that divides eukaryotes into eight supergroups. To make each topic easier to follow, the chapter is now subdivided into five sections: Taxonomy, Phylogenetic Trees, Cladistics, Molecular Clocks, and Horizontal Gene Transfer.

Diversity Unit

- **Chapter 27. Bacteria and Archaea:** In this chapter featuring bacterial and archeal diversity, several illustrations have been improved. New information has been added to the Feature Investigation highlighting radiation resistance in Deinococcus.
- **Chapter 28. Protists:** In this exploration of protist diversity, recent research findings have been incorporated into chapter organization and phylogenetic trees. The evolutionary and ecological importance of cryptomonads and haptophytes are emphasized more completely. Life-cycle diagrams have been improved for clarity. A new Genomes and Proteomes Connection features genomic studies of the human pathogens trichomonas and giardia.
- **Chapter 29. Plants and the Conquest of Land:** This chapter on seedless plant diversity incorporates new molecular phylogenetic information on relationships. A new Genomes and Proteomes Connection features the model fern genus *Ceratopteris*. Life cycles have been improved for greater clarity.
- **Chapter 30. The Evolution and Diversity of Modern Gymnosperms and Angiosperms:** This chapter, highlighting seed plant diversity, features a new Genomes and Proteomes Connection on the role of whole genome duplication via autopolyploidy and allopolyploidy in the evolution of seed plants.
- **Chapter 31. Fungi:** The fungal diversity chapter's position has been changed to emphasize the close relationship of fungi to animals. There is an increased emphasis upon the role of fungi as pathogens and in other biotic associations. For example, a new Genomes and Proteomes Connection explores the genetic basis of beneficial plant associations with ectomycorrhizal fungi, and a new Feature Investigation features experiments that reveal a partnership between a virus and endophytic fungi that increases heat tolerance in plants. Life cycles of higher fungi have been modified to highlight heterokaryotic phases.

- **Chapter 32: An Introduction to Animal Diversity:** A brief evolutionary history of animal life has been added. A new figure shows the similarity of a sponge to its likely ancestor, a colonial choanoflagellate. The summary characteristics of the major animal phyla have been simplified.
- **Chapter 33: The Invertebrates:** With the huge number of invertebrate species and the medical importance of many, a new Genomes and Proteomes Connection discusses DNA barcoding, which may allow for rapid classification of species. The taxonomy of the annelids, arthropods, and chordates has been updated.
- **Chapter 34: The Vertebrates:** The organization of the section headings now follows the vertebrate cladogram introduced at the start of the chapter. A more modern approach to the taxonomy of vertebrates has been adopted, particularly in the discussion of primates. In addition, there is an extended treatment of human evolution and a new Genomes and Proteomes Connection comparing the human and chimpanzee genetic codes.

Plant Unit

- **Chapter 35. An Introduction to Flowering Plant Form and Function:** This overview of flowering plant structure and function has been revised to better serve as an introduction to Chapters 36–39. A new Genomes and Proteomes Connection features the genetic control of stomatal development and emphasizes the role of asymmetric division in the formation of specialized plant cells. A new Feature Investigation reveals how recent experiments have demonstrated the adaptive value of palmate venation in leaves.
- **Chapter 36. Flowering Plants: Behavior:** In this chapter on plant behavior, the general function of plant hormones in reducing gene repression, thereby allowing gene expression, provides a new unifying theme. As an example, new findings on the stepwise evolution of the interaction between gibberellin and DELLA proteins are highlighted. The Feature Investigation, highlighting classic discoveries concerning auxin's role in phototropism, has been condensed to achieve greater impact.
- **Chapter 37. Flowering Plants: Nutrition:** In this chapter on plant nutrition, a new Genomes and Proteomes Connection features the development of legume-rhizobium symbioses.
- **Chapter 38. Flowering Plants: Transport:** In this chapter on plant transport, the recent use of synthetic tree models has been added to further highlight experimental approaches toward understanding plant structure-function relationships.
- **Chapter 39. Flowering Plants: Reproduction:** In this chapter on flowering plant reproduction, greater attention is paid to the trade-offs of sexual versus asexual reproduction, explaining why both commonly occur and are important in nature and agricultural applications. A new Genomes and Proteomes Connection describes a study of the evolution of plants that reproduce via only asexual means from sexually reproducing ancestral species.

Animal Unit

Key changes to the animal unit include reorganization of the chapters such that animal nervous systems are presented first, an expanded emphasis on comparative features of invertebrate and vertebrate animal biology, and updates to each of the Impact on Public Health sections.

- **Chapter 40. Animal Bodies and Homeostasis:** This opening chapter has numerous new and improved photos and illustrations, such as those associated with an expanded discussion of different types of connective and epithelial tissue. The utility of the Fick diffusion equation has now been explained, and the very important relationship between surface area and volume in animals has been more thoroughly developed.
- **Chapter 41. Neuroscience I: Cells of the Nervous System:** Discussion of animal nervous systems has been moved to the beginning chapters of the animal unit, rather than appearing midway through the unit. This was done to better set the stage for all subsequent chapters. In this way, students will gain an appreciation for how the nervous system regulates the functions of all other organ systems. This concept will be continually reinforced as the students progress through the unit. Specific changes to Chapter 41 include an expanded treatment of equilibrium potential, a new discussion and figure on spatial and temporal summation in neurons, and a false-color SEM image of a synapse.
- **Chapter 42. Neuroscience II: Evolution and Function of the Brain and Nervous Systems:** In this second chapter devoted to nervous systems, the many functions of individual regions of animals' brains have been more extensively described and also summarized for easy reference in a new table. The epithalamus is now included in this discussion, and the structure and function of the autonomic nervous system has received expanded coverage.
- **Chapter 43. Neuroscience III: Sensory Systems:** An expanded, detailed, and step-by-step treatment of visual and auditory signaling mechanisms has been added to this third and concluding chapter on animal nervous systems. A fascinating comparison of the visual fields of predator and prey animals has been added, along with a figure illustrating the differences. A new figure illustrating how people see the world through eyes that are diseased due to glaucoma, macular degeneration, or cataracts is now included.
- **Chapter 44. Muscular-Skeletal System and Locomotion:** The events occurring during cross-bridge cycling in muscle have been newly illustrated and detailed. A new figure showing the histologic appearance of healthy versus osteoporotic bones, and the skeleton of a child with rickets has been added.
- **Chapter 45. Nutrition, Digestion, and Absorption:** An overview figure illustrating the four basic features of energy assimiliation in animals has been added to the beginning of the chapter to set the stage for the later discussions of ingestion, digestion, absorption, and elimination. A more developed

comparative emphasis on ingestive and digestive processes in animals has been added, with expanded treatment of adaptations that occur in animals that live in freshwater or marine environments. This is accompanied by newly added photographs of different animals' teeth being used to chew, tear, grasp, and nip food in their native environments.

- **Chapter 46. Control of Energy Balance, Metabolic Rate, and Body Temperature:** The text and artwork in this chapter have been considerably streamlined to emphasize major principles of fat digestion and absorption in animals.
- **Chapter 47. Circulatory Systems:** The local and systemic relationships between pressure, blood flow, and resistance are now distinguished more clearly from each other and described in separate sections to emphasize the differences between them. The organization of major topics has been adjusted to better reflect general principles of circulatory systems that apply across taxa, as well as comparative features of vertebrate circulatory systems.
- **Chapter 48. Respiratory Systems:** This chapter has benefited from a general upgrade in artwork, but particularly that of the human respiratory system, including the addition of a cross section through alveoli to illustrate their cellular structures and associations with capillaries.
- **Chapter 49. Excretory Systems and Salt and Water Balance:** A new photo of proximal tubule cells that reveals their extensive microvilli has been added to reinforce the general principle of surface-area adaptations described in earlier chapters. A major reorganization of the manner in which the anatomy and function of nephrons has been introduced; each part of the nephron has now been separated into multiple figures for easier understanding.
- **Chapter 50. Endocrine Systems:** The layout of many figures has been adjusted to improve readability and flow; this has also been facilitated with new orientation illustrations that reveal where within the body a given endocrine organ is located. Along with the new layouts, several figures have been simplified to better illustrate major concepts of hormone synthesis, action, and function. As part of a unit-wide attempt to increase quantitative descriptions of animal biology, additional data have been added in the form of a bar graph to this chapter's Feature Investigation.
- **Chapter 51. Animal Reproduction:** The major concepts of asexual and sexual reproduction have been pulled together from various sections of the text into a newly organized single section immediately at the start of the chapter. This reorganization and consolidation of material has eliminated some redundancy, but more importantly allows for a direct, integrated comparison of the two major reproductive processes found in animals. In keeping with a unit-wide effort to improve the flow of major illustrations, certain complex, multipart figures have been broken into multiple figures linked with the text.
- **Chapter 52. Animal Development:** To better allow this chapter to be understood on its own, a new introductory section has been added that reinforces basic concepts of cellular and molecular control of animal development that were first introduced in Chapter 19 (Developmental Genetics). The complex processes occurring during gastrulation have been rendered in a newly simplified and clarified series of illustrations. The treatment of Frzb and Wnt proteins in the Genomes and Proteomes Connection has been removed and replaced with a discussion of Spemann's organizer to better reflect the genetic basis of development across taxa in animals. An amazing series of photographs depicting cleft lip/palate and its surgical reconstruction has also been added to the Impact on Public Health section.
- **Chapter 53. Immune Systems:** A key change in this chapter is the effective use of additional or reformatted text boxes in illustrations of multistep processes. The layout of nearly every figure has been modified for clarity and ease of understanding. The topic of specific immunity has been reorganized such that the cellular and humoral aspects of immunity are clearly defined and distinguished. A new figure illustrating clonal selection has been added.

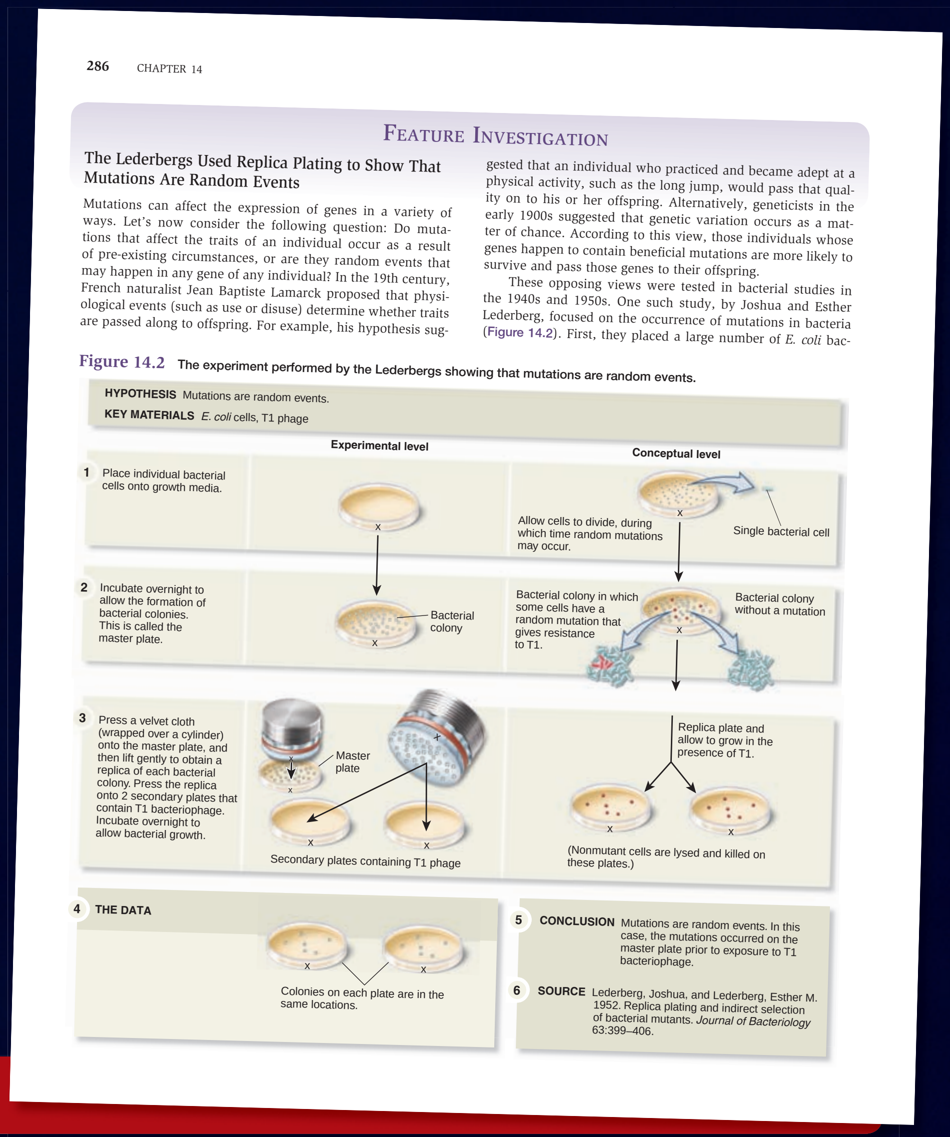
Ecology Unit

- **Chapter 54: An Introduction to Ecology and Biomes:** A new table summarizes the various abiotic factors and their effects on organisms. New information on greenhouse gases is provided, including their contributions to global warming.
- **Chapter 55: Behavioral Ecology:** Portions of the section on mating systems have been rewritten in this updated chapter on behavior.
- **Chapter 56: Population Ecology:** Additional information on population growth models has been provided by discussing the finite rate of increase, λ, and by discussing growth of black-footed ferret populations in Wyoming, which are recovering after being pushed to the brink of extinction.
- **Chapter 57: Species Interactions:** This new treatment of species interactions has been streamlined, but at the same time, new information is provided on how shark fishing along the eastern seaboard of the United States has disrupted marine food webs.
- **Chapter 58: Community Ecology:** The content of this chapter has been updated and rewritten, and historical information regarding community recovery following volcanic eruption on the island of Krakatau, Indonesia, has been added. The section of species richness has also been reorganized.
- **Chapter 59: Ecosystems Ecology:** New art and text on the pyramid of numbers has been provided in the first section. The carbon cycle has been rewritten, and information on net primary production in different biomes has been updated.
- **Chapter 60: Biodiversity and Conservation Biology:** The link between biodiversity and ecosystem function has been underscored by better explaining Tilman's field experiments. The chapter also provides a new section on climate change as a cause of species extinction and loss of biodiversity. A new discussion of bioremediation has been provided in the restoration ecology section.

A STEP AHEAD IN PREPARING STUDENTS FOR THE FUTURE

I really like the Feature Investigation so students can begin to grasp how scientists come to the conclusions that are simply presented as facts in these introductory texts.

Richard Murray, Hendrix College



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FEATURE INVESTIGATION

The Lederbergs Used Replica Plating to Show That Mutations Are Random Events

Mutations can affect the expression of genes in a variety of ways. Let's now consider the following question: Do mutations that affect the traits of an individual occur as a result of pre-existing circumstances, or are they random events that may happen in any gene of any individual? In the 19th century, French naturalist Jean Baptiste Lamarck proposed that physiological events (such as use or disuse) determine whether traits are passed along to offspring. For example, his hypothesis suggested that an individual who practiced and became adept at a physical activity, such as the long jump, would pass that quality on to his or her offspring. Alternatively, geneticists in the early 1900s suggested that genetic variation occurs as a matter of chance. According to this view, those individuals whose genes happen to contain beneficial mutations are more likely to survive and pass those genes to their offspring.

These opposing views were tested in bacterial studies in the 1940s and 1950s. One such study, by Joshua and Esther Lederberg, focused on the occurrence of mutations in bacteria (Figure 14.2). First, they placed a large number of *E. coli* bac-

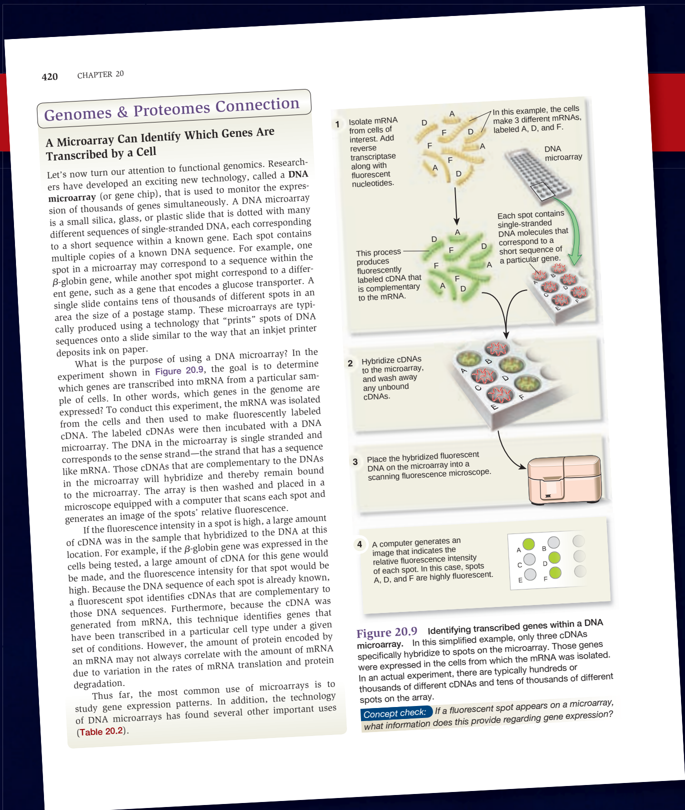
Figure 14.2 The experiment performed by the Lederbergs showing that mutations are random events.

EXPERIMENTAL APPROACH

Feature Investigations provide a complete description of experiments, including data analysis, so students can understand how experimentation leads to an understanding of biological concepts. There are two types of *Feature Investigations*. Most describe experiments according to the scientific method. They begin with observations and then progress through the hypothesis, experiment, data, and the interpretation of the data (conclusion). Some *Feature Investigations* involve discovery-based science, which does not rely on a preconceived hypothesis. The illustrations of the *Feature Investigations* are particularly innovative by having parallel drawings at the experimental and conceptual levels. By comparing the two levels, students will be able to understand how the researchers were able to interpret the data and arrive at their conclusions.

This is one of the best features of these chapters. It is absolutely important to emphasize evolution themes at the molecular level in undergraduate biology courses.

Jorge Busciglio, University of California – Irvine



420 CHAPTER 20

Genomes & Proteomes Connection

A Microarray Can Identify Which Genes Are Transcribed by a Cell

Let's now turn our attention to functional genomics. Researchers have developed an exciting new technology, called a **DNA microarray** (or gene chip), that is used to monitor the expression of thousands of genes simultaneously. A DNA microarray is a small silica, glass, or plastic slide that is dotted with many different sequences of single-stranded DNA, each corresponding to a short sequence within a known gene. Each spot contains multiple copies of a known DNA sequence. For example, one spot in a microarray may correspond to a sequence within the β-globin gene, while another spot might correspond to a different gene, such as a gene that encodes a glucose transporter. A single slide contains tens of thousands of different spots in an area the size of a postage stamp. These microarrays are typically produced using a technology that "prints" spots of DNA sequences onto a slide similar to the way that an inkjet printer deposits ink on paper.

What is the purpose of using a DNA microarray? In the experiment shown in Figure 20.9, the goal is to determine which genes are transcribed into mRNA from a particular sample of cells. In other words, which genes in the genome are expressed? To conduct this experiment, the mRNA was isolated from the cells and then used to make fluorescently labeled cDNA. The labeled cDNAs were then incubated with a DNA microarray. The DNA in the microarray is single stranded and corresponds to the sense strand—the strand that has a sequence like mRNA. Those cDNAs that are complementary to the DNAs in the microarray will hybridize and thereby remain bound to the microarray. The array is then washed and placed in a microscope equipped with a computer that scans each spot and generates an image of the spots' relative fluorescence.

If the fluorescence intensity in a spot is high, a large amount of cDNA was in the sample that hybridized to the DNA at this location. For example, if the β-globin gene was expressed in the cells being tested, a large amount of cDNA for this gene would be made, and the fluorescence intensity for that spot would be high. Because the DNA sequence of each spot is already known, a fluorescent spot identifies cDNAs that are complementary to those DNA sequences. Furthermore, because the cDNA was generated from mRNA, this technique identifies genes that have been transcribed in a particular cell type under a given set of conditions. However, the amount of protein encoded by an mRNA may not always correlate with the amount of mRNA due to variation in the rates of mRNA translation and protein degradation.

Thus far, the most common use of microarrays is to study gene expression patterns. In addition, the technology of DNA microarrays has found several other important uses (Table 20.2).

Figure 20.9 Identifying transcribed genes within a DNA microarray. In this simplified example, only three cDNAs specifically hybridize to spots on the microarray. Those genes were expressed in the cells from which the mRNA was isolated. In an actual experiment, there are typically hundreds or thousands of different cDNAs and tens of thousands of different spots on the array.

Concept check: If a fluorescent spot appears on a microarray, what information does this provide regarding gene expression?

EVOLUTIONARY PERSPECTIVE

Modern techniques have enabled researchers to study many genes simultaneously, allowing them to explore genomes (all the genes an organism has) and proteomes (all the proteins encoded by those genes). This allows us to understand biology in a more broad way. Beginning in Chapter 3, each chapter has a topic called the *Genomes & Proteomes Connection* that provides an understanding of how genomes and proteomes underlie the inner workings of cells and explains how evolution works at the molecular level. The topics that are covered in the *Genomes & Proteomes Connection* are very useful in preparing students for future careers in biology. The study of genomes and proteomes has revolutionized many careers in biology, including those in medicine, research, biotechnology, and many others.

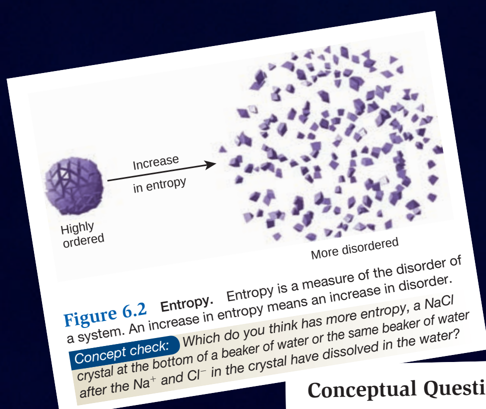
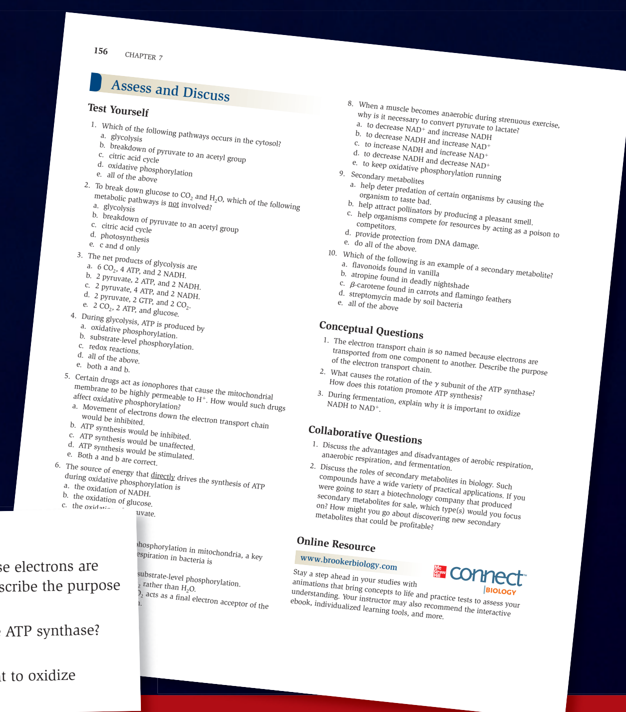
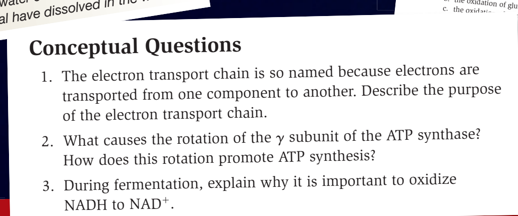


Figure 6.2 Entropy. Entropy is a measure of the disorder of a system. An increase in entropy means an increase in disorder.

Concept check: Which do you think has more entropy, a NaCl crystal at the bottom of a beaker of water or the same beaker of water after the Na^+ and Cl^- in the crystal have dissolved in the water?





Conceptual Questions

1. The electron transport chain is so named because electrons are transported from one component to another. Describe the purpose of the electron transport chain.
2. What causes the rotation of the γ subunit of the ATP synthase? How does this rotation promote ATP synthesis?
3. During fermentation, explain why it is important to oxidize NADH to NAD^+.

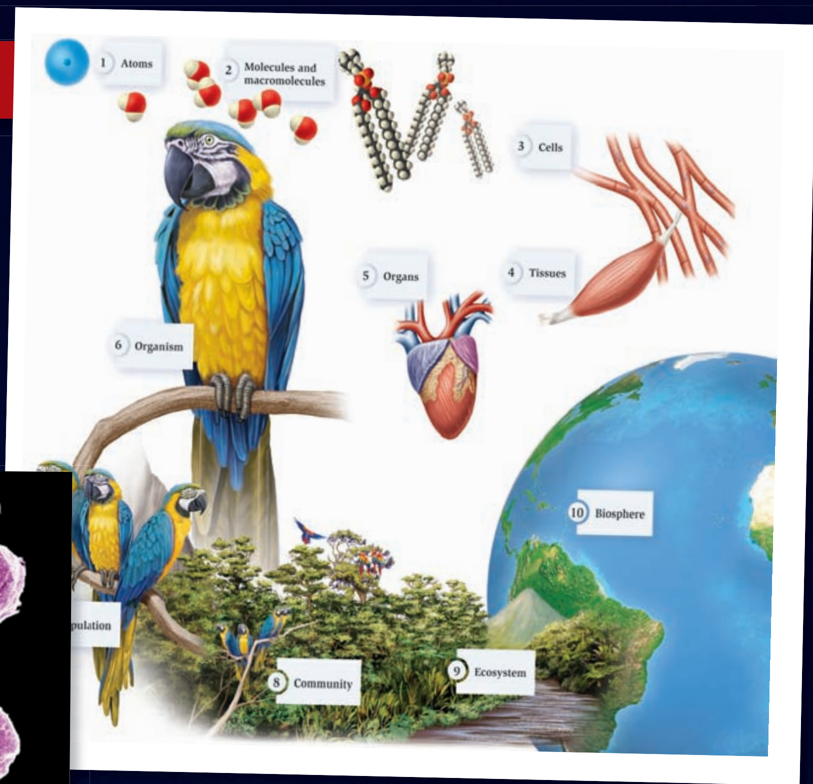
CRITICAL THINKING

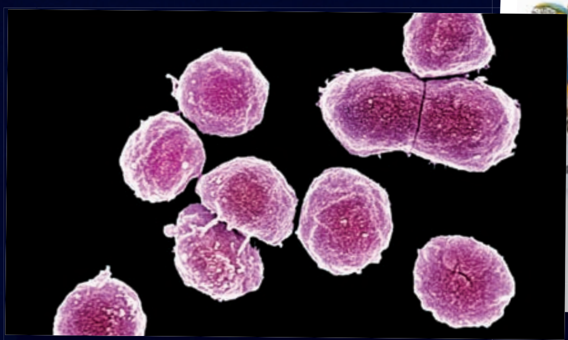
Students can test their knowledge and critical thinking skills with the *Concept check* questions that are associated with the figure legends. These questions go beyond simple recall of information and ask students to apply or interpret information presented in the illustrations.

Conceptual Questions can be found at the end of each chapter. Again, these questions take students a step ahead in their thought process by asking them to explain, describe, differentiate, distinguish, and so on, key concepts of the chapter.

A VISUAL OUTLINE

Working with a large team of editors, scientific illustrators, photographers, educators, and students, the authors have created an accurate, up-to-date, and visually appealing illustration program that is easy to follow, realistic, and instructive. The artwork and photos serve as a "visual outline" and guide students through complex processes.





I'm very impressed with the accuracy and quality of the figures. I especially like the explanatory captions within certain figures.

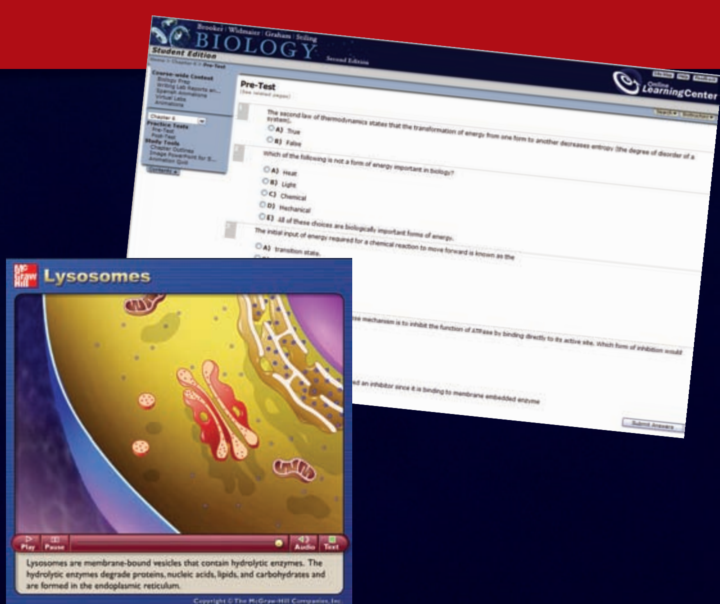
Ernest DuBrul, University of Toledo

The illustrations were very effective in detailing the processes. The drawings were more detailed than our current book, which allowed for a better idea of what the proteins' (or whatever the object) structure was.

Amy Weber, student, Ohio University

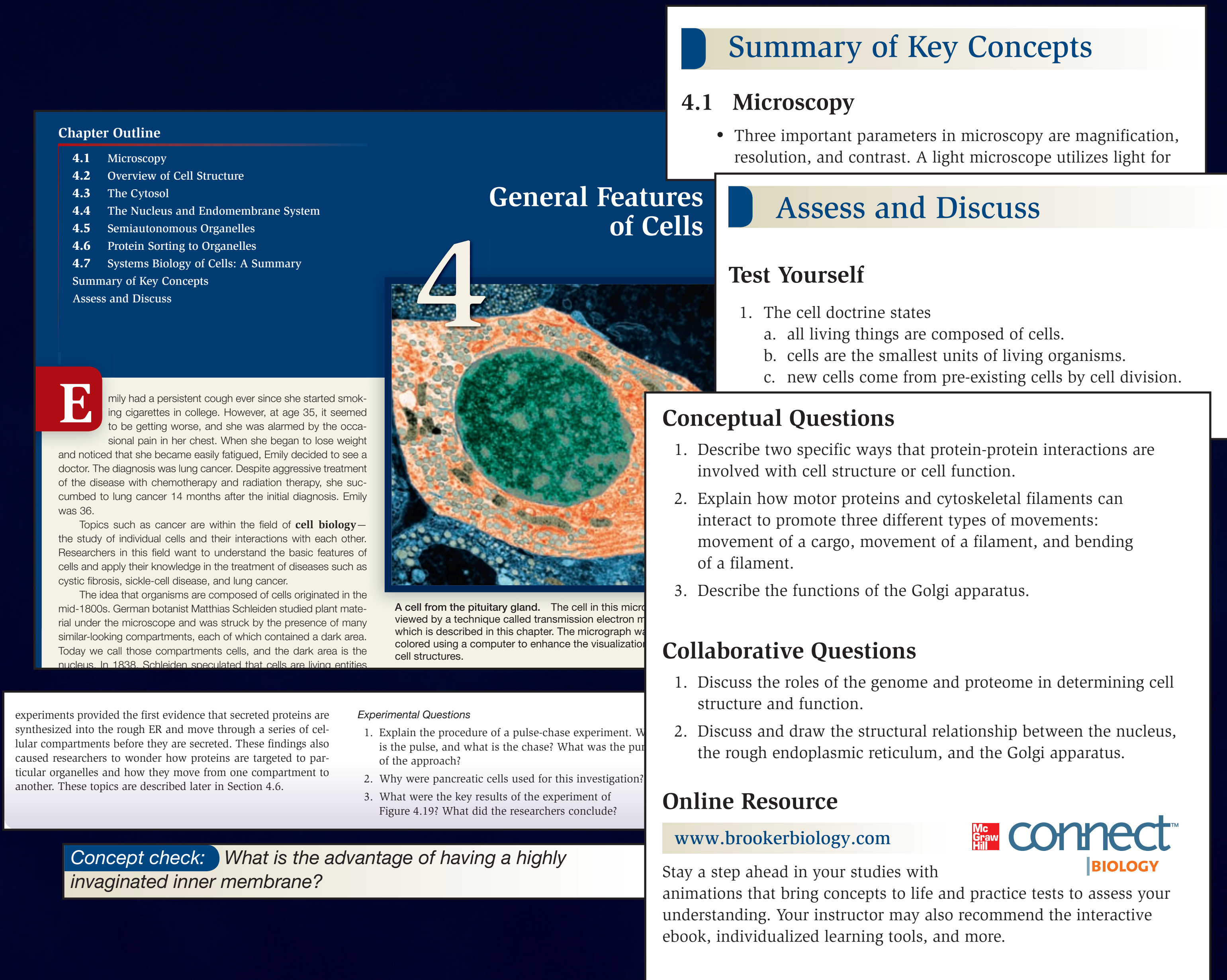
COMPANION WEBSITE

Students can enhance their understanding of the concepts with the rich study materials available at www.brookerbiology.com. This open access website provides self-study options with chapter quizzes to assess current understanding, animations that highlight topics students typically struggle with and textbook images that can be used for notetaking and study.



Overall, this is a great chapter where the text, photos, and diagrams come together to make for easy reading and easy understanding of concepts and terminology. Depth of coverage is right on, and bringing in current research results is a winner.

Donald Baud, University of Memphis



THE LEARNING SYSTEM

Each chapter starts with a simple outline and engaging story that highlights why the information in the chapter is important and intriguing. Concept checks and the questions with the Feature Investigations throughout the chapter continually ask the student to check their understanding and push a bit further. We end each chapter with a thorough review section that returns to our outline and emphasizes higher-level learning through multiple-question types.

A STEP AHEAD IN PREPARING YOUR COURSE

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Connect™ Biology is a web-based assignment and assessment platform that gives students the means to better connect with their course work, with their instructors, and with the important concepts that they will need to know for success now and in the future.

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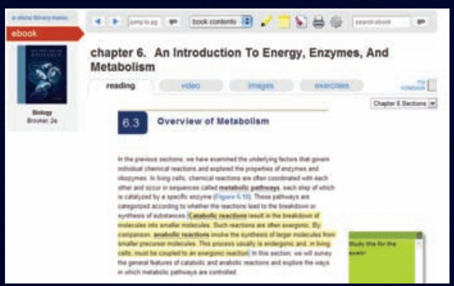

ConnectPlus™ Biology provides students with all the advantages of Connect Biology, plus 24/7 access to an eBook—a media-rich version of the book that includes animations, videos, and inline assessments placed appropriately throughout the chapter. ConnectPlus Biology allows students to practice important skills at their own pace and on their own schedule. By purchasing eBooks from McGraw-Hill students can save as much as 50% on selected titles delivered on the most advanced eBook platforms available. Contact your McGraw-Hill sales representative to discuss eBook packaging options.

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In addition to the images from your book, this online digital library contains photos, artwork, animations, and other media from an array of McGraw-Hill textbooks that can be used to create customized lectures, visually enhanced tests and quizzes, compelling course websites, or attractive printed support materials.

Quality Test Bank

All questions have been written to fully align with the learning objectives and content of the textbook. Provided within a computerized test bank powered by McGraw-Hill's flexible electronic testing program EZ Test Online, instructors can create paper and online tests or quizzes in this easy-to-use program! A new tagging scheme allows you to sort questions by difficulty level, topic, and section. Now, with EZ Test Online, instructors can select questions from multiple McGraw-Hill test banks or author their own, and then either print the test for paper distribution or give it online.

Active Learning Exercises

Supporting biology faculty in their efforts to make introductory courses more active and student-centered is critical to improving undergraduate biological education. Active learning can broadly be described as strategies and techniques in which students are engaged in their own learning, and is typically characterized by the utilization of higher order critical thinking skills. The use of these techniques is critical to biological education because of their powerful impact on students' learning and development of scientific professional skills.

Active learning strategies are highly valued and have been shown to:

- Help make content relevant
- Be particularly adept at addressing common misconceptions
- Help students to think about their own learning (metacognition)

- Promote meaningful learning of content by emphasizing application
- Foster student interest in science

Guided Activities have been provided for instructors to use in their course for both in-class and out-of-class activities. The Guided Activities make it easy for you to incorporate active learning into your course and are flexible to fit your specific needs.

FLEXIBLE DELIVERY OPTIONS

Brooker et al. *Biology* is available in many formats in addition to the traditional textbook to give instructors and students more choices when deciding on the format of their biology text.

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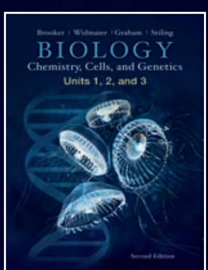

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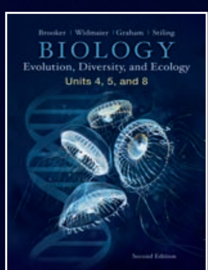

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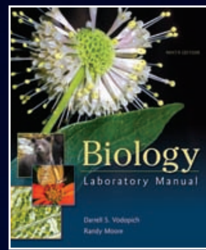
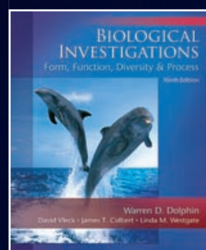


Biology Lab Manual, Ninth Edition,
Vodopich/Moore
ISBN 0073383066

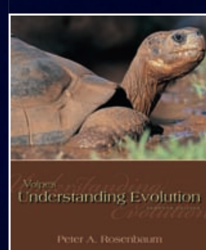
This laboratory manual is designed for an introductory majors biology course with a broad survey of basic laboratory techniques. The experiments and procedures are simple, safe, easy to perform, and especially appropriate for large classes. Few experiments require a second class-meeting to complete the procedure. Each exercise includes many photographs, traditional topics, and experiments that help students learn about life. Procedures within each exercise are numerous and discrete so that an exercise can be tailored to the needs of the students, the style of the instructor, and the facilities available.



Biological Investigations,
Ninth Edition,
Dolphin et al.
ISBN 0073383058

This independent laboratory manual can be used for a one- or two-semester majors-level general biology lab and can be used with any majors-level general biology textbook. The labs are investigative and ask students to use more critical thinking and hands-on learning. The author emphasizes investigative, quantitative, and comparative approaches to studying the life sciences.

FOCUS ON EVOLUTION



Understanding Evolution,
Seventh Edition,
by Rosenbaum and Volpe
ISBN 0073383236

As an introduction to the principles of evolution, this paperback textbook is ideally suited as a main textbook for general evolution or as a supplement for general biology, genetics, zoology, botany, anthropology, or any life science course that utilizes evolution as the underlying theme of all life.

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A NOTE FROM THE AUTHORS

The lives of most science-textbook authors do not revolve around an analysis of writing techniques. Instead, we are people who understand science and are inspired by it, and we want to communicate that information to our students. Simply put, we need a lot of help to get it right.

Editors are a key component that help the authors modify the content of their book so it is logical, easy to read, and inspiring. The editorial team for this *Biology* textbook has been a catalyst that kept this project rolling. The members played various roles in the editorial process. Lisa Bruflodt, Senior Developmental Editor, has been the master organizer. Coordinating the efforts of dozens of people and keeping them on schedule is not always fun. Lisa's success at keeping us on schedule has been truly amazing.

Our Freelance Developmental Editors worked directly with the authors to greatly improve the presentation of the textbook's content. Suzanne Olivier and Joni Frasier did an outstanding job in editing chapters and advising the authors on improvements for the second edition. Deborah Brooker painstakingly analyzed all of the illustrations in the textbook to make sure they are accurate, consistent, and student-friendly. She also took the lead role in the editing of the glossary. We would also like to acknowledge our copy editor, Jane DeShaw, for keeping our grammar on track.

Another important aspect of the editorial process is the actual design, presentation, and layout of materials. It's confusing if the text and art aren't on the same page or if a figure is too large or too small. We are indebted to the tireless efforts of Peggy Selle, Lead Project Manager, and David Hash, Senior Designer of McGraw-Hill. Their artistic talents, ability to size and arrange figures, and attention to the consistency of the figures have been remarkable.

We would like to acknowledge the ongoing efforts of the superb marketing staff at McGraw-Hill. Kent Peterson, Vice President, Director of Marketing, oversees a talented staff of people who work tirelessly to promote our book. Special thanks to Michelle Watnick, Marketing Director, and Chris Loewenberg, Marketing Manager, for their ideas and enthusiasm for this book.

Finally, other staff members at McGraw-Hill Higher Education have ensured that the authors and editors were provided with adequate resources to achieve the goal of producing a superior textbook. These include Kurt Strand, President, Science, Engineering, and Math; Marty Lange, Vice President, Editor-in-Chief; and Janice Roerig-Blong, Publisher.

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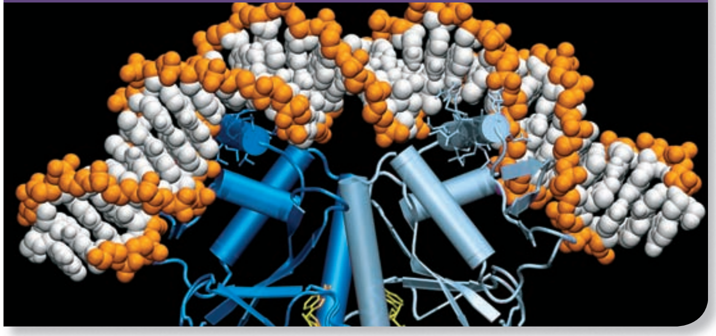

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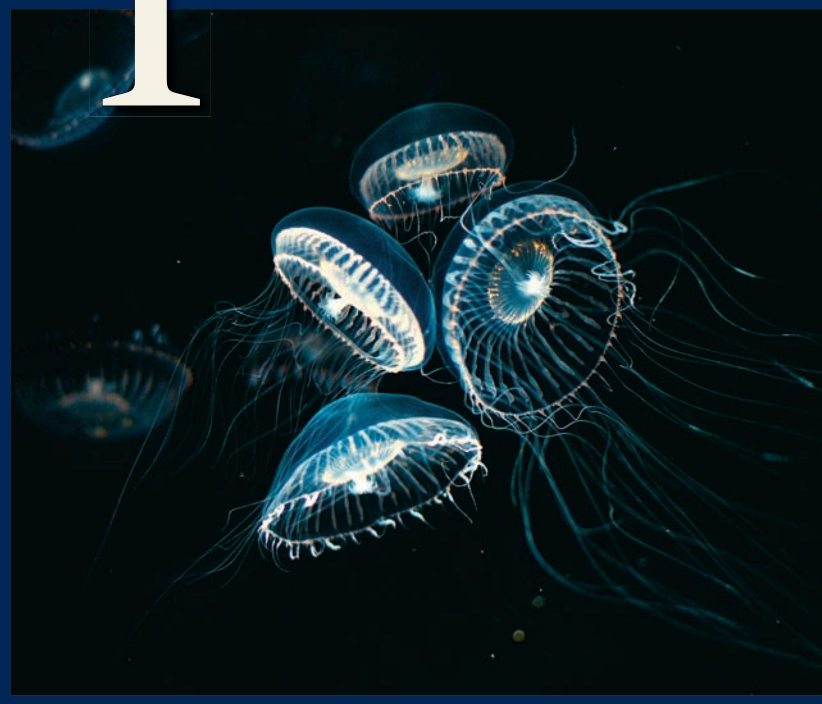
1 An Introduction to Biology



The crystal jelly (*Aequorea victoria*), which produces a green fluorescent protein (GFP). The gene that encodes GFP has been widely used by researchers to study gene expression and to determine the locations of proteins in cells.

Biology is the study of life. The diverse forms of life found on Earth provide biologists with an amazing array of organisms to study. In many cases, the investigation of living things leads to unforeseen discoveries that no one would have imagined. For example, researchers determined that the venom from certain poisonous snakes contains a chemical that lowers blood pressure in humans. By analyzing that chemical, drugs were later developed to treat high blood pressure (Figure 1.1). Certain ancient civilizations, such as the Greeks, Romans, and Egyptians, discovered that the bark of the white willow tree can be used to fight fever. Modern chemists determined that willow bark contains a substance called salicylic acid, which led to the development of the related compound acetylsalicylic acid, more commonly known as aspirin (Figure 1.2). In the last century, biologists studied soil bacteria that naturally produce "chemical weapons" to kill competing bacteria in their native environment. These chemicals have been characterized and used to develop antibiotics such as streptomycin to treat bacterial infections (Figure 1.3). Finally, for many decades, biologists have known that the Pacific yew tree produces a toxin in its bark and needles that kills insects.

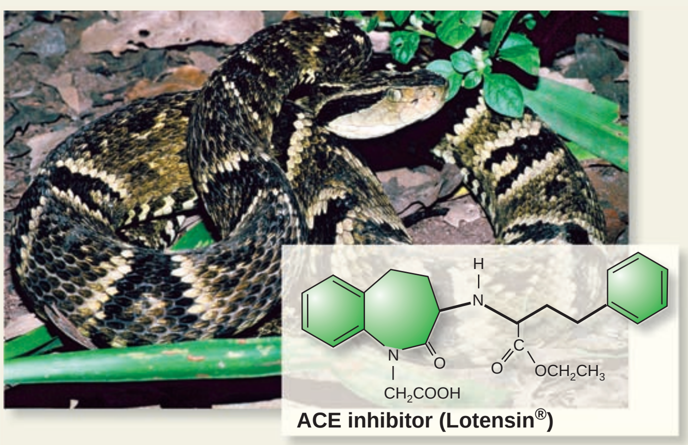


Figure 1.1 **The Brazilian arrowhead viper and inhibitors of high blood pressure.** Derivatives of a chemical found in the venom of the Brazilian arrowhead viper, called angiotensin-converting enzyme (ACE) inhibitors, are commonly used to treat high blood pressure.

Figure 1.2 **The white willow and aspirin.** Modern aspirin, acetylsalicylic acid, was developed after analyzing a chemical found in the bark of the white willow tree.

Since the 1990s, this toxin, known by the drug name Taxol, has been used to treat patients with ovarian and breast cancer (Figure 1.4). These are but a few of the many discoveries that make biology an intriguing discipline. The study of life not only reveals the fascinating characteristics of living species but also leads to the development of drugs and research tools that benefit the lives of people.

To make new discoveries, biologists view life from many different perspectives. What is the composition of living things? How is life organized? How do organisms reproduce? Sometimes the questions posed by biologists are fundamental and even philosophical in nature. How did living organisms originate? Can we live forever? What is the physical basis for memory? Can we save endangered species? Can we understand intriguing changes in body function, such as the green light given off by certain jellyfish?

Future biologists will continue to make important advances. Biologists are scientific explorers looking for answers to some of the world's most enduring mysteries. Unraveling these mysteries presents an exciting challenge to the best and brightest minds. The rewards of a career in biology include the excitement of forging into uncharted territory, the thrill of making discoveries that can improve the health and lives of people, and the impact of biology on the preservation of the environment and endangered species. For these and many other compelling reasons, students seeking challenging and rewarding careers may wish to choose biology as a lifelong pursuit.

In this chapter, we will begin our survey of biology by examining the basic features that are common to all living organisms. We will consider how evolution has led to the development of modern genomes—the entire genetic compositions of living organisms—which can explain the unity and diversity that we observe among modern species. Finally, we will explore the general approaches that scientists follow when making new discoveries.

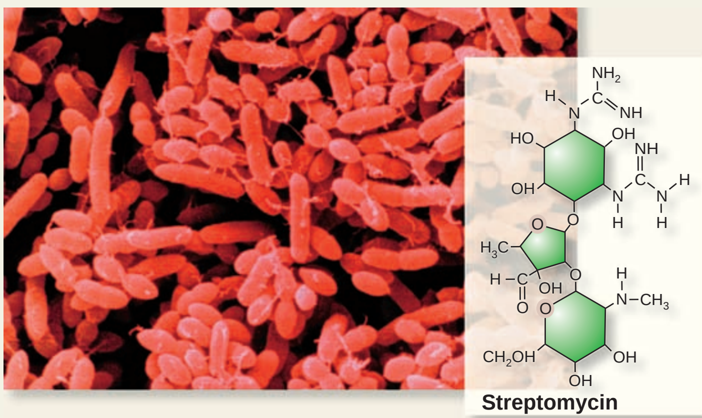


Figure 1.3 **The soil bacterium *Streptomyces griseus*, which naturally produces streptomycin that kills competing bacteria in the soil.** Doctors administer streptomycin to people to treat bacterial infections.

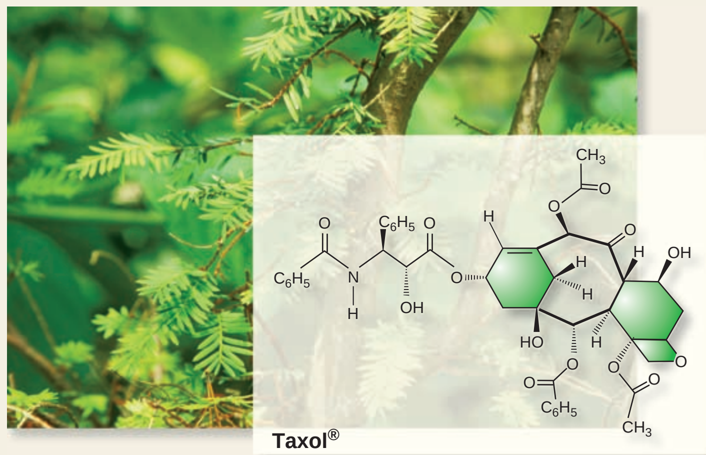


Figure 1.4 **The Pacific yew and Taxol.** A toxin called Taxol, found in the Pacific yew tree, is effective in the treatment of certain cancers.

Concept check: How does biology—the study of life—benefit humans?

1.1 The Properties of Life

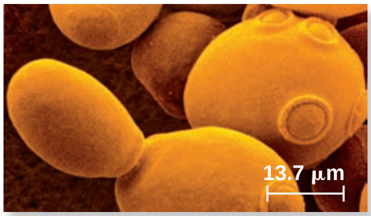
A good way to begin a biology textbook is to distinguish living organisms from nonliving objects. At first, the distinction might seem intuitively obvious. A person is alive, but a rock is not. However, the distinction between living and nonliving may seem less obvious when we consider microscopic entities. Is a bacterium alive? What about a virus or a chromosome? In this section, we will examine the characteristics that are common to all forms of life and consider the levels of organization that biologists study.

A Set of Characteristics Is Common to All Forms of Modern Life

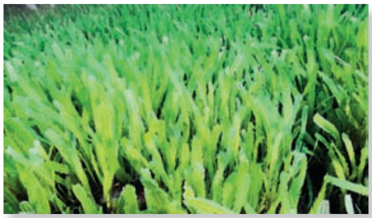
Living organisms have consistent features that set them apart from nonliving things. Biologists have determined that all living organisms display seven common characteristics, as described next.

Cells and Organization The concept of organization is so fundamental to biology that the term **organism** can be applied to all living species. Organisms maintain an internal order that is separated from the environment (Figure 1.5a). The simplest unit of such organization is the **cell**, which we will examine in Unit II. The **cell theory** states that (1) all organisms are made of cells, (2) cells are the smallest units of life, and (3) cells come from pre-existing cells via cell division. Unicellular organisms are composed of one cell, whereas multicellular organisms such as plants and animals contain many cells. In plants and animals, each cell has internal order, and the cells within the body have specific arrangements and functions.

Energy Use and Metabolism The maintenance of organization requires energy. Therefore, all living organisms acquire



(a) Cells and organization: Organisms maintain an internal order. The simplest unit of organization is the cell. Yeast cells are shown here.



(b) Energy use and metabolism: Organisms need energy to maintain internal order. These algae harness light energy via photosynthesis. Energy is used in chemical reactions collectively known as metabolism.

(c) Response to environmental changes: Organisms react to environmental changes that promote their survival.

(d) Regulation and homeostasis: Organisms regulate their cells and bodies, maintaining relatively stable internal conditions, a process called homeostasis.

(e) Growth and development: Growth produces more or larger cells, whereas development produces organisms with a defined set of characteristics.

(f) Reproduction: To sustain life over many generations, organisms must reproduce. Due to the transmission of genetic material, offspring tend to have traits like their parents.

(g) Biological evolution: Populations of organisms change over the course of many generations. Evolution results in traits that promote survival and reproductive success.

Figure 1.5 Seven characteristics common to life.

energy from the environment and use that energy to maintain their internal order. Cells carry out a variety of chemical reactions that are responsible for the breakdown of nutrients. Such reactions often release energy in a process called **respiration**. The energy may be used to synthesize the components that make up individual cells and living organisms. Chemical reactions involved with the breakdown and synthesis of cellular molecules are collectively known as **metabolism**. Plants, algae, and certain bacteria can directly harness light energy to produce their own nutrients in the process of **photosynthesis** (Figure 1.5b). They are primary producers of food on Earth. In contrast, some organisms, such as animals and fungi, are consumers—they must use other organisms as food to obtain energy.

Response to Environmental Changes To survive, living organisms must be able to respond to environmental changes. For example, bacterial cells have mechanisms to detect that certain nutrients in the environment are in short supply while others are readily available. In the winter, many species of mammals develop a thicker coat of fur that protects them from the cold temperatures. Also, plants can respond to changes in the angle of the sun. If you place a plant in a window, it will grow toward the light (Figure 1.5c). The response shown in Figure 1.5c is a short-term response. As discussed later, biological evolution over the course of many generations can lead to more permanent adaptations of a species to its environment.

Regulation and Homeostasis As we have just seen, one way that organisms can respond to environmental variation is to change themselves. The growth of thick fur in the wintertime is an example. Although life is a dynamic process, living cells and organisms regulate their cells and bodies to maintain relatively stable internal conditions, a process called **homeostasis** (from the Greek, meaning to stay the same). The degree to which homeostasis is achieved varies among different organisms. For example, most mammals and birds maintain a relatively stable body temperature in spite of changing environmental temperatures (Figure 1.5d), whereas reptiles and amphibians tolerate a wider fluctuation in body temperature. By comparison, all organisms continually regulate their cellular metabolism so that nutrient molecules are used at an appropriate rate and new cellular components are synthesized when they are needed.

Growth and Development All living things grow and develop. **Growth** produces more or larger cells, whereas **development** is a series of changes in the state of a cell, tissue, organ, or organism. The process of development produces organisms with a defined set of characteristics. Among unicellular organisms such as bacteria, new cells are relatively small, and they increase in volume by the synthesis of additional cellular components. Multicellular organisms, such as plants and animals, begin life at a single-cell stage (for example, a fertilized egg) and then undergo multiple cell divisions to develop into a complete organism with many cells (Figure 1.5e).

Reproduction All living organisms have a finite life span. To sustain life over many generations, organisms must **reproduce** (Figure 1.5f). A key feature of reproduction is that offspring tend to have characteristics that greatly resemble those of their parent(s). How is this possible? All living organisms contain genetic material composed of **DNA** (**deoxyribonucleic acid**), which provides a blueprint for the organization, development, and function of living things. During reproduction, a copy of this blueprint is transmitted from parent to offspring. As discussed in Unit III, **genes**, which are segments of DNA, govern the characteristics, or traits, of organisms. Most genes are transcribed into a type of **RNA** (**ribonucleic acid**) molecule called messenger RNA (mRNA) that is then translated into a **polypeptide** with a specific amino acid sequence. A **protein** is composed of one or more polypeptides. The structures and functions of proteins are largely responsible for the traits of living organisms.

Biological Evolution The first six characteristics of life, which we have just considered, apply to individual organisms over the short run. Over the long run, another universal characteristic of life is **biological evolution**, which refers to the phenomenon that populations of organisms change from generation to generation. As a result of evolution, organisms may become more successful at survival and reproduction. Populations become better adapted to the environment in which they live. For example, the long snout of an anteater is an adaptation that enhances its ability to obtain food, namely ants, from hard-to-reach places (Figure 1.5g). Over the course of many generations, the long snout occurred via biological evolution in which modern anteaters evolved from populations of organisms that did not have such long snouts. Unit IV is devoted to the topic of evolution, and Unit V surveys the evolutionary diversity among different forms of life.

Living Organisms Can Be Viewed at Different Levels of Organization

As we have just learned, life exhibits a set of characteristics, beginning with the concept of organization. The organization of living organisms can be analyzed at different levels of complexity, starting with the tiniest level of organization and progressing to levels that are physically much larger and more complex. Figure 1.6 depicts a scientist's view of biological organization at different levels.

1. **Atoms:** An **atom** is the smallest unit of an element that has the chemical properties of the element. All matter is composed of atoms.
2. **Molecules and macromolecules:** As discussed in Unit I, atoms bond with each other to form **molecules**. Many molecules bonded together to form a polymer such as a polypeptide is called a **macromolecule**. Carbohydrates, proteins, and nucleic acids (for example, DNA and RNA) are important macromolecules found in living organisms.
3. **Cells:** Molecules and macromolecules associate with each other to form larger structures such as membranes. A **cell** is formed from the association of these larger structures.
4. **Tissues:** In the case of multicellular organisms such as plants and animals, many cells of the same type associate with each other to form **tissues**. An example is muscle tissue (Figure 1.6).
5. **Organs:** In complex multicellular organisms, an **organ** is composed of two or more types of tissue. For example, the heart is composed of several types of tissues, including muscle, nervous, and connective tissue.
6. **Organism:** All living things can be called **organisms**. A single organism possesses the set of characteristics that define life. Biologists classify organisms as belonging to a particular **species**, which is a related group of organisms that share a distinctive form and set of attributes in nature. The members of the same species are closely related genetically. In Units VI and VII, we will examine plants and animals at the level of cells, tissues, organs, and complete organisms.
7. **Population:** A group of organisms of the same species that occupy the same environment is called a **population**.
8. **Community:** A biological **community** is an assemblage of populations of different species. The types of species found in a community are determined by the environment and by the interactions of species with each other.
9. **Ecosystem:** Researchers may extend their work beyond living organisms and also study the environment. Ecologists analyze **ecosystems**, which are formed by interactions of a community of organisms with their physical environment. Unit VIII considers biology from populations to ecosystems.
10. **Biosphere:** The **biosphere** includes all of the places on the Earth where living organisms exist. Life is found in the air, in bodies of water, on the land, and in the soil.

1.2 The Unity and Diversity of Life

Unity and diversity are two words that often are used to describe the living world. As we have seen, all modern forms of life display a common set of characteristics that distinguish them from nonliving objects. In this section, we will explore how this unity of common traits is rooted in the phenomenon of biological evolution. As you will learn, life on Earth is united by an evolutionary past in which modern organisms have evolved from pre-existing organisms.

Evolutionary unity does not mean that organisms are exactly alike. The Earth has many different types of environments, ranging from tropical rain forests to salty oceans, hot and dry deserts, and cold mountaintops. Diverse forms of life have evolved in ways that help them prosper in the diverse environments the Earth has to offer. In this section, we will begin to examine the diversity that exists within the biological world.

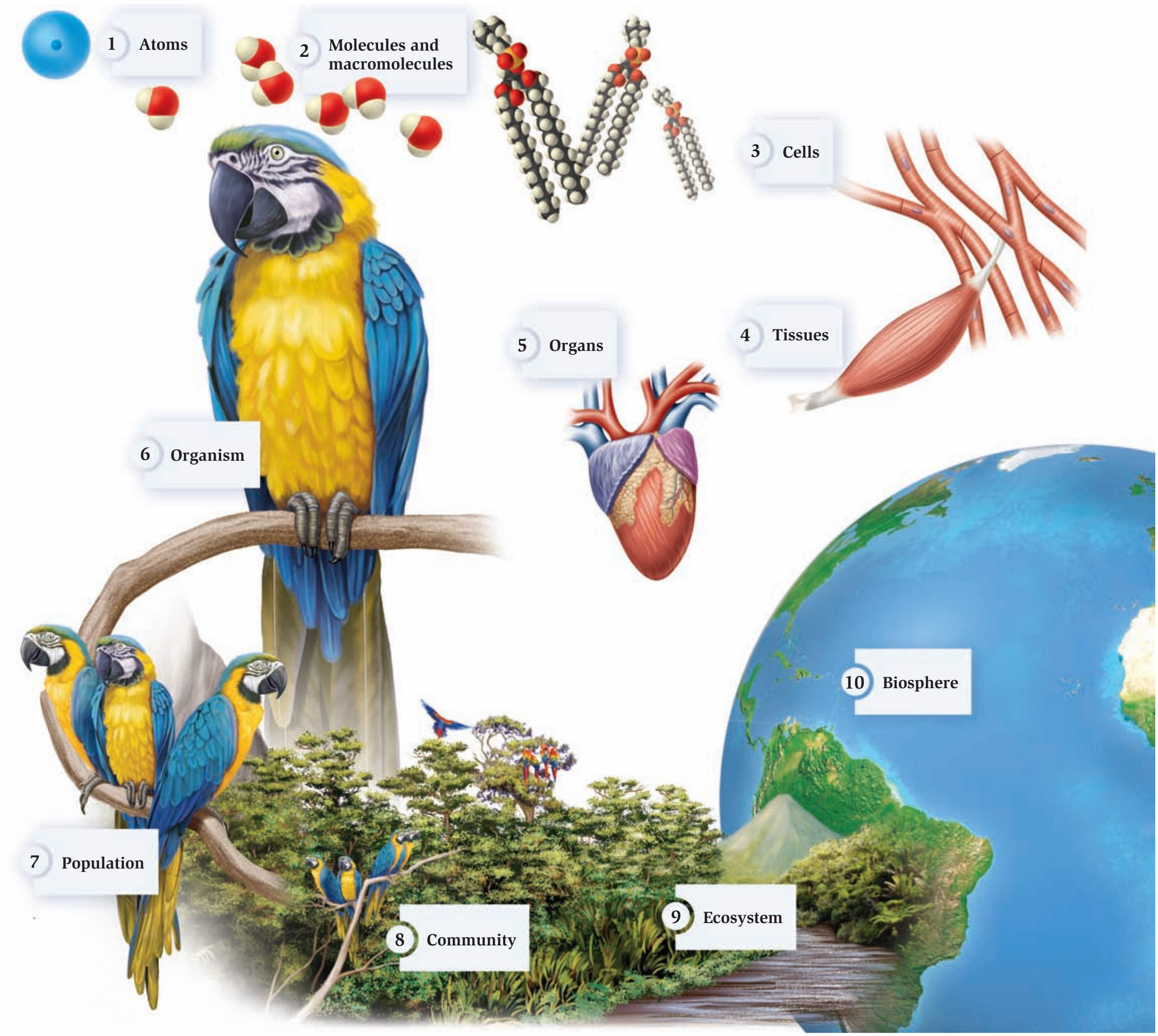


Figure 1.6 The levels of biological organization.

Concept check: *At which level of biological organization would you place a herd of buffalo?*

Modern Forms of Life Are Connected by an Evolutionary History

Life began on Earth as primitive cells about 3.5 to 4 billion years ago. Since that time, those primitive cells underwent evolutionary changes that ultimately gave rise to the species we see today. Understanding the evolutionary history of species often provides key insights into the structure and function of an organism's body. As a way to help you appreciate this idea, **Figure 1.7** shows a photograph of a bird using a milk carton in which to build a nest. If we did not already know that the milk carton had served an earlier purpose—namely, to contain milk—we might wonder why the bird had made a nesting site with this shape. Obviously, we do not need to wonder about this because we immediately grasp that the milk carton had a previous history and that it has been modified by a person to serve a new purpose—a nesting site for a bird. Understanding history allows us to make sense out of this nest.

Likewise, evolutionary change involves modifications of characteristics in pre-existing populations. Over long periods of time, populations may change such that structures with a particular function may become modified to serve a new function. For example, the wing of a bat is used for flying, and the flipper of a dolphin is used for swimming. Both structures were modified from a limb that was used for walking in a pre-existing ancestor (Figure 1.8).

Evolutionary change occurs by two mechanisms: vertical descent with mutation and horizontal gene transfer. Let's take a brief look at each of these mechanisms.

Vertical Descent with Mutation The traditional way to view evolution is in a vertical manner, which involves a progression of changes in a series of ancestors. Such a series is called a **lineage**. Figure 1.9 shows a portion of the lineage that gave rise to modern horses. This type of evolution is called **vertical evolution** because it occurs in a lineage. Biologists have traditionally depicted such evolutionary change in a diagram like the one shown in Figure 1.9. In this mechanism of evolution, new species evolve from pre-existing species by the accumulation of **mutations**, which are random changes in the genetic material of organisms. But why would some mutations accumulate in a population and eventually change the characteristics of an entire species? One reason is that a mutation may alter the traits of organisms in a way that increases their chances of survival and reproduction. When a mutation causes such a beneficial change, the frequency of the mutation may increase in a population from one generation to the next, a process called **natural selection**. This process is discussed in Units IV and V. Evolution also involves the accumulation of neutral changes that do not either benefit or harm a species, and sometimes even involves rare changes that may be harmful.

With regard to the horses shown in Figure 1.9, the fossil record has revealed adaptive changes in various traits such as size and tooth morphology. The first horses were the size of dogs, whereas modern horses typically weigh more than a half ton. The teeth of *Hyracotherium* were relatively small compared to those of modern horses. Over the course of millions of years, horse teeth have increased in size, and a complex pattern of ridges has developed on the molars. How do evolutionary biologists explain these changes in horse characteristics? They can be attributed to natural selection producing adaptations to changing global climates. Over North America, where much of horse evolution occurred, large areas changed from dense forests to grasslands. The horses' increase in size allowed them to escape predators and travel great distances in search of food. The changes seen in horses' teeth are consistent with a dietary shift from eating more tender leaves to eating grasses and other vegetation that are more abrasive and require more chewing.

Horizontal Gene Transfer The most common way for genes to be transferred is in a vertical manner. This can involve the transfer of genetic material from a mother cell to daughter cells, or it can occur via gametes—sperm and egg—that unite to form a new organism. However, as discussed in later chapters, genes are sometimes transferred between organisms by other mechanisms. These other mechanisms are collectively known as **horizontal gene transfer**. In some cases, horizontal gene transfer can occur between members of different species. For example, you may have heard in the news media that resistance to antibiotics among bacteria is a growing medical problem. As discussed in Chapter 18, genes that confer antibiotic resistance are sometimes transferred between different bacterial species (Figure 1.10).

Figure 1.7 An example of modification of a structure for a new function. The bird shown here has used a modified milk carton in which to build its nest. By analogy, evolution also involves the modification of pre-existing structures for a new function.

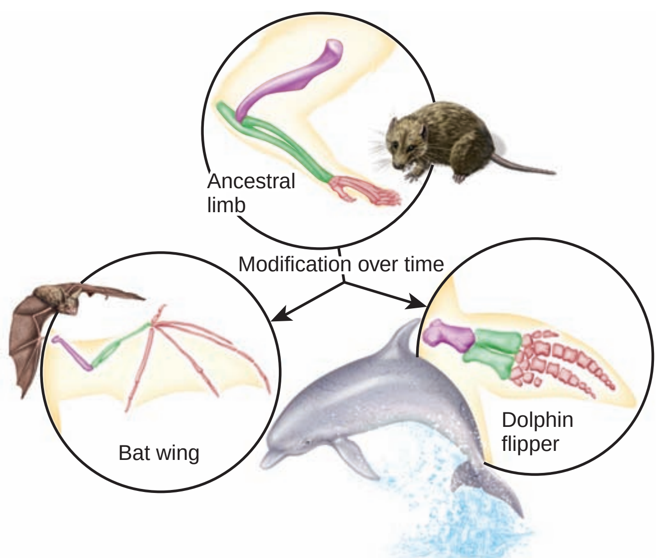


Figure 1.8 An example showing a modification that has occurred as a result of biological evolution. The wing of a bat and the flipper of a dolphin were modified from a limb that was used for walking in a pre-existing ancestor.

Concept check: Among mammals, give two examples of how the tail has been modified for different purposes.

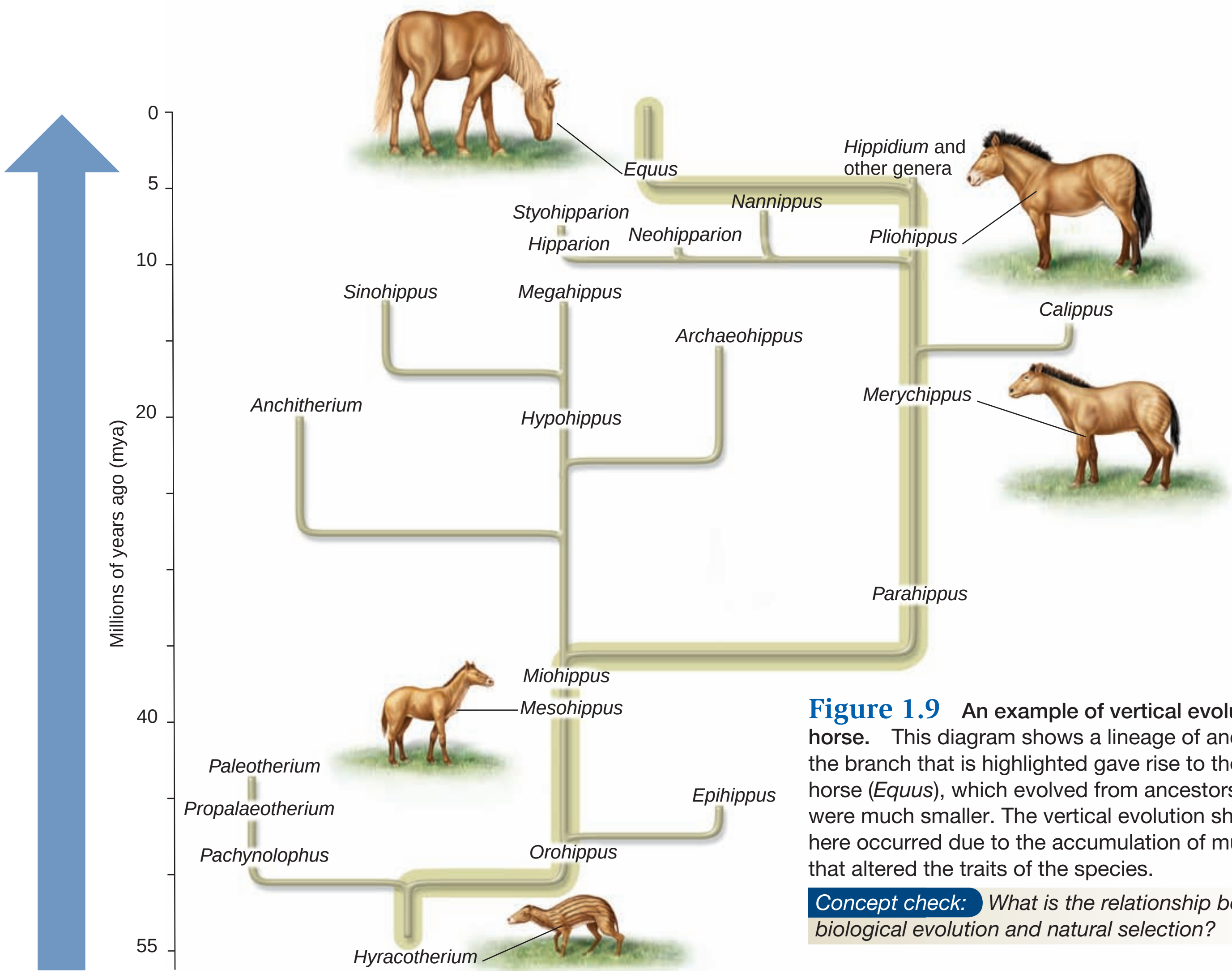


Figure 1.9 **An example of vertical evolution: the horse.** This diagram shows a lineage of ancestors; the branch that is highlighted gave rise to the modern horse (*Equus*), which evolved from ancestors that were much smaller. The vertical evolution shown here occurred due to the accumulation of mutations that altered the traits of the species.

Concept check: *What is the relationship between biological evolution and natural selection?*

In a lineage in which the time scale is depicted on a vertical axis, horizontal gene transfer between different species is shown as a horizontal line (Figure 1.11). Genes transferred horizontally may be subjected to natural selection and promote changes in an entire species. This has been an important mechanism of evolutionary change, particularly among bacterial species. In addition, during the early stages of evolution, which occurred a few billion years ago, horizontal gene transfer was an important part of the process that gave rise to all modern species.

Traditionally, biologists have described evolution using diagrams that depict the vertical evolution of species on a long time scale. This is the type of evolutionary tree that was shown in Figure 1.9. For many decades, the simplistic view held that all living organisms evolved from a common ancestor, resulting in a "tree of life" that could describe the vertical evolution that gave rise to all modern species. Now that we understand the great importance of horizontal gene transfer in the evolution of life on Earth, biologists have needed to re-evaluate the concept of evolution as it occurs over time. Rather than a tree of life, a more appropriate way to view the unity of living organisms is

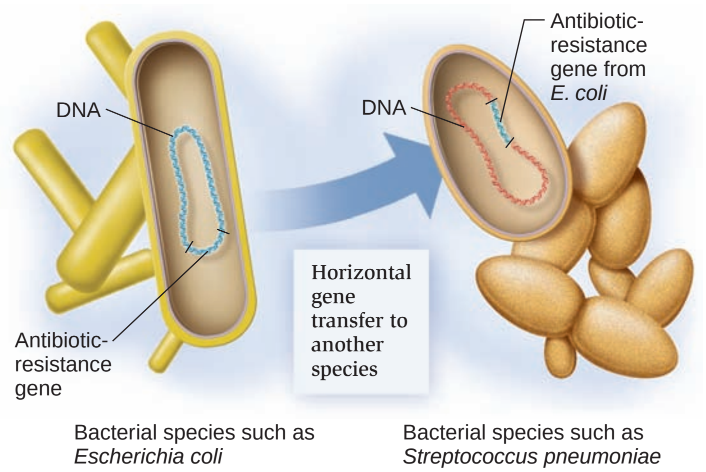


Figure 1.10 **An example of horizontal gene transfer: antibiotic resistance.** One bacterial species may transfer a gene to a different bacterial species, such as a gene that confers resistance to an antibiotic.

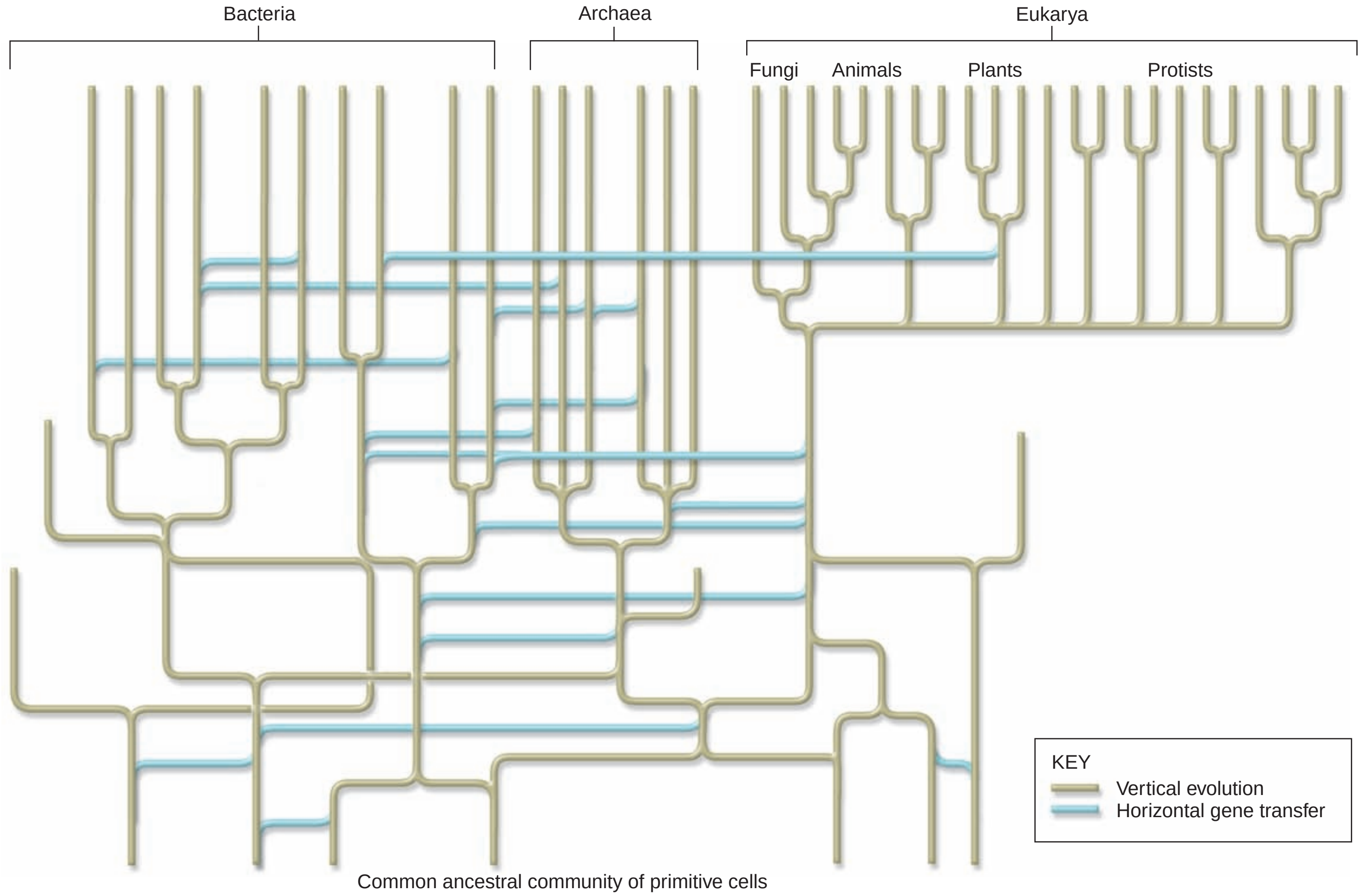


Figure 1.11 **The web of life, showing both vertical evolution and horizontal gene transfer.** This diagram of evolution includes both of these important mechanisms in the evolution of life on Earth. Note: Archaea are unicellular species.

Concept check: *How does the concept of a tree of life differ from that of a web of life?*

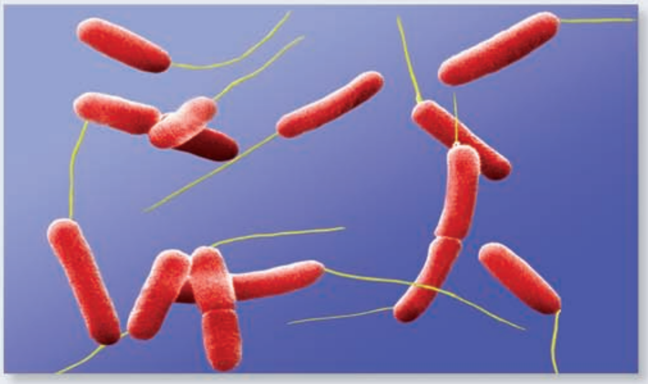
to describe it as a "web of life," which accounts for both vertical evolution and horizontal gene transfer (Figure 1.11).

The Classification of Living Organisms Allows Biologists to Appreciate the Unity and Diversity of Life

As biologists discover new species, they try to place them in groups based on their evolutionary history. This is a difficult task because researchers estimate the Earth has between 10 and 100 million different species! The rationale for categorization is usually based on vertical descent. Species with a recent common ancestor are grouped together, whereas species whose common ancestor is in the very distant past are placed into different groups. The grouping of species is termed **taxonomy**.

Let's first consider taxonomy on a broad scale. You may have noticed that Figure 1.11 showed three main groups of organisms. All forms of life can be placed into three large categories, or domains, called **Bacteria**, **Archaea**, and **Eukarya** (Figure 1.12). Bacteria and Archaea are microorganisms that are also termed **prokaryotic** because their cell structure is relatively simple. At the molecular level, bacterial and archaeal cells show significant differences in their compositions. By comparison, organisms in domain Eukarya are **eukaryotic** and have larger cells with internal compartments that serve various functions. A defining distinction between prokaryotic and eukaryotic cells is that eukaryotic cells have a **cell nucleus** in which the genetic material is surrounded by a membrane. The organisms in domain Eukarya had once been subdivided into four major categories, or kingdoms, called Protista (protists), Plantae (plants), Fungi, and Animalia (animals). However, as discussed in Chapter 26 and Unit V, this traditional view has become invalid as biologists have gathered new information regarding the evolutionary relationships of these organisms. We now know that the protists do not form a single kingdom but instead can be divided into seven broad groups.

Taxonomy involves multiple levels in which particular species are placed into progressively smaller and smaller groups of organisms that are more closely related to each other evolutionarily. Such an approach emphasizes the unity and diversity of different species. As an example, let's consider the clownfish, which is a common saltwater aquarium fish (Figure 1.13).



(a) Domain Bacteria: Mostly unicellular prokaryotes that inhabit many diverse environments on Earth.

(b) Domain Archaea: Unicellular prokaryotes that often live in extreme environments, such as hot springs.

Protists: Unicellular and small multicellular organisms that are now subdivided into seven broad groups based on their evolutionary relationships.

Plants: Multicellular organisms that can carry out photosynthesis.

Fungi: Unicellular and multicellular organisms that have a cell wall but cannot carry out photosynthesis. Fungi usually survive on decaying organic material.

Animals: Multicellular organisms that usually have a nervous system and are capable of locomotion. They must eat other organisms or the products of other organisms to live.

(c) Domain Eukarya: Unicellular and multicellular organisms having cells with internal compartments that serve various functions.

Figure 1.12 **The three domains of life.** Two of these domains, **(a)** Bacteria and **(b)** Archaea, are prokaryotes. The third domain, **(c)** Eukarya, comprises species that are eukaryotes.

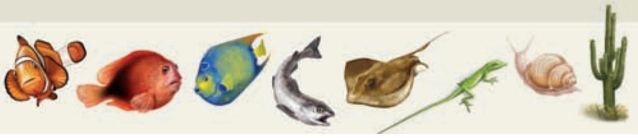
Taxonomic group	Clown anemonefish is found in	Approximate time when the common ancestor for this group arose	Approximate number of modern species in this group	Examples
Domain	Eukarya	2,000 mya	> 5,000,000	
Kingdom	Animalia	600 mya	> 1,000,000	
Phylum	Chordata	525 mya	50,000	
Class	Actinopterygii	420 mya	30,000	
Order	Perciformes	80 mya	7,000	
Family	Pomacentridae	~ 40 mya	360	
Genus	*Amphiprion*	~ 9 mya	28	
Species	*ocellaris*	< 3 mya	1	

Figure 1.13 Taxonomic and evolutionary groupings leading to the clownfish.

Concept check: Why is it useful to place organisms into taxonomic groupings?

Several species of clownfish, also called clown anemonefish, have been identified. One species of clownfish, which is orange with white stripes, has several common names, including Ocellaris clownfish, false clownfish, and false-clown anemonefish. The broadest grouping for this clownfish is the domain, namely, Eukarya, followed by progressively smaller divisions, from kingdom (Animalia) to species. In the animal kingdom, clownfish are part of a phylum, Chordata, the chordates, which is subdivided into classes. Clownfish are in a class called Actinopterygii, which includes all ray-finned fishes. The common ancestor that gave rise to ray-finned fishes arose about 420 million years ago (mya). Actinopterygii is subdivided into several smaller orders. The clownfish are in the order Perciformes (bony fish). The order is, in turn, divided into families; the clownfish belong to the family of marine fish called Pomacentridae, which are often brightly colored. Families are divided into genera (singular, genus). The genus *Amphiprion* is composed of 28 different species; these are various types of clownfish. Therefore, the genus contains species that are very similar to each other in form and have evolved from a common (extinct) ancestor that lived relatively recently on an evolutionary time scale.

Biologists use a two-part description, called **binomial nomenclature**, to provide each species with a unique scientific name. The scientific name of the Ocellaris clownfish is *Amphiprion ocellaris*. The first part is the genus, and the second part is the specific epithet or species descriptor. By convention, the genus name is capitalized, whereas the specific epithet is not. Both names are italicized. Scientific names are usually Latinized, which means they are made similar in appearance to Latin words. The origins of scientific names are typically Latin or Greek, but they can come from a variety of sources, such as a person's name.

Genomes & Proteomes Connection

The Study of Genomes and Proteomes Provides an Evolutionary Foundation for Our Understanding of Biology

The unifying concept in biology is evolution. We can understand the unity of modern organisms by realizing that all living species evolved from an interrelated group of ancestors. However, from an experimental perspective, this realization presents a dilemma—we cannot take a time machine back over the course of 4 billion years to carefully study the characteristics of extinct organisms and fully appreciate the series of changes that have led to modern species. Fortunately though, evolution has given biologists some wonderful puzzles to study, including the fossil record and, more recently, the genomes of modern species. As mentioned, the term **genome** refers to the complete genetic composition of an organism (Figure 1.14a). The genome is critical to life because it performs these functions:

- *Stores information in a stable form:* The genome of every organism stores information that provides a blueprint to create its characteristics.
- *Provides continuity from generation to generation:* The genome is copied and transmitted from generation to generation.
- *Acts as an instrument of evolutionary change:* Every now and then, the genome undergoes a mutation that may alter the characteristics of an organism. In addition, a genome may acquire new genes by horizontal gene transfer. The accumulation of such changes from generation to generation produces the evolutionary changes that alter species and produce new species.

The evolutionary history and relatedness of all living organisms can be illuminated by genome analysis. The genome of every organism carries the results and the evidence of millions of years of evolution. The genomes of prokaryotes usually contain a few thousand genes, whereas those of eukaryotes may contain tens of thousands. An exciting advance in biology over the past couple of decades has been the ability to analyze the DNA sequence of genomes, a technology called **genomics**. For instance, we can compare the genomes of a frog, a giraffe, and a petunia and discover intriguing similarities and differences. These comparisons help us to understand how new traits evolved. For example, all three types of organisms have the same kinds of genes needed for the breakdown of nutrients such as sugars. In contrast, only the petunia has genes that allow it to carry out photosynthesis.

An extension of genome analysis is the study of **proteomes**, which refers to all of the proteins that a cell or organism can make. The function of most genes is to encode polypeptides that become units in proteins. As shown in Figure 1.14b, these include proteins that form a cytoskeleton, proteins that function in cell organization and as enzymes, transport proteins, cell signaling proteins, and extracellular proteins. The genome of each species carries the information to make its proteome, the hundreds or thousands of proteins that each cell of that species makes. Proteins are largely responsible for the structures and functions of cells and organisms. The technical approach called **proteomics** involves the analysis of the proteome of a single species and the comparison of the proteomes of different species. Proteomics helps us understand how the various levels of biology are related to one another, from the molecular level—at the level of protein molecules—to the higher levels, such as how the functioning of proteins produces the characteristics of cells and organisms and affects the ability of populations of organisms to survive in their natural environments.

As a concrete way to understand the unifying concept of evolution in biology, a recurring theme in the chapters that follow is a brief topic called “Genomes & Proteomes Connection” that will allow you to appreciate how evolution produced the characteristics of modern species. These topics explore how the genomes of different species are similar to each other and how they are different. You will learn how genome changes affect the proteome and thereby control the traits of modern species. Ultimately, these concepts provide you with a way to relate information at the molecular level to the traits of organisms and their survival within ecosystems.

The Textbook Cover Provides an Example of How Genomes and Proteomes Are Fundamental to an Organism’s Characteristics

As shown on the cover of your textbook, the crystal jelly (*Aequorea victoria*) is a bioluminescent jellyfish found off the west coast of North America. What is **bioluminescence**? The term refers to the ability of some living organisms, such as jellyfish, to produce and emit light due to reactions in which chemical energy is converted to light energy. Biologists currently do not know the function of bioluminescence in this species. Possible roles could be defense against predators or attracting prey.

In the case of the crystal jelly, most of the organism is transparent and not bioluminescent. The bioluminescence is largely restricted to a ring of discrete spots around the bell margin (Figure 1.15a). The spots occasionally give off flashes of green light, which is due to a protein the jellyfish makes, called green fluorescent protein (GFP). From the perspective of genomes and proteomes, biologists would say that the GFP gene is found in the genome of this jellyfish, but the green fluorescent protein is expressed only in the proteome of the cells that form these spots around the bell margin.

Researchers interested in bioluminescence have studied how it occurs at the molecular level. The crystal jelly produces light in a two-step process. First, the release of Ca^{2+} in a cell interacts with a protein called aequorin, which produces a blue light. Why don’t the jellyfish glow blue? The answer is that, in a second step, the blue light is absorbed by GFP, which then emits a green light.

Because GFP is easily activated by UV or blue light and then specifically gives off green light, researchers have also adapted and used GFP as a visualization tool in medicine, research,

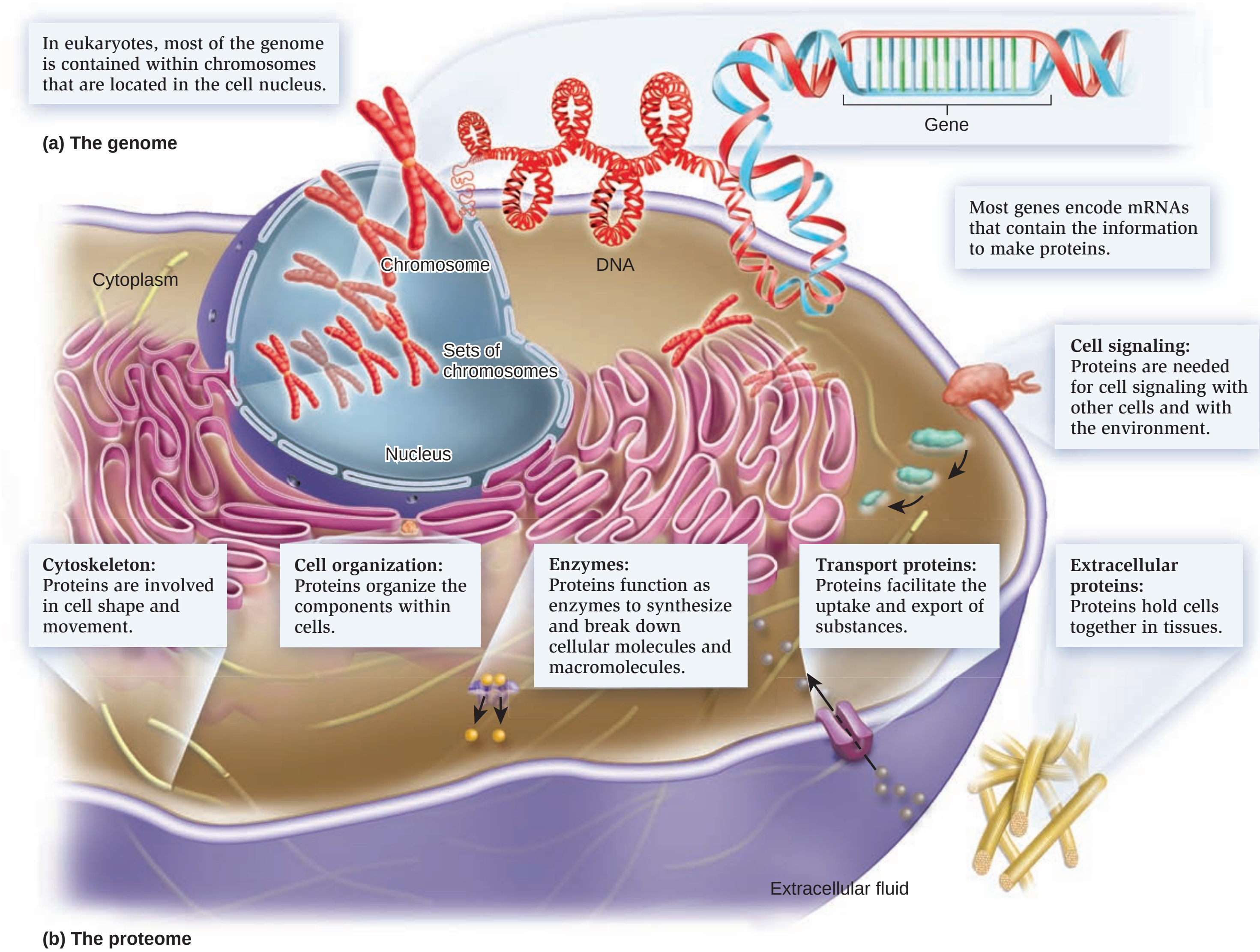
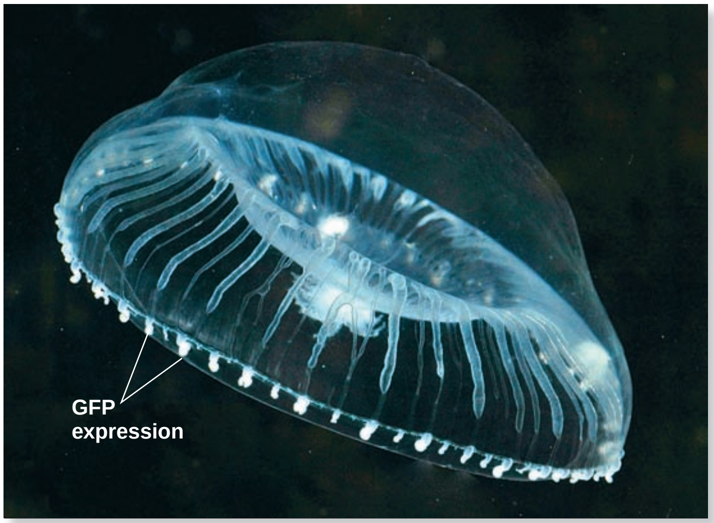


Figure 1.14 **Genomes and proteomes.** **(a)** The genome, which is composed of DNA, is the entire genetic composition of an organism. Most of the genetic material in eukaryotic cells is found in the cell nucleus. Its primary function is to encode the proteome. **(b)** The proteome is the entire protein complement of a cell or organism. Six general categories of proteins are illustrated. Proteins are largely responsible for the structure and function of cells and complete organisms.

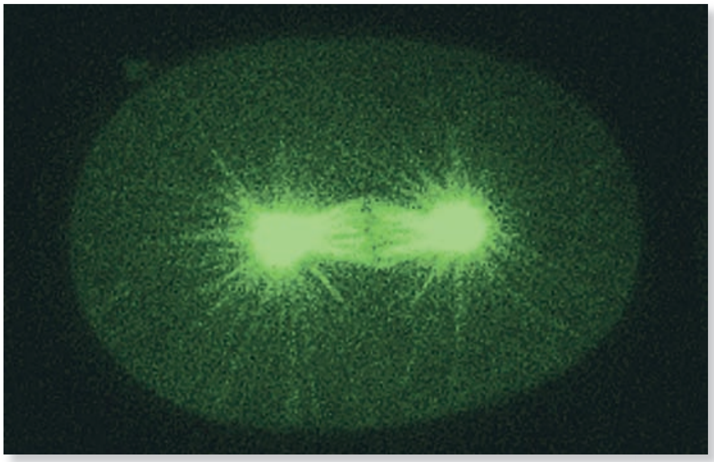
Concept check: *Biologists sometimes say the genome is a storage unit, whereas the proteome is largely the functional unit of life. Explain this statement.*

and biotechnology. With the aid of GFP, researchers can "see" where genes are expressed in a multicellular organism and where in a cell a particular protein is located. How is this possible? As mentioned, the gene for GFP is found in the genome of the crystal jelly. Using molecular techniques, copies of the GFP gene have been made from this species and placed into the cells of other species. Researchers can create hybrid genes in which a gene from a species of interest is fused with the GFP gene. For example, Figure 1.15b shows the results of an experiment where researchers created a hybrid gene by fusing a gene that encodes a protein called tubulin to the GFP gene. Tubulin is a component of microtubules that form a spindle in dividing cells. This hybrid gene encodes a protein in which tubulin is linked to GFP. When this hybrid protein is made in dividing cells and the cells are exposed to UV light, the spindle glows green, enabling researchers to visualize its location. These results confirm that tubulin is a component of the spindle.

The discovery of GFP and its development as a molecular tool has involved the efforts of several scientists. In the 1960s, Osamu Shimomura was the first researcher to identify and purify GFP from *Aequorea victoria*. Over 20 years later, Martin Chalfie and colleagues obtained the GFP gene from Douglas Prasher, who was also interested in GFP as a molecular tool. Chalfie's work demonstrated that GFP could be used as a colored tag in both bacteria and animals. In addition, Roger Tsien studied the molecular properties of GFP, enabling biologists to understand how GFP gives off light and leading to the development of altered forms of GFP that glow in different colors



(a) Bioluminescence in *Aequorea victoria*



(b) Using GFP to label a spindle in a dividing cell

Figure 1.15 **Expression of green fluorescent protein (GFP) in the crystal jelly and its use as a molecular tool.**
(a) This jellyfish is mostly transparent. GFP is naturally expressed in spots along the bell margin. **(b)** When GFP is linked to tubulin, the spindle (described in Chapter 15) glows green.

such as cyan, yellow, and red. In 2008, Shimomura, Chalfie, and Tsien received the Nobel Prize for the discovery and the development of GFP, which has become a widely used tool in biology.

1.3 Biology as a Scientific Discipline

What is science? Surprisingly, the definition of science is not easy to state. Most people have an idea of what science is, but actually articulating that idea proves difficult. In biology, we might define **science** as the observation, identification, experimental investigation, and theoretical explanation of natural phenomena.

Science is conducted in different ways and at different levels. Some biologists study the molecules that compose life, while others try to understand how organisms survive in their natural environments. In some cases, experiments are designed to test the validity of ideas suggested by researchers. In this section, we will examine how biologists follow a standard approach, called the **scientific method**, to test their ideas. We will learn that scientific insight is not based solely on intuition. Instead, scientific knowledge makes predictions that can be experimentally tested.

Even so, not all discoveries are the result of researchers following the scientific method. Some discoveries are simply made by gathering new information. As described earlier in Figures 1.1 to 1.4, the characterization of many plants and animals has led to the development of many important medicines and research tools. In this section, we will also consider how researchers often set out on "fact-finding missions" that are aimed at uncovering new information that may eventually lead to modern discoveries in biology.

Biologists Investigate Life at Different Levels of Organization

Earlier, in Figure 1.6, we examined the various levels of biological organization. The study of these different levels depends not only on the scientific interests of biologists but also on the tools available to them. The study of organisms in their natural environments is a branch of biology called **ecology** (Figure 1.16a). In addition, researchers examine the structures and functions of plants and animals, which are disciplines called **anatomy** and **physiology** (Figure 1.16b). With the advent of microscopy, **cell biology**, which is the study of cells, became an important branch of biology in the early 1900s and remains so today (Figure 1.16c). In the 1970s, genetic tools became available to study single genes and the proteins they encode. This genetic technology enabled researchers to study individual molecules, such as proteins, in living cells and thereby spawned the field of **molecular biology**. Together with chemists and biochemists, molecular biologists focus their efforts on the structure and function of the molecules of life (Figure 1.16d). Such researchers want to understand how biology works at the molecular and even atomic levels. Overall, the 20th century saw a progressive increase in the number of biologists who used a reductionist approach to understanding biology. **Reductionism** involves reducing complex systems to simpler components as a way to understand how the system works. In biology, reductionists study the parts of a cell or organism as individual units.

In the 1980s, the pendulum began to swing in the other direction. Scientists have invented new tools that allow us to study groups of genes (genomic techniques) and groups of proteins (proteomic techniques). Biologists now use the term **systems biology** to describe research aimed at understanding how the properties of life arise by complex interactions. This term is often applied to the study of cells. In this context, systems biology may involve the investigation of groups of proteins with a common purpose (Figure 1.16e). For example, a systems biologist may conduct experiments that try to characterize an entire cellular process, which is driven by dozens of different proteins.

Ecologists study species in their native environments.

(a) Ecology—population/community/ecosystem levels

Anatomists and physiologists study how the structures of organisms are related to their functions.

(b) Anatomy and physiology—tissue/organ/organism levels

Cell biologists often use microscopes to learn how cells function.

(c) Cell biology—cellular levels

Molecular biologists and biochemists study the molecules and macromolecules that make up cells.

(d) Molecular biology—atomic/molecular levels

Systems biologists may study groups of molecules. The microarray shown in the inset determines the expression of many genes simultaneously.

(e) Systems biology—all levels, shown here at the molecular level

Figure 1.16 Biological investigation at different levels.

However, systems biology is not new. Animal and plant physiologists have been studying the functions of complex organ systems for centuries. Likewise, ecologists have been characterizing ecosystems for a very long time. The novelty and excitement of systems biology in recent years have been the result of new experimental tools that allow us to study complex interactions at the molecular level. As described throughout this textbook, the investigation of genomes and proteomes has provided important insights regarding many interesting topics in systems biology.

A Hypothesis Is a Proposed Idea, Whereas a Theory Is a Broad Explanation Backed by Extensive Evidence

Let's now consider the process of science. In biology, a **hypothesis** is a proposed explanation for a natural phenomenon. It is a proposition based on previous observations or experimental studies. For example, with knowledge of seasonal changes, you might hypothesize that maple trees drop their leaves in the autumn because of the shortened amount of daylight. An alternative hypothesis might be that the trees drop their leaves because of colder temperatures. In biology, a hypothesis requires more work by researchers to evaluate its validity.

A useful hypothesis must make **predictions**—expected outcomes that can be shown to be correct or incorrect. In other words, a useful hypothesis is testable. If a hypothesis is incorrect, it should be **falsifiable**, which means that it can be shown to be incorrect by additional observations or experimentation. Alternatively, a hypothesis may be correct, so further work will not disprove it. In such cases, we would say that the researcher(s) has failed to reject the hypothesis. Even so, a hypothesis is never really proven but rather always remains provisional. Researchers accept the possibility that perhaps they have not yet conceived of the correct hypothesis. After many experiments, biologists may conclude that their hypothesis is consistent with known data, but they should never say the hypothesis is proven.

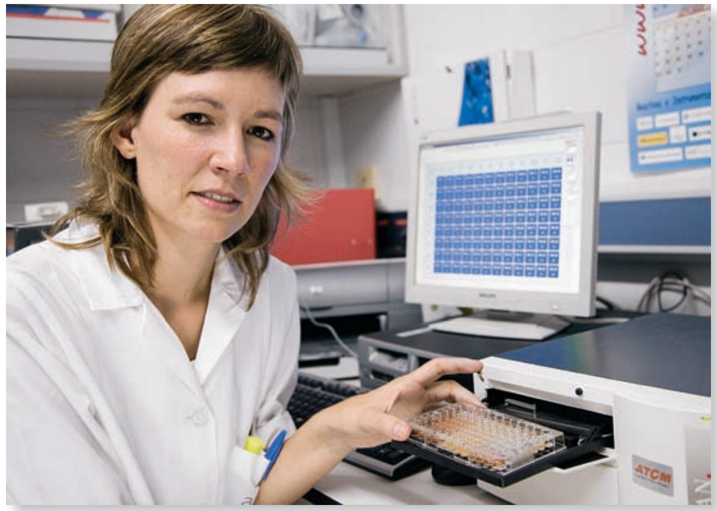
By comparison, the term **theory**, as it is used in biology, is a broad explanation of some aspect of the natural world that is substantiated by a large body of evidence. Biological theories incorporate observations, hypothesis testing, and the laws of other disciplines such as chemistry and physics. The power of theories is they allow us to make many predictions regarding the properties of living organisms. As an example, let's consider the theory that DNA is the genetic material and that it is organized into units called genes. An overwhelming body of evidence has substantiated this theory. Thousands of living species have been analyzed at the molecular level. All of them have been found to use DNA as their genetic material and to express genes that produce the proteins that lead to their characteristics. This theory makes many valid predictions. For example, certain types of mutations in genes are expected to affect the traits of organisms. This prediction has been confirmed experimentally. Similarly, this theory predicts that genetic material is copied and transmitted from parents to offspring. By comparing the DNA of parents and offspring, this prediction has also been confirmed. Furthermore, the theory explains the observation that offspring resemble their parents. Overall, two key attributes of a scientific theory are (1) consistency with a vast amount of known data and (2) the ability to make many correct predictions. Two other important biological theories we have touched on in this chapter are the cell theory and the theory of evolution by natural selection.

The meaning of the term theory is sometimes muddled because it is used in different situations. In everyday language, a "theory" is often viewed as little more than a guess or a hypothesis. For example, a person might say, "My theory is that Professor Simpson did not come to class today because he went to the beach." However, in biology, a theory is much more than a guess. A theory is an established set of ideas that explains a vast amount of data and offers valid predictions that can be tested. Like a hypothesis, a theory can never be proven to be true. Scientists acknowledge that they do not know everything. Even so, biologists would say that theories are extremely likely to be true, based on all known information. In this regard, theories are viewed as **knowledge**, which is the awareness and understanding of information.

Discovery-Based Science and Hypothesis Testing Are Scientific Approaches That Help Us Understand Biology

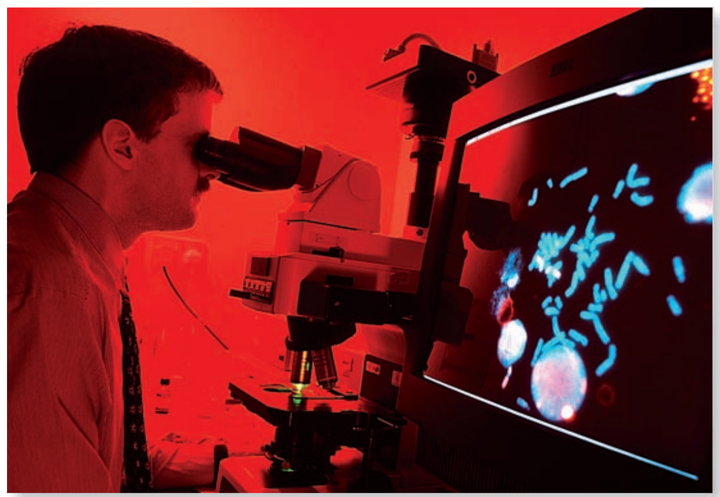
The path that leads to an important discovery is rarely a straight line. Rather, scientists ask questions, make observations, ask modified questions, and may eventually conduct experiments to test their hypotheses. The first attempts at experimentation may fail, and new experimental approaches may be needed. To suggest that scientists follow a rigid scientific method is an oversimplification of the process of science. Scientific advances often occur as scientists dig deeper and deeper into a topic that interests them. Curiosity is the key phenomenon that sparks scientific inquiry. How is biology actually conducted? As discussed next, researchers typically follow two general types of approaches—discovery-based science and hypothesis testing.

Discovery-Based Science The collection and analysis of data without the need for a preconceived hypothesis is called **discovery-based science**, or simply **discovery science**. Why is discovery-based science carried out? The information gained from discovery-based science may lead to the formation of new hypotheses, and, in the long run, may have practical applications that benefit people. Drug companies, for example, may test hundreds or even thousands of compounds to determine if any of them are useful in the treatment of disease (Figure 1.17a). Once a drug has been discovered that is effective in disease treatment, researchers may dig deeper and try to understand how the drug exerts its effects. In this way, discovery-based science may help us learn about basic concepts in medicine and biology. Another example involves the study of genomes (Figure 1.17b). Over the past few decades, researchers have identified and begun to investigate newly discovered genes within the human genome without already knowing the function of the gene they are studying. The goal is to gather additional clues that may eventually allow them to propose a hypothesis that explains the gene's function. Discovery-based science often leads to hypothesis testing.



Drug companies may screen hundreds or thousands of different compounds, trying to discover ones that may prove effective in the treatment of a particular disease.

(a) Drug discovery



Genetic researchers search through the genomes of humans and other species, trying to discover new genes. Such discoveries may help us understand molecular biology and provide insight into the causes of inherited diseases in people.

(b) Discovery of genes

Figure 1.17 Discovery-based science.

Concept check: How is discovery-based science different from hypothesis testing?

Hypothesis Testing In biological science, the scientific method, also known as **hypothesis testing**, is usually followed to test the validity of a hypothesis. This strategy may be described as a five-stage process:

1. Observations are made regarding natural phenomena.
2. These observations lead to a hypothesis that tries to explain the phenomena. A useful hypothesis is one that is testable because it makes specific predictions.
3. Experimentation is conducted to determine if the predictions are correct.
4. The data from the experiment are analyzed.
5. The hypothesis is considered to be consistent with the data, or it is rejected.

The scientific method is intended to be an objective way to gather knowledge. As an example, let's return to our scenario of maple trees dropping their leaves in autumn. By observing the length of daylight throughout the year and comparing that data with the time of the year when leaves fall, one hypothesis might be that shorter daylight causes the leaves to fall (Figure 1.18). This hypothesis makes a prediction—exposure of maple trees to shorter daylight will cause their leaves to fall. To test this prediction, researchers would design and conduct an experiment.

How is hypothesis testing conducted? Although hypothesis testing may follow many paths, certain experimental features are common to this approach. First, data are often collected in two parallel manners. One set of experiments is done on the **control group**, while another set is conducted on the **experimental group**. In an ideal experiment, the control and experimental groups differ by only one factor. For example, an experiment could be conducted in which two groups of trees would be observed and the only difference between their environments would be the length of light each day. To conduct such an experiment, researchers would grow small trees in a greenhouse where they could keep factors such as temperature and water the same between the control and experimental groups, while providing them with different amounts of daylight. In the control group, the number of hours of light provided by lightbulbs would be kept constant each day, while in the experimental group, the amount of light each day would become progressively shorter to mimic seasonal light changes. The researchers would then record the number of leaves dropped by the two groups of trees over a certain period of time.

Another key feature of hypothesis testing is data analysis. The result of experimentation is a set of data from which a biologist tries to draw conclusions. Biology is a quantitative science. When experimentation involves control and experimental groups, a common form of analysis is to determine if

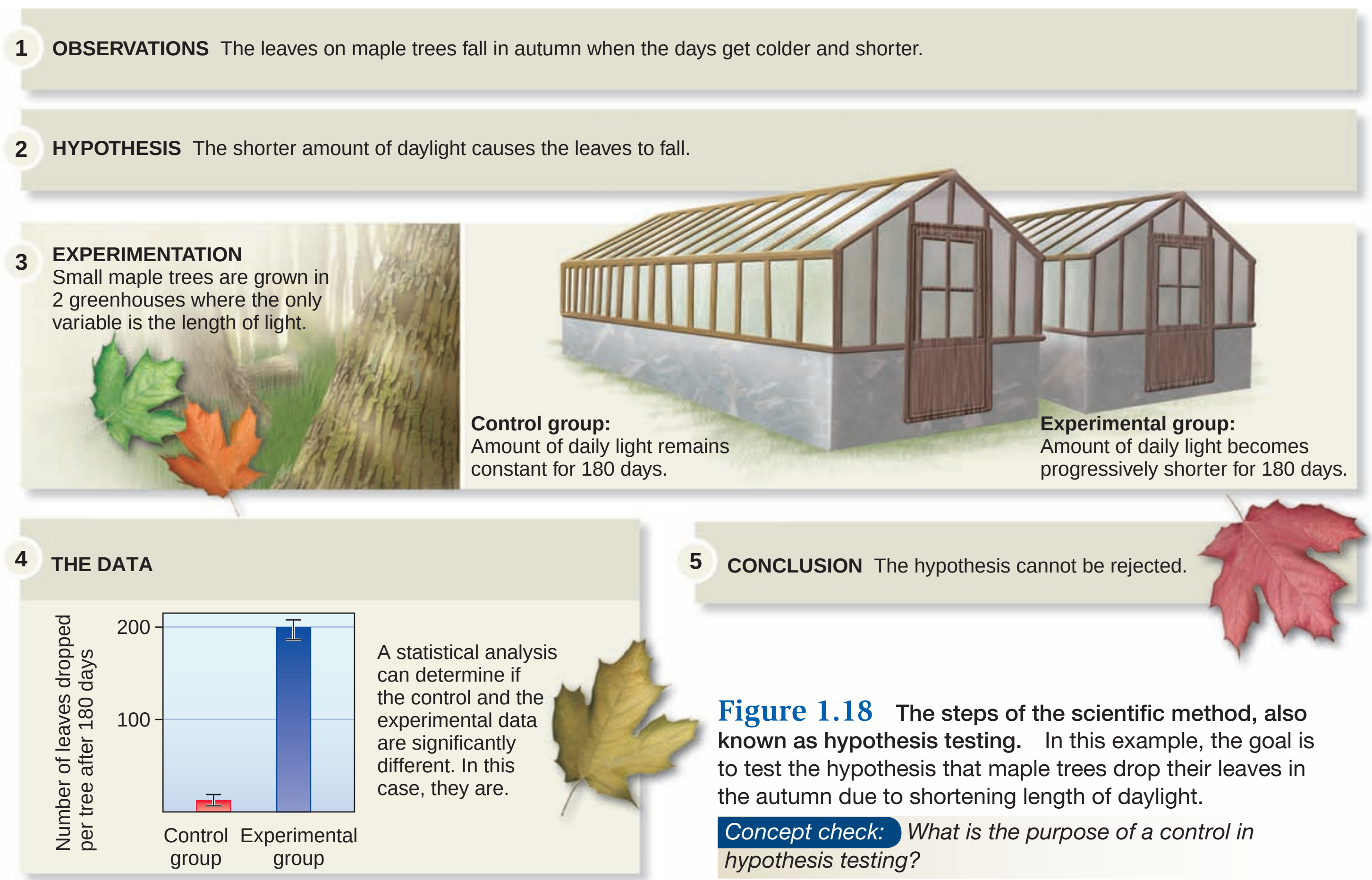


Figure 1.18 **The steps of the scientific method, also known as hypothesis testing.** In this example, the goal is to test the hypothesis that maple trees drop their leaves in the autumn due to shortening length of daylight.

Concept check: What is the purpose of a control in hypothesis testing?

the data collected from the two groups are truly different from each other. Biologists apply statistical analyses to their data to determine if the control and experimental groups are likely to be different from each other because of the single variable that is different between the two groups. When they are statistically significant, this means that the differences between the control and experimental data are not likely to have occurred as a matter of random chance. In our tree example shown in Figure 1.18, the trees in the control group dropped far fewer leaves than did those in the experimental group. A statistical analysis could determine if the data collected from the two greenhouses are significantly different from each other. If the two sets of data are found not to be significantly different, the hypothesis would be rejected. Alternatively, if the differences between the two sets of data are significant, as shown in Figure 1.18, biologists would conclude that the hypothesis is consistent with the data, though it is not proven. These results may cause researchers to ask further questions. For example, they may want to understand how decreases in the length of daylight promote cellular changes that cause the leaves to fall.

As described next, discovery-based science and hypothesis testing are often used together to learn more about a particular scientific topic. As an example, let's look at how both approaches have led to successes in the study of the disease called cystic fibrosis.

The Study of Cystic Fibrosis Provides Examples of Both Discovery-Based Science and Hypothesis Testing

Let's consider how biologists made discoveries related to the disease cystic fibrosis (CF), which affects about 1 in every 3,500 Americans. Persons with CF produce abnormally thick and sticky mucus that obstructs the lungs and leads to life-threatening lung infections. The thick mucus also blocks the pancreas, which prevents the digestive enzymes this organ produces from reaching the intestine. For this reason, CF patients tend to have excessive appetites but poor weight gain. Persons with this disease may also experience liver damage because the thick mucus can obstruct the liver. The average life span for people with CF is currently in their mid- to late 30s. Fortunately, as more advances have been made in treatment, this number has steadily increased.

Because of its medical significance, many scientists are interested in cystic fibrosis and have conducted studies aimed at gaining greater information regarding its underlying cause. The hope is that a better understanding of the disease may lead to improved treatment options, and perhaps even a cure. As described next, discovery-based science and hypothesis testing have been critical to gaining a better understanding of this disease.

The CF Gene and Discovery-Based Science In 1945, Dorothy Anderson determined that cystic fibrosis is a genetic disorder. Persons with CF have inherited two faulty *CF* genes, one from each parent. Over 40 years later, researchers used discovery-based science to identify this gene. Their search for the *CF* gene did not require any preconceived hypothesis regarding the function of the gene. Rather, they used genetic strategies similar to those described in Chapter 20. In 1989, research groups headed by Lap-Chi Tsui, Francis Collins, and John Riordan identified the *CF* gene.

The discovery of the gene made it possible to devise diagnostic testing methods to determine if a person carries a faulty *CF* gene. In addition, the characterization of the *CF* gene provided important clues regarding its function. Researchers observed striking similarities between the *CF* gene and other genes that were already known to encode proteins called transporters, which function in the transport of substances across membranes. Based on this observation, as well as other kinds of data, the researchers hypothesized that the function of the normal *CF* gene is to encode a transporter. In this way, the identification of the *CF* gene led researchers to conduct experiments aimed at testing a hypothesis of its function.

The CF Gene and Hypothesis Testing Researchers considered the characterization of the *CF* gene along with other studies showing that patients with the disorder have an abnormal regulation of salt balance across their plasma membranes. They hypothesized that the normal *CF* gene encodes a transporter that functions in the transport of chloride ions (Cl^-), a component of common table salt (NaCl), across the membranes of cells (**Figure 1.19**). This hypothesis led to experimentation in which researchers tested normal cells and cells from CF patients

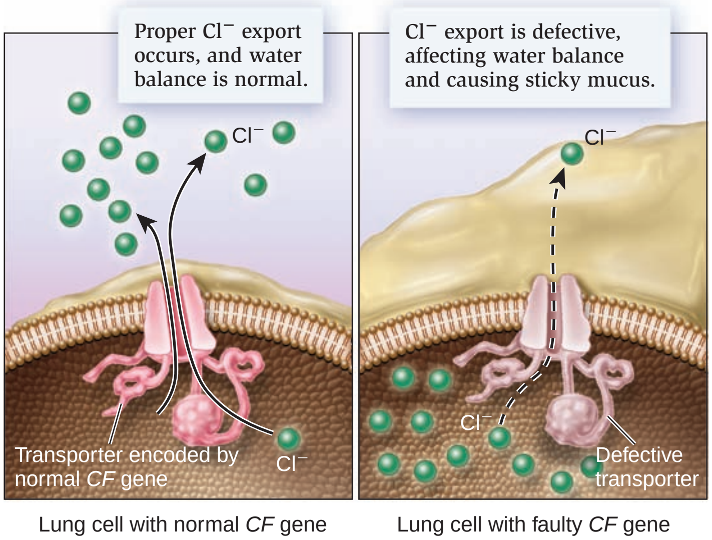


Figure 1.19 **A hypothesis that suggests an explanation for the function of the gene that is defective in patients with cystic fibrosis.** The normal *CF* gene, which does not carry a mutation, encodes a transporter that transports chloride ions (Cl^-) across the plasma membrane to the outside of the cell. In persons with CF, this transporter is defective due to a mutation in the *CF* gene.

Concept check: *Explain how discovery-based science helped researchers to hypothesize that the CF gene encodes a transporter.*

for their ability to transport Cl^-. The CF cells were found to be defective in chloride transport. In 1990, scientists successfully transferred the normal *CF* gene into CF cells in the laboratory. The introduction of the normal gene corrected the cells' defect in chloride transport. Overall, the results showed that the *CF* gene encodes a transporter that transports Cl^- across the plasma membrane. A mutation in this gene causes it to encode a defective transporter, leading to a salt imbalance that affects water levels outside the cell, which explains the thick and sticky mucus in CF patients. In this example, hypothesis testing has provided a way to evaluate a hypothesis regarding how a disease is caused by a genetic change.

Feature Investigation

Observation and Experimentation Form the Core of Biology

Because biology is the study of life, a biology textbook that focuses only on a description of living organisms would miss the main point. Biology is largely about the process of discovery. Therefore, a recurring theme of this textbook is discovery-based science and hypothesis testing. While each chapter contains many examples of data collection and experiments, a consistent element is a "Feature Investigation"—an actual study by current or past researchers. Some of these involve discovery-based science in which biologists collect and analyze data in an attempt to make discoveries that are not hypothesis driven. Alternatively, most Feature Investigations involve hypothesis testing in which a hypothesis is stated and the experiment and resulting data are presented. See Figure 1.18 to see the form of these Feature Investigations.

The Feature Investigations allow you to appreciate the connection between science and scientific theories. We hope you will find this a more interesting and rewarding way to learn about biology. As you read a Feature Investigation, you may find yourself thinking about different approaches and alternative hypotheses. Different people can view the same data and arrive at very different conclusions. As you progress through the experiments in this textbook, you will enjoy biology far more if you try to develop your own skills at formulating hypotheses, designing experiments, and interpreting data.

Experimental Questions

1. Discuss the difference between discovery-based science and hypothesis testing.
2. What are the steps in the scientific method, also called hypothesis testing?
3. When conducting an experiment, explain how a control group and an experimental group differ from each other.

Science as a Social Discipline

Finally, it is worthwhile to point out that science is a social discipline. After performing observations and experiments, biologists communicate their results in different ways. Most importantly, papers are submitted to scientific journals. Following submission, most papers undergo a **peer-review process** in which other scientists, who are experts in the area, evaluate the paper and make suggestions regarding its quality. Following peer review, a paper is either accepted for publication, rejected, or the authors of the paper may be given suggestions for how to revise the work or conduct additional experiments before it will be acceptable for publication.

Another social aspect of research is that biologists often attend meetings where they report their most recent work to the scientific community (Figure 1.20). They comment on each other's ideas and work, eventually shaping together the information that builds into scientific theories over many years. As you develop your skills at scrutinizing experiments, it is satisfying to discuss your ideas with other people, including fellow students and faculty members. Importantly, you do not need to "know all the answers" before you enter into a scientific discussion. Instead, a more rewarding way to view science is as an ongoing and never-ending series of questions.

Figure 1.20 **The social aspects of science.** At scientific meetings, researchers gather to discuss new data and discoveries. Research conducted by professors, students, lab technicians, and industrial participants is sometimes hotly debated.

Summary of Key Concepts

- Biology is the study of life. Discoveries in biology help us understand how life exists, and they also have many practical applications, such as the development of drugs to treat human diseases. (Figures 1.1, 1.2, 1.3, 1.4)

1.1 The Properties of Life

- Seven characteristics are common to all forms of life. All living things (1) are composed of cells; (2) use energy; (3) respond to environmental changes; (4) regulate their internal conditions (homeostasis); (5) grow and develop; (6) reproduce; and (7) evolve over the course of many generations. (Figure 1.5)
- Living organisms can be viewed at different levels of complexity: atoms, molecules and macromolecules, cells, tissues, organs, organisms, populations, communities, ecosystems, and the biosphere. (Figure 1.6)

1.2 The Unity and Diversity of Life

- Changes in species often occur as a result of modification of pre-existing structures. (Figures 1.7, 1.8)
- Vertical evolution involves mutations in a lineage that alter the characteristics of species over many generations. During this process, natural selection results in the survival of individuals with greater reproductive success. Over the long run, this process alters species and may produce new species. In addition, evolution involves the accumulation of neutral changes. (Figure 1.9)
- Horizontal gene transfer may involve the transfer of genes between different species. Along with vertical evolution, it is an important force in biological evolution, producing a web of life. (Figures 1.10, 1.11)
- Taxonomy involves the grouping of species according to their evolutionary relatedness to other species. Going from broad to narrow, each species is placed into a domain, kingdom, phylum, class, order, family, and genus. (Figures 1.12, 1.13)
- The genome is the genetic composition of a species. It provides a blueprint for the traits of an organism, is transmitted from parents to offspring, and acts as an instrument for evolutionary change. The proteome is the collection of proteins that a cell or organism can make. Beginning with Chapter 3, each chapter in this textbook has a brief discussion called "Genomes & Proteomes Connection." (Figure 1.14)
- An analysis of genomes and proteomes helps us to understand the characteristics of individuals and how they survive in their native environments. (Figure 1.15)

1.3 Biology as a Scientific Discipline

- Biological science involves the observation, identification, experimental investigation, and theoretical explanation of natural phenomena.
- Biologists study life at different levels, ranging from ecosystems to molecular components in cells. (Figure 1.16)
- A hypothesis is a proposal to explain a natural phenomenon. A useful hypothesis makes a testable prediction. A biological theory is a broad explanation based on vast amounts of data and makes many valid predictions.
- Discovery-based science is an approach in which researchers conduct experiments without a preconceived hypothesis. It is a fact-finding mission. (Figure 1.17)
- The scientific method, also called hypothesis testing, is a series of steps to test the validity of a hypothesis. The experimentation often involves a comparison between control and experimental groups. (Figure 1.18)
- The study of cystic fibrosis is an interesting example in which both discovery-based science and hypothesis testing have provided key insights regarding the nature of the disease. (Figure 1.19)
- Each chapter in this textbook has a "Feature Investigation" to help you appreciate how science has led to key discoveries in biology.
- To be published, scientific papers are usually subjected to peer review. Advances in science often occur when scientists gather and discuss their data. (Figure 1.20)

Assess and Discuss

Test Yourself

1. The process where living organisms maintain a relatively stable internal condition is
   a. adaptation.
   b. evolution.
   c. metabolism.
   d. homeostasis.
   e. development.
2. Populations of organisms change over the course of many generations. Many of these changes result in increased survival and reproduction. This phenomenon is
   a. evolution.
   b. homeostasis.
   c. development.
   d. genetics.
   e. metabolism.
3. All of the places on Earth where living organisms are found is
   a. the ecosystem.
   b. a community.
   c. the biosphere.
   d. a viable land mass.
   e. a population.
4. Which of the following would be an example of horizontal gene transfer?
   a. the transmission of an eye color gene from father to daughter
   b. the transmission of a mutant gene causing cystic fibrosis from father to daughter
   c. the transmission of a gene conferring pathogenicity (the ability to cause disease) from one bacterial species to another
   d. the transmission of a gene conferring antibiotic resistance from a mother cell to its two daughter cells
   e. all of the above
5. The scientific name for humans is *Homo sapiens*. The name *Homo* is the _____ to which humans are classified.
   a. kingdom
   b. phylum
   c. order
   d. genus
   e. species