BIOLOGY

Brooker
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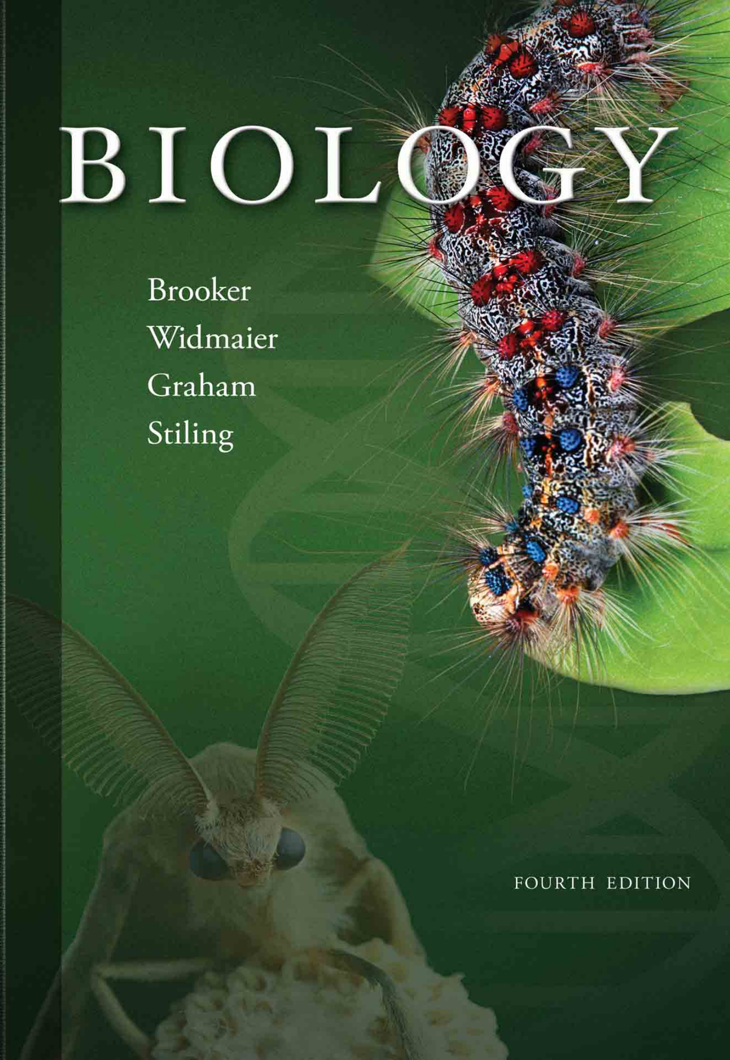
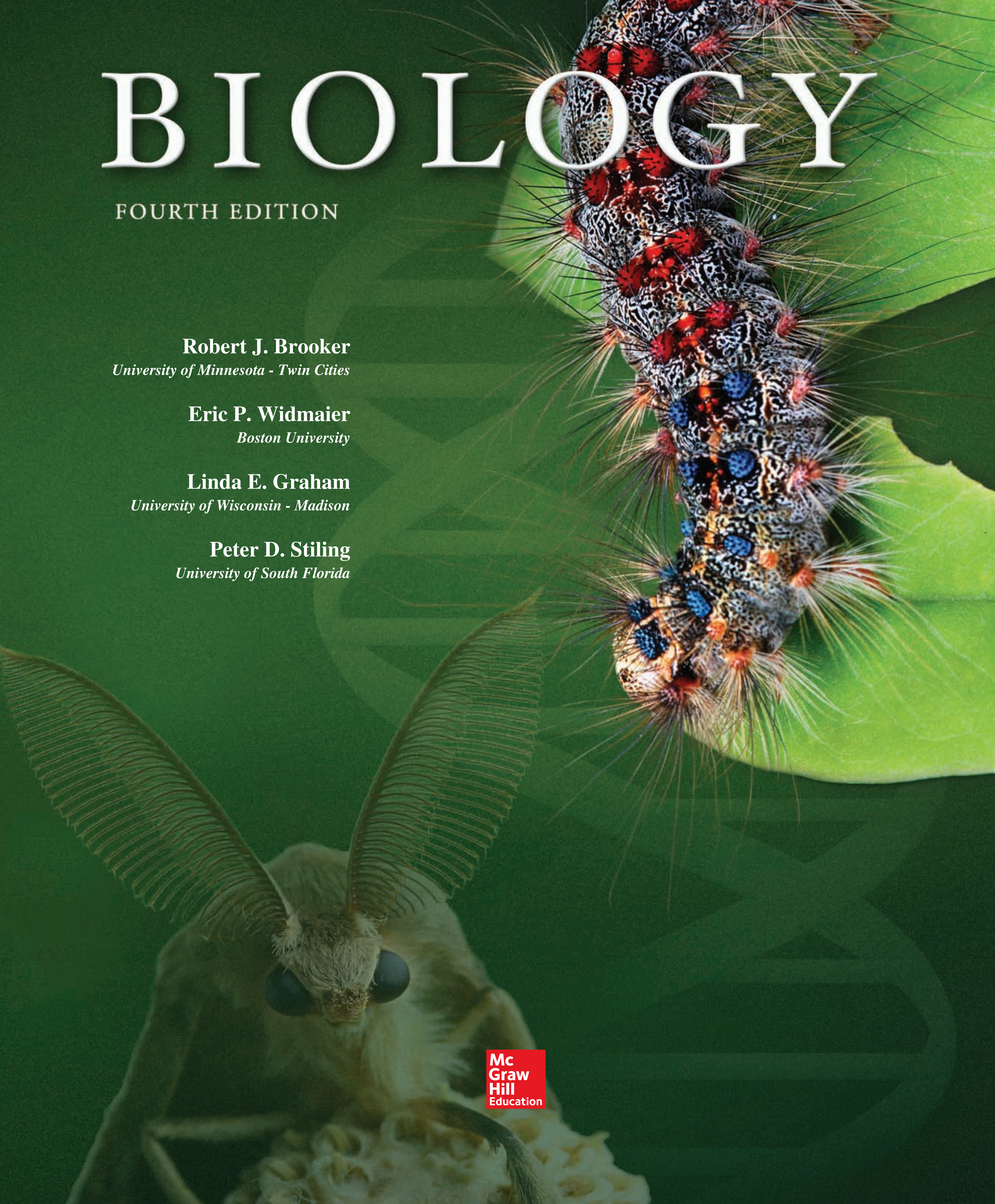


FOURTH EDITION

McGraw Hill Education



BIOLOGY

FOURTH EDITION

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Brief Contents

About the Authors

Robert J. Brooker

Rob Brooker (Ph.D., Yale University) received his B.A. in biology at Wittenberg University, Springfield, Ohio, in 1978. At Harvard, he studied lactose permease, the product of the *lacY* gene of the *lac* operon. He continued working on transporters at the University of Minnesota, where he is a Professor in the Department of Genetics, Cell Biology, and Development and the Department of Biology Teaching and Learning. 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 two undergraduate genetics texts published by McGraw-Hill: *Genetics: Analysis & Principles*, 5th edition, copyright 2015, and *Concepts of Genetics*, 2nd edition, copyright 2016.

Eric P. Widmaier

Eric Widmaier received his Ph.D. in 1984 in endocrinology from the University of California at San Francisco. His research focuses 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 teaches undergraduate human physiology and 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*, 14th edition, published by McGraw-Hill, copyright 2017.

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 algae and land-adapted plants, focusing on their cell and molecular biology as well as ecological interactions with microbes. Dr. Graham is now Professor of Botany at the University of Wisconsin-Madison. She teaches undergraduate courses in microbiology and plant biology. She is the coauthor of, among other publications, *Algae*, 3rd edition, copyright 2015, a major's textbook on algal biology, and *Plant Biology*, 3rd edition, copyright 2015, both published by LJLM Press.

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 postdoctoral fellow at Florida State University and later spent two 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. His 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. 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*, 2nd edition, published by McGraw-Hill, copyright 2015.

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and patience of their families, friends, and students,
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Maria, Rick, and Carrie Widmaier,
Jim, Michael, Shannon, and Melissa Graham, and
Jacqui, Zoe, Leah, and Jenna Stiling.

Lead Digital Author

Ian Quitadamo

Ian Quitadamo is a Professor with a dual appointment in Biological Sciences and Science Education at Central Washington University in Ellensburg, Washington. He teaches introductory and majors biology courses and cell biology, genetics, and biotechnology, as well as science teaching methods courses for future science teachers and interdisciplinary content courses in alternative energy and sustainability. Dr. Quitadamo was educated at Washington State University and holds a BA in biology, Masters degree in genetics and cell biology, and an interdisciplinary Ph.D. in science, education, and technology. Previously a researcher of tumor angiogenesis, he now investigates the behavioral and neurocognitive basis of critical thinking and has published numerous studies of factors that improve student critical thinking performance. He has received the Crystal Apple award for teaching excellence, led multiple initiatives in critical thinking and assessment, and is active nationally in helping transform university faculty practice. He served as a coauthor on *Biology*, 11th edition, by Mader and Windelspecht, copyright 2013 and is the lead digital author for *Biology*, 10th and 11th editions by Raven, copyright 2014 and 2017, *Biology*, 3rd edition, by Brooker, copyright 2014, *Understanding Biology* by Mason, copyright 2015, and *Principles of Biology* by Brooker, copyright 2015, all published by McGraw-Hill. For fun, Dr. Quitadamo practices Kyokushin full contact karate and is a 5th degree blackbelt.

Improving Biology Education: We Listened to You

A Modern Vision for Learning: Emphasizing Core Principles and Problem Solving Skills

Over the course of four editions, the ways in which biology is taught have dramatically changed. We have seen a shift away from the memorization of details, which are easily forgotten, and a movement toward emphasizing core concepts and critical thinking skills. For example, the previous edition of *Biology* put biology principles at the forefront by introducing them in Chapter 1 and then emphasizing them over and over again within the figure legends of hundreds of figures throughout the textbook. This focus on biology principles has been retained in the new edition. New to the fourth edition is a greater emphasis on skill development, thereby striking a better balance between foundational knowledge and critical thinking skills. In particular, two new features, called SciSKILLS and BioTIPS, described later, are aimed at helping students develop effective strategies for solving problems and applying their knowledge in novel situations.

Through our classroom experiences and research work, we became inspired by the prospect that the first three editions of *Biology* could move biology education forward. We are confident that this new edition of *Biology* is another step in the right direction 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

Problem solving skills

Media—Active teaching and learning with technology

Continued feedback from instructors using this textbook and other educators in the field of biology 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 for areas for improvement. Our textbook continues to be comprehensive and cutting-edge, featuring an evolutionary focus and an emphasis on scientific inquiry.

To help guide our revision for this fourth edition, we were able to incorporate student usage data and input, derived from thousands of our SmartBook® users. SmartBook "heat maps" provided a quick visual snapshot of chapter usage data and the relative difficulty students experienced in mastering the content. With these data, we were able to hone not only our text content but also the SmartBook probes.

- If the data indicated that the subject was more difficult than other parts of the chapter, as evidenced by a high proportion of students responding incorrectly to the probes, we revised or reorganized the content to be as clear and illustrative as possible.
- In other cases, one or more of the SmartBook probes for a section was not as clear as it might be or did not appropriately reflect the content. In these cases the *probe*, rather than the text, was edited.

A Message from the Authors

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 digital resources 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

KEY PEDAGOGICAL FEATURES OF THIS EDITION

The author team is dedicated to producing the most engaging and current text that is available for undergraduate students who are majoring in biology. We have listened to educators and reviewed documents, such as *Vision and Change, A Call to Action*, which includes a summary of recommendations made at a national conference organized by the American Association for the Advancement of Science (see www.visionandchange.org). We want our textbook to reflect core competencies and provide a more learner-centered approach. To achieve these goals, *Biology*, 4th edition, has the following features.

- **Principles of Biology:** Based on educational literature and feedback from biology educators, we have listed 12 Principles of Biology in Chapter 1 (see Figure 1.4). These 12 principles align with the overarching core concepts described in *Vision and Change*, with 1 to 3 principles included per core concept.
- The Principles of Biology are threaded throughout the entire textbook. This is achieved in two ways. First, the principles are explicitly stated in selected figure legends in every chapter. Such legends are given a Principle of Biology icon. In addition, a question at the end of each chapter is directly aimed at a particular principle.
- **BioTIPS:** A new feature added to *Biology*, 4th edition will help students develop their problem-solving skills. Chapters 2 through 60 contain solved problems called **BioTIPS**, which stands for **T**opic, **I**nformation, and **P**roblem-Solving **S**trategy. These solved problems follow a consistent pattern in which students are given advice on how to solve problems in biology using different types of problem-solving strategies. These strategies include: Make a drawing; Compare and contrast; Relate structure and function; Sort out the steps in a complicated process; Propose a hypothesis; Design an experiment; Predict the outcome; Interpret data; Use statistics; Make a calculation; and Search the literature.
- **SciSKILLS:** Another new feature in *Biology*, 4th edition, called **SciSKILLS**, emphasizes experimental skills needed in the study of biology. Skills such as Analyze data, Form hypotheses, Make predictions, Make calculations, are skills that scientists generally perform and students majoring in biology should be practicing. Unfortunately, students often focus on learning concepts and don't develop these important skills. SciSKILLS are incorporated in two places in *Biology*, 4th edition: as Learning Outcomes and in the Feature Investigation questions. The Learning Outcomes set expectations for student learning. Those Learning Outcomes that are designated SciSKILLS will direct students to devote time to developing certain skills associated with experimentation. Further, by including SciSKILLS questions in the Feature Investigations, students are challenged to develop scientific thinking skills.
- **Unit openers:** Each unit begins with a Unit opener that provides an overview of the chapters within that unit. They allow the student to see the big picture of the unit. In addition, the unit openers draw attention to the principles of biology that will be emphasized in that unit.
- **BioConnections:** The BioConnections inform students of how a topic in one chapter is connected to a topic in another.
- **Learning Outcomes:** As advocated in *Vision and Change*, educational materials should have well-defined learning goals. Each section of every chapter begins with a set of Learning Outcomes. These outcomes inform students of the key concepts they will learn and the skills they will acquire when mastering the material. They also provide a tangible understanding of how student learning will be assessed. The assessments in Connect were developed using these Learning Outcomes as a guide in formulating online questions, thereby linking the learning goals of the text with the assessment in Connect.

CONTENT CHANGES TO THIS EDITION

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

- **Chapter 1. An Introduction to Biology:** Chapter 1 contains a new subsection that relates genomes and proteomes, and also explores the fascinating topic of "zombie parasites" (see Figure 1.13 and Table 1.1). It also contains a subsection that describes our new BioTIPS feature (pp. 19–20).

Chemistry Unit

- **Chapter 2. The Chemical Basis of Life I: Atoms, Molecules, and Water:** Chapter 2 contains a new BioTIPS feature that helps students to calculate molarity and to relate their calculation to a disease condition.
- **Chapter 3. The Chemical Basis of Life II: Organic Molecules:** The section on Proteins (Section 3.6) has a new figure that explains the concept of protein domains (Figure 3.20).

Cell Unit

- **Chapter 4. General Features of Cells:** This chapter has an expanded discussion of how to calculate the surface area-to-volume ratio, depending on the shape of a cell.
- **Chapter 5. Membrane Structure, Synthesis, and Transport:** The section of membrane transport has been revised to better distinguish simple diffusion from facilitated diffusion.
- **Chapter 6. An Introduction to Energy, Enzymes, and Metabolism:** This chapter has a new BioTIPS feature that helps students understand how a mutation could affect an allosteric site in an enzyme.
- **Chapter 7. Cellular Respiration and Fermentation:** The section on oxidative phosphorylation has been divided into two sections, the second of which takes a closer look at ATP synthase.
- **Chapter 8. Photosynthesis:** This chapter has a new BioTIPS feature that asks students to distinguish between the light-harvesting complex, P680, and the primary electron acceptor.
- **Chapter 9. Cell Communication:** In *Biology*, 4th edition, the topic of apoptosis has been expanded to include a discussion of how it plays a role in certain diseases (see Table 9.2).
- **Chapter 10. Multicellularity:** The section comparing animal and plant cells has been streamlined. The discussion of plasmodesmata in plants has also been revised.

Genetics Unit

- **Chapter 11. Nucleic Acid Structure, DNA Replication, and Chromosome Structure:** This chapter has a new BioTIPS feature that pertains to the role of DNA ligase during DNA replication. The illustration regarding the Avery, MacLeod, and McCarty experiment has been revised (see Figure 11.2).
- **Chapter 12. Gene Expression at the Molecular Level:** The section on RNA modification (formerly RNA processing) has been reorganized.
- **Chapter 13. Gene Regulation:** A new section has been added (Section 13.5) on Epigenetic Gene Regulation, including a new figure (Figure 13.21) and two new tables (Tables 13.1 and 13.2).
- **Chapter 14. Mutation, DNA Repair, and Cancer:** Section 14.1 that was in *Biology*, 3rd edition, is now subdivided into two sections on the Causes of Mutation and the Consequences of Mutation.
- **Chapter 15. The Eukaryotic Cell Cycle, Mitosis, and Meiosis:** The Genomes & Proteomes Connection has been changed to the topic of how mitosis in eukaryotes evolved from binary fission that occurs in prokaryotic cells (see Figure 15.10).
- **Chapter 16. Simple Patterns of Inheritance:** This chapter has a new BioTIPS feature that helps students learn how to use probability and a Punnett square to predict the outcome of crosses.
- **Chapter 17. Complex Patterns of Inheritance:** Building on the BioTIPS feature in Chapter 17, Chapter 18 has a BioTIPS feature that focuses on maternal inheritance.
- **Chapter 18. Genetics of Viruses and Bacteria:** The first part of Chapter 18 has been reorganized by adding a new section (Section 18.2) on viral reproductive cycles.
- **Chapter 19. Developmental Genetics:** In many places, the information in this chapter has been broken down into bulleted and numbered lists to make it easier for students to follow. The illustration of the effects of the bicoid mutation has been revised (see Figure 19.8).
- **Chapter 20. Genetic Technology:** In Chapter 20 of *Biology*, 4th edition, a new subsection has been added on how genetically modified organisms can make products that are useful to people (also see Table 20.1).
- **Chapter 21. Genomes, Proteomes, and Bioinformatics:** The rapidly changing information on the properties of bacterial, archaeal, and eukaryotic genomes has been updated.

Evolution Unit

- **Chapter 22. The Origin and History of Life:** This chapter has a new BioTIPS feature that helps students to learn how the calculation of radioisotope decay is used to date fossils.
- **Chapter 23. An Introduction to Evolution:** The topic of whale evolution from tetrapod mammals has been added, along with a new figure (see Figure 23.7).
- **Chapter 24. Population Genetics:** An example has been added to help students use the Hardy-Weinberg equation to calculate allele and genotype frequencies.
- **Chapter 25. Origin of Species and Macroevolution:** This chapter has a new BioTIPS feature that helps students learn how to design an experiment to determine if two populations constitute different species.
- **Chapter 26. Taxonomy and Systematics:** The information on eukaryotic supergroups has been updated. The chapter also includes an example to help students learn how to assess evolutionary trees using the principle of parsimony.

Diversity Unit

- **Chapter 27. Archaea and Bacteria:** Phylogenetic history of major lineages of Bacteria and Archaea has been updated to reflect recent progress, including identification of archaea most closely related to eukaryotes.
- **Chapter 28. Protists:** The phylogenetic history of major lineages of protists has been updated to reflect recent progress, including identification of the root of the eukaryotic tree of life. A new Feature Investigation describes an experiment that tests hypotheses of protist fossil identifications and provides results useful in industrial applications of materials produced by common protists.
- **Chapter 29. Plants and the Conquest of Land:** Table 29.1 that summarizes the features of major groups of land plants has been reorganized to enhance reader access.
- **Chapter 30. The Evolution and Diversity of Modern Gymnosperms and Angiosperms:** To emphasize the importance of whole genome duplication (WGD) events in the evolutionary history of seed plants, major WGD events have been mapped onto phylogenetic diagrams.
- **Chapter 31. Fungi:** Phylogenetic history of the fungi has been updated to reflect recent progress. Table 31.1 has been simplified to include major derived fungal lineages of most concern to human society.
- **Chapter 32. An Introduction to Animal Diversity:** The chapter opening photograph has been changed to illustrate a

naked mole rat. The introductory paragraph discusses some of the unusual features of naked mole rat biology as well as the potential value of naked mole rats to medicine. Some data in Table 32.3 have been updated.

- **Chapter 33. The Invertebrates:** The sections on both cnidarians and flatworms have been simplified. A new photograph has been provided to illustrate a molluscan veliger larva. The sections on the annelid body plan and crustacean diversity have been rewritten. The major echinoderm classes are now illustrated using five new photographs.
- **Chapter 34. The Vertebrates:** The section introducing the vertebrates has been simplified. The material on the chondrchthyans has been completely re-organized. New photographs have been used to illustrate reptile diversity.

Flowering Plants Unit

- **Chapter 38. Flowering Plants: Transport:** The Feature Investigation has been replaced. The new Feature Investigation discusses new ways to genetically modify crop plants for enhanced drought resistance. The Genomes & Proteomes feature was also replaced. The new Genomes & Proteomes feature explores the evolutionary history of plant resistance to drought. Both of these are related to the increasing need to feed populations living in arid lands and the need to cope with climate change.

Animal Unit

- **Chapter 40. Animal Bodies and Homeostasis:** A new confocal micrograph showing the complexity of nervous tissue has been added, and other figures have been modified for additional clarity. Several assessments have been added that require making predictions and analyzing data, including a new BioConnections question. A new BioTIPS feature related to body temperature homeostasis has been added.
- **Chapter 41. Neuroscience I: Cells of the Nervous System:** The material on resting membrane potential and action potentials has been subdivided into seven shorter sections to allow this challenging material to be more easily assimilated by beginning students. Several new assessments, BioConnections, and SciSKILLS have been added that require critical thinking and the ability to make predictions and perform calculations. A new figure illustrates the structural features of nerves. A new BioTIPS feature related to the ionic basis of action potentials has been added.
- **Chapter 42. Neuroscience II: Evolution, Structure, and Function of the Nervous System:** Several figures have been revised for clarity and new detail, particularly that of the structures of the human brain. Test questions have been updated to include higher Bloom's level questions. The description of the evolution of the brain has been updated, as have the discussions of the formation of memories and the effects of training on brain plasticity. The discussion of the anatomy of the vertebrate central nervous system has been reorganized and broken into smaller segments for greater clarity and manageability. A new BioTIPS feature related to the anatomical features of the vertebrate brain has been added.
- **Chapter 43. Neuroscience III: Sensory Systems:** The chapter has been reorganized by the addition of numerous subheadings to help break up complex areas of text into more manageable portions for the reader. Ten figures have been revised and updated with additional labeling and text boxes to help the reader navigate through complex topics. Many of the test questions at the end of the chapter have been revised, updated, and, where appropriate, changed to a higher Bloom's level. The chapter has been tightened to focus the reader on fundamental features of sensory biology. A new BioTIPS feature asks students to make conclusions about the relation between structure and function in different organs.
- **Chapter 44. Muscular-Skeletal Systems and Locomotion:** The chapter has been reorganized to include more subheadings and bulleted lists to assist the reader in navigating through complex material, particularly the material on the sarcomere and its bands, and material on the cross bridge cycle. Numerous figures have been revised for clarity and improved labeling and visibility. A new discussion and figure relating to myostatin have been added. Many of the test questions at the end of the chapter have been updated or revised including the addition of higher level Bloom's questions. A new BioTIPS feature asks students to make calculations and interpret graphical data related to the metabolic cost of flying.
- **Chapter 45. Nutrition and Animal Digestive Systems:** The chapter has been consolidated and shortened to focus less on feeding behavior and more on the processes of digestion and absorption. The chapter has been reorganized with eleven new subheadings for easier navigation through complex material. A new figure illustrating protein digestion and absorption in the small intestine has been added, and several figures have been improved with additional labeling and text. A new Feature Investigation (Marshall and Warren's investigation of the relation of *H. pylori* to stomach ulcers) has been added. Test questions at the end of the chapter and in the Feature Investigation have been modified to include higher order Bloom's questions. A new BioTIPS feature asks students to predict the benefits of segregated function in the alimentary canal.
- **Chapter 46. Control of Energy Balance, Metabolic Rate, and Body Temperature:** Numerous figures and test questions have been modified and updated, and the text has been reorganized to include several new subheadings. The chapter has been shortened to better focus on key, fundamental features of energy balance and thermal regulation. A new BioTIPS feature has been added that asks students to propose an hypothesis regarding the experimental effects of the hormone leptin on body mass in mice.
- **Chapter 47. Circulatory Systems:** The chapter has been shortened and consolidated to better focus on the similarities and differences between open and closed circulations, and single and double circulations. The events of the ECG have been reorganized into a bulleted list for emphasis and clarity. The table describing comparative features of mammalian hearts has been expanded. Numerous new subheadings have been added, as have several new test questions and Concept Checks. A new BioTIPS feature has been added that requires students to describe the sequence of steps in the vertebrate heart cycle.
- **Chapter 48. Respiratory Systems:** Several new subheadings have been added, as have numerous new or revised test questions, Concept Checks, BioConnections, and collaborative ques-

tions. A new figure illustrating asthma and bronchoconstriction has been added. A new Feature Investigation describing the effectiveness of surfactant in human newborns has been added. A new photomicrograph of an emphysematous lung has been added. A new BioTIPS feature has been added that requires students to make a graph and make calculations regarding the relation between altitude and oxygen pressure.

- **Chapter 49. Excretory Systems and the Homeostasis of Internal Fluids:** The title has been changed to reflect the important role of excretory systems in homeostasis. The concept of osmolarity is now introduced very early in the text, to lay the groundwork for later discussions in the chapter. Numerous bulleted lists (for example, in the discussion about individual parts of a nephron) and subheadings have been added to break up complex material and provide a useful study guide. Many of the test questions have been updated or revised, including BioConnection questions and Feature Investigation questions, in some cases where appropriate at higher Bloom's levels. A new BioTIPS feature has been added that requires students to relate the structure of a nephron to its function.
- **Chapter 50. Endocrine Systems:** Eleven figures have been revised with improved labeling and text box detail where appropriate, to better help the student work through illustrations of complex processes. Numerous subheadings and revised test questions, including Feature Investigation questions, have been added. The introductory material on the chemical nature and mechanisms of actions of hormones has been consolidated and tightened to focus on major concepts. The material on endocrine disruptors has been updated. A new BioTIPS feature has been added that requires students to predict the outcome of a scenario in which Ca^{2+} homeostasis may be compromised.
- **Chapter 51. Animal Reproduction:** New conceptual, collaborative, and multiple choice questions have been added to the end of the chapter. Several new subheadings and six revised figures have been added. A new BioTIPS feature has been added that requires students to predict what might happen in a person who takes supplements of the androgen testosterone.
- **Chapter 52. Animal Development:** New BioConnection questions, Concept Checks, and multiple choice questions have been added. The figures on fertilization, cleavage, and neurulation have been revised. The section on morphogenesis and control of development has been shortened, consolidated and reorganized to reduce redundancy and improve clarity. A new BioTIPS feature has been added that asks students to place various events in their correct stage of development.
- **Chapter 53. Immune Systems:** Eleven figures have been revised and updated (such as the latest figures on people living with HIV worldwide). New subheadings have been added to shorten complex regions of text (for example, the discussion of the production and recirculation of lymphocytes). Several new collaborative questions and Concept Checks have been added. A new figure of a micrograph of a mast cell has been added. The discussion of the different cell types of the immune system now includes a bulleted list as a visual aid to the reader and a handy study reference. A new BioTIPS feature has been added that requires students to make a prediction about immune responses in the absence of memory cells.

Ecology Unit

- **Chapter 54. An Introduction to Ecology and Biomes:** Section 54.2, Ecological Methods, has been completely rewritten. Instead of using a hypothetical example of locust ecology, we have instead used a real life example of oak winter moth ecology. We discuss how knowledge of the oak winter moth life cycle was vital in addressing control of this important apple orchard pest in the U.S. northwest and western Canada. Several new figures have been prepared to help in illustrating main points of this section. In Section 54.3, The Environment's Effect on the Distribution of Organisms, we have provided a new example of the effects of cold temperatures on organismal distribution by including a figure on how the frequency of the cyanide-producing form of white clover in Europe is affected by temperature. In the section on Global Warming, data on selected greenhouse gases have been updated in Table 54.2. Many new photographs have been included in Section 54.5 on major biomes. Finally, in Section 54.6, Continental Drift and Biogeography, we have included a new figure on the distribution of fossil land plants and animals to illustrate the concept of continental drift.
- **Chapter 55. Behavioral Ecology:** In Section 55.3, Foraging Behavior, we have illustrated the concept of optimal foraging by including new information, and a new figure, on optimal foraging by leafcutter ants, and the disruption of this foraging by parasitic flies. We have also simplified the chapter by eliminating the section on sexual selection and mate choice, which is already covered in Chapter 24.
- **Chapter 56. Ecology:** The section on Quantifying Population Density has been divided into more easily digestible parts by the use of subheadings. The section of Human Population Growth has been updated.
- **Chapter 57. Species Interactions:** The section on Predation, Herbivory, and Parasitism has been substantially rewritten and simplified. The example of cactus control by the cactus moth, *Cactoblastis cactorum*, has been added to this section. Section 57.4, on bottom-up and top-down control, has been simplified and a new figure on the nitrogen content of plants and animals has been added. In addition, a new figure illustrates the trophic interactions that can result from the effects of wolf addition, using data from Banff National Park, Canada.
- **Chapter 58. Community Ecology:** In Section 58.3, Calculating Species Diversity, we introduce the new concept of effective number of species and provide details of how to calculate it. This measure of species diversity permits easy and meaningful comparisons between different communities.
- **Chapter 59. Ecosystem Ecology:** The distinction between decomposers and detritivores has been made clearer throughout the chapter. Figure 59.19, which concerns the increase in atmosphere CO_2 levels and temperatures due to the burning of fossil fuels, has been updated.
- **Chapter 60. Biodiversity and Conservation Biology:** Section 60.2, Why Conserve Biodiversity, has been updated. Tables 60.1 and 60.2, which provide data on examples of the world's ecosystem services and the valuation of those services, have been completely rewritten and modernized using the latest data. We have also added an additional question to the Feature Investigation.

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. Rebecca Olson and following her, Justin Wyatt, Brand Managers (Major Biology) did outstanding jobs overseeing the fourth edition. Their insights with regard to pedagogy, content, and organization have been invaluable. Elizabeth Sievers, Lead Product Developer, has been the master organizer. Liz's success at keeping us on schedule is greatly appreciated. We would also like to acknowledge our copy editor, Jane Hoover, 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 Jayne Klein, Content Project Manager; and David Hash, Senior Designer at McGraw-Hill. Likewise, our production company, Lachina Publishing Services, did an excellent job with the paging, revision of existing art, and the creation of new art for the fourth edition. 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. Special thanks to Patrick Reidy, Executive Marketing Manager-Life Sciences, for his 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, Senior Vice President, Products & Markets, and Marty Lange, Vice President, General Manager, Products & Markets, and Michael Hackett, Director for Life Sciences.

EMPHASIZING PROBLEM-SOLVING AND SKILLS DEVELOPMENT

Skills Development

At the beginning of each section, **Learning Outcomes** inform students of concepts they should understand and new to the fourth edition are skills-based Learning Outcomes. Labeled as **SciSKILLS**, these Learning Outcomes are specific to the skills students will acquire when mastering the material and provide a specific understanding of how such skills may be assessed. SciSKILLS is a mental action such as analyze data, form hypotheses, make predictions, or perform calculations. These are skills scientists generally perform and students should practice.

The emphasis on skills development continues in the ***Feature Investigations***. Feature Investigations provide a complete description of experiments, including data analysis, so students can understand how experimentation leads to an understanding of biological concepts.

104 CHAPTER 5

5.2 Fluidity of Membranes

Learning Outcomes:
1. Describe the fluidity of membranes.
2. SciSKILLS » Predict how changes in lipid composition affect membrane fluidity.
3. SciSKILLS » Analyze the results of experiments that showed the lateral diffusion of membrane proteins.

Membranes Are Semifluid

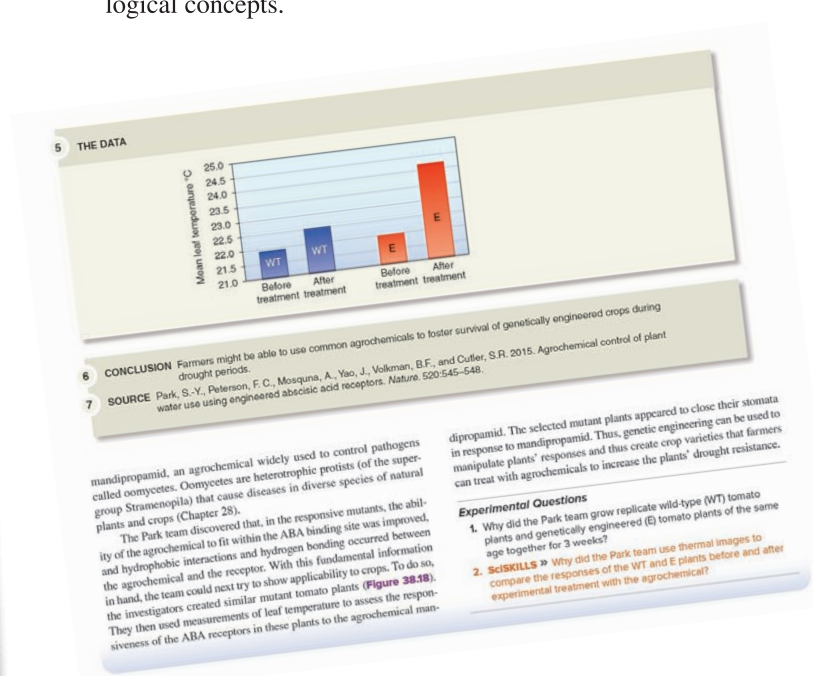
Lipid Composition Affects Membrane Fluidity

The biochemical properties of phospholipids affect the fluidity of the phospholipid bilayer.

Length of Phospholipid Tails One key factor that affects membrane fluidity is the length of the lipid tails, which range from 14

Figure 5.4 Semifluidity of the lipid bilayer. (a) Spontaneous movements in the bilayer. Lipids can rotate (that is, move 360°) and move laterally (for example, from left to right in the plane of the bilayer). (b) Flip-flop does not happen spontaneously, because the polar head group would have to pass through the hydrophobic region of the bilayer. Instead, the enzyme flippase uses ATP to flip phospholipids from one leaflet to the other.

Concept Check: In an animal cell, how can changes in lipid composition affect membrane fluidity?



5 THE DATA

6 CONCLUSION Farmers might be able to use common agrochemicals to foster survival of genetically engineered crops during drought periods.

7 SOURCE Park, S.-Y., Peterson, F. C., Mosquna, A., Yao, J., Volkman, B.F., and Cutler, S.R. 2015. Agrochemical control of plant water use using engineered abscisic acid receptors. *Nature*. 520:545–548.

mandipropamid, an agrochemical widely used to control pathogens called oomycetes. Oomycetes are heterotrophic protists (of the supergroup Stramenopila) that cause diseases in diverse species of natural plants and crops (Chapter 28).

The Park team discovered that, in the responsive mutants, the ability of the agrochemical to fit within the ABA binding site was improved, and hydrophobic interactions and hydrogen bonding occurred between the agrochemical and the receptor. With this fundamental information in hand, the team could next try to show applicability to crops. To do so, the investigators created similar mutant tomato plants (Figure 38.18). They then used measurements of leaf temperature to assess the responsiveness of the ABA receptors in these plants to the agrochemical mandipropamid. The selected mutant plants appeared to close their stomata in response to mandipropamid. Thus, genetic engineering can be used to manipulate plants' responses and thus create crop varieties that farmers can treat with agrochemicals to increase the plants' drought resistance.

Experimental Questions

1. Why did the Park team grow replicate wild-type (WT) tomato plants and genetically engineered (E) tomato plants of the same age together for 3 weeks?
2. SciSKILLS » Why did the Park team use thermal images to compare the responses of the WT and E plants before and after experimental treatment with the agrochemical?

Problem Solving

A new feature added to *Biology*, 4th edition, will help students develop their problem solving skills. Chapters 2 through 60 contain solved problems called **BioTIPS**, which stands for **T**opic, **I**nformation, and **P**roblem Solving **S**trategy. These solved problems follow a consistent pattern in which students are given advice on how to solve problems in biology using different types of problem solving strategies. These strategies include: Make a drawing; Compare and contrast; Relate structure and function; Sort out the steps in a complicated process; Propose a hypothesis; Design an experiment; Predict the outcome; Interpret data; Use statistics; Make a calculation; and Search the literature.


BIO TIPS **THE QUESTION** *The data in step 5 of Figure 38.18 reveal that genetically engineered (E) tomato plants showed a higher level of response to application of an agrochemical than did wild-type (WT) plants. Did the WT plants also show a response to the experimental treatment, and if so, why might this response have occurred?*

TOPIC ***What topic in biology does this question address?*** The topic is leaf stomatal responses of angiosperms to drought stress. More specifically, the question concerns how fundamental biochemical knowledge regarding leaf stomatal responses can be applied to improve crop productivity.

INFORMATION ***What information do you know based on the question and your understanding of the topic?*** From this chapter and Chapter 35, you know that stomata are pores that occur on plant surfaces, particularly the undersides of leaves. Stomata in angiosperms open and close in response to changes in the water content of guard cells, and the formation of a pore is determined by differences in the thickness of guard-cell walls as well as the orientation of microtubules (shown in Figure 38.16). From this chapter and Chapter 36, you also know that roots under water stress produce the plant hormone ABA, which is transported via the xylem to shoots, providing an early warning of impending water stress (water deficit). Figure 38.17 illustrates the role of ABA receptor proteins that occur in stomatal guard-cell membranes; when such receptors bind ABA, they stimulate changes in the movement of solutes and the consequent movement of water, due to osmosis. In this way, seed plants use ABA to induce stomatal closure, thereby reducing water loss by transpiration. These observations reveal the key role of ABA in seed plants' responses to water stress. The Park team knew that ABA binds to a specific receptor protein, and they decided to explore whether genetic engineering could be used to improve

A biological question related to chapter content is posed. The BioTIPS then walks the student through the process of answering the question. First helping the student identify the topic of the question—what is really being asked in the question? Then helping the student collect information that was presented in the chapter that is related to the question. Finally helping the student settle on one or more strategies that can be followed to answer the question. The answers are provided to complete the problem solving process.

The emphasis on developing problem solving skills is carried over to the digital content, as described later.

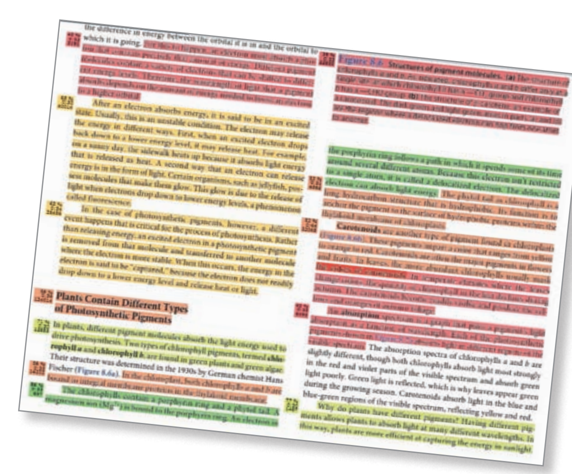
USING STUDENT USAGE DATA TO MAKE IMPROVEMENTS

To help guide the revision for the fourth edition, student usage data and input were used, derived from thousands of SmartBook® users of the 3rd edition. SmartBook "heat maps" provided a quick visual snapshot of chapter usage data and the relative difficulty students experienced in mastering the content. These data directed the authors to evaluate text content that was particularly challenging for students. These same data were also used to revise the SmartBook probes.

· If the data indicated that the subject was more difficult than other parts of the chapter, as evidenced by a high proportion of students responding incorrectly to the probes, the authors revised or reorganized the content to be as clear and illustrative as possible by rewriting the section, providing additional examples or revised figures to assist visual learners, etc.

· In other cases, one or more of the SmartBook probes for a section was not as clear as it might be or did not appropriately reflect the content in the chapter. In these cases the *probe*, rather than the text, was edited.

Below is an example of one of the heat maps from Chapter 8. The color-coding of highlighted sections indicates the various levels of difficulty students experienced in learning the material, topics highlighted in red being the most challenging for students.



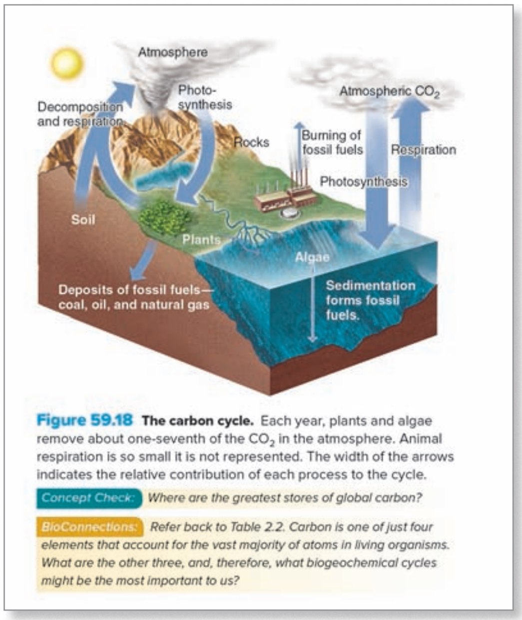


Figure 59.18 **The carbon cycle.** Each year, plants and algae remove about one-seventh of the CO_2 in the atmosphere. Animal respiration is so small it is not represented. The width of the arrows indicates the relative contribution of each process to the cycle.

Concept Check: *Where are the greatest stores of global carbon?*

BioConnections: *Refer back to Table 2.2. Carbon is one of just four elements that account for the vast majority of atoms in living organisms. What are the other three, and, therefore, what biogeochemical cycles might be the most important to us?*

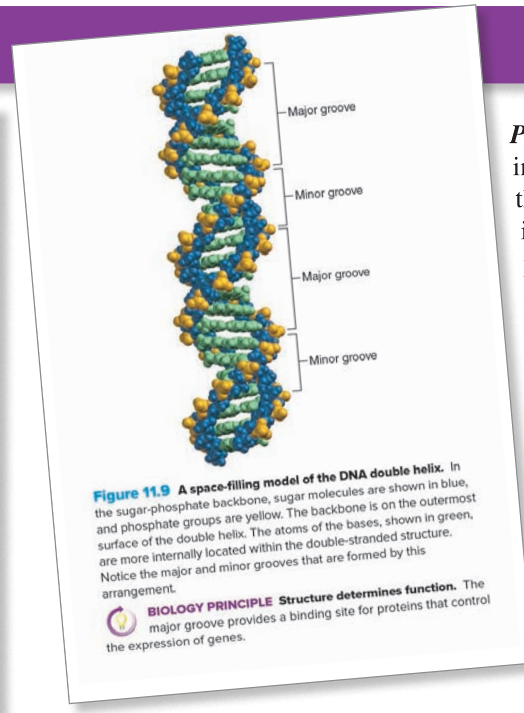


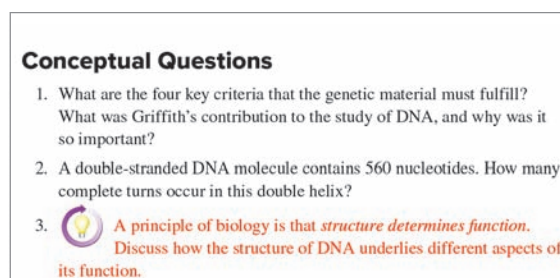
Figure 11.9 **A space-filling model of the DNA double helix.** In the sugar-phosphate backbone, sugar molecules are shown in blue, and phosphate groups are yellow. The backbone is on the outermost surface of the double helix. The atoms of the bases, shown in green, are more internally located within the double-stranded structure. Notice the major and minor grooves that are formed by this arrangement.

BIOLOGY PRINCIPLE **Structure determines function.** The major groove provides a binding site for proteins that control the expression of genes.

Principles of Biology are introduced in Chapter 1 and are then threaded throughout the entire textbook. This is achieved in two ways. First, the principles are explicitly stated in selected figure legends for figures in which the specific principle is illustrated. The legends that relate to a Principle of Biology are highlighted with an icon.

In addition, a Conceptual Question at the end of each chapter is directly aimed at exploring a particular principle related to the content of the chapter.

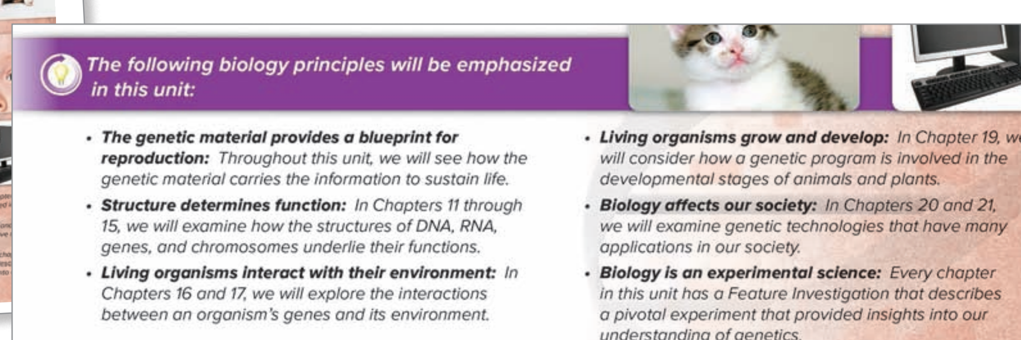
BioConnections BioConnections are questions found in selected figure legends in each chapter that help students make connections between biological concepts. BioConnections help students understand that their study of biology involves linking concepts together and building on previously learned information. Answers to the BioConnections are found in Appendix B.



Conceptual Questions

1. What are the four key criteria that the genetic material must fulfill? What was Griffith's contribution to the study of DNA, and why was it so important?
2. A double-stranded DNA molecule contains 560 nucleotides. How many complete turns occur in this double helix?
3. A principle of biology is that *structure determines function*. Discuss how the structure of DNA underlies different aspects of its function.

Unit openers serve two purposes. They allow the student to see the big picture of the unit. In addition, the unit openers draw attention to the principles of biology that will be emphasized in that unit.



The following biology principles will be emphasized in this unit:

- ***The genetic material provides a blueprint for reproduction:*** *Throughout this unit, we will see how the genetic material carries the information to sustain life.*
- ***Structure determines function:*** *In Chapters 11 through 15, we will examine how the structures of DNA, RNA, genes, and chromosomes underlie their functions.*
- ***Living organisms interact with their environment:*** *In Chapters 16 and 17, we will explore the interactions between an organism's genes and its environment.*
- ***Living organisms grow and develop:*** *In Chapter 19, we will consider how a genetic program is involved in the developmental stages of animals and plants.*
- ***Biology affects our society:*** *In Chapters 20 and 21, we will examine genetic technologies that have many applications in our society.*
- ***Biology is an experimental science:*** *Every chapter in this unit has a Feature Investigation that describes a pivotal experiment that provided insights into our understanding of genetics.*

Strengthen Problem Solving Skills and Key Concept Development with Connect®

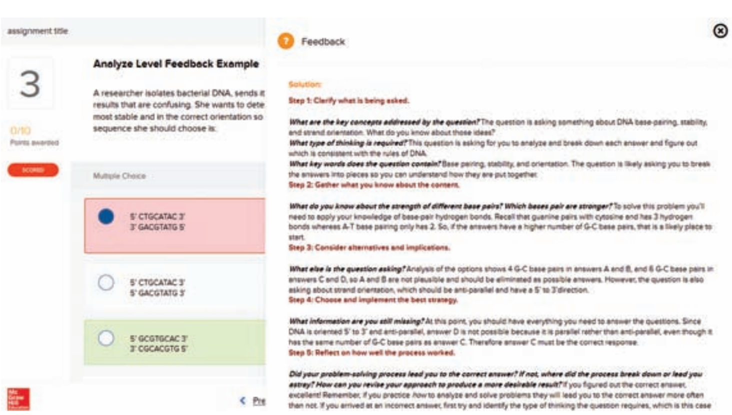
Problem Solving Skills

Detailed Feedback in Connect®

Learning is a process of iterative development, of making mistakes, reflecting, and adjusting over time. The question and test banks in Connect® for *Biology*, 4th edition, are more than direct assessments; they are self-contained learning experiences that systematically build student learning over time.

For many students, choosing the right answer is not necessarily based on applying content correctly; it is more a matter of increasing their statistical odds of guessing. A major fault with this approach is students don't learn how to process the questions correctly, mostly because they are repeating and reinforcing their mistakes rather than reflecting and learning from them. To help students develop problem solving skills, all higher level Blooms questions in Connect are supported with hints, to help students focus on important information for answering the questions, and detailed feedback that walks students through the problem solving process, using Socratic questions in a decision tree-style framework to scaffold learning, where each step models and reinforces the learning process.

The feedback for each higher level Blooms question (Apply, Analyze, Evaluate) follows a similar process: Clarify Question, Gather Content, Consider Possibilities, Choose Answer, Reflect on Process.



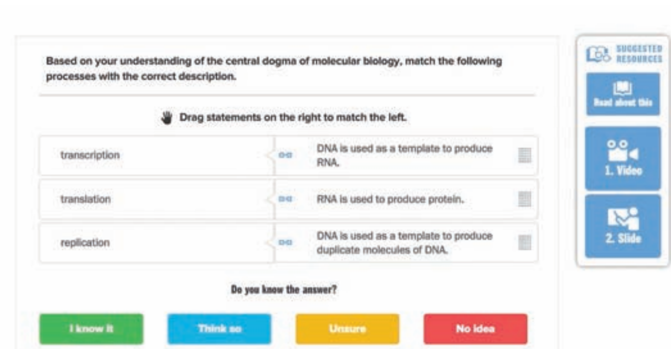
Unpacking the Concepts

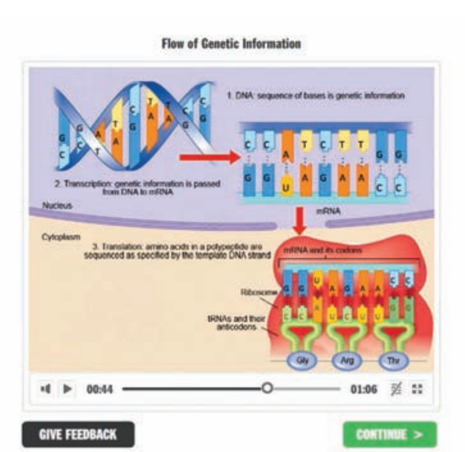
We've taken problem solving a step further. In each chapter, 3 to 5 higher level Blooms questions in the question and test banks are broken out by the steps in detailed feedback. Rather than leaving it up to the student to work through the detailed feedback, a second version of the question is presented in a stepwise format. Following the problem solving steps, students need to answer questions about earlier steps, such as "What is the key concept addressed by the question?" before proceeding to answer the question. A professor can choose which version of the question to include in the assignment based on the problem solving skills of the students.

Key Concept Development

SmartBook with Learning Resources

To help students understand key concepts, SmartBook® for *Biology*, 4th edition, is enhanced with Learning Resources. Based on student usage data, derived from thousands of SmartBook users of the third edition, concepts that proved more challenging for students are supported with Learning Resources to enhance the textbook presentation. Learning Resources, such as animations and tutorials, are indicated in Smartbook adjacent to the textbook content. If a student is struggling with a concept based on his/her performance of the SmartBook questions, the student is given an option to review the Learning Resource or the student can click on the Learning Resources at any time.





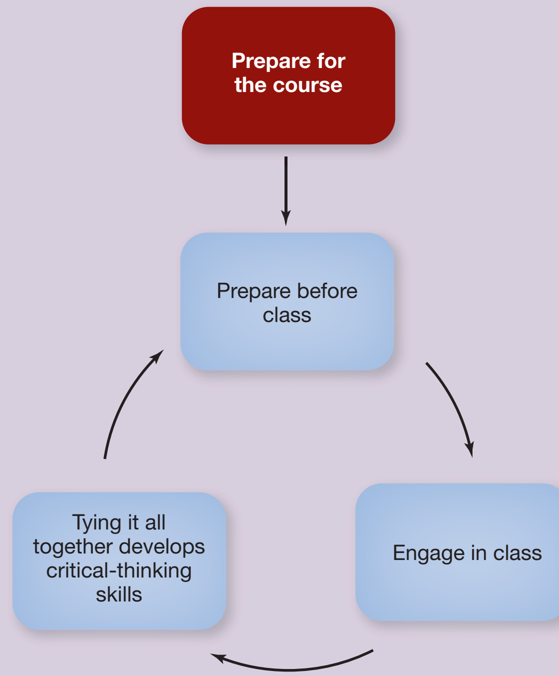
USING CONNECT AND *BIOLOGY*, 4TH EDITION

Biology, 4th edition, and its online assets have been carefully crafted to help professors and students, work efficiently and effectively through the material in the course, making the most of instructional and study time.

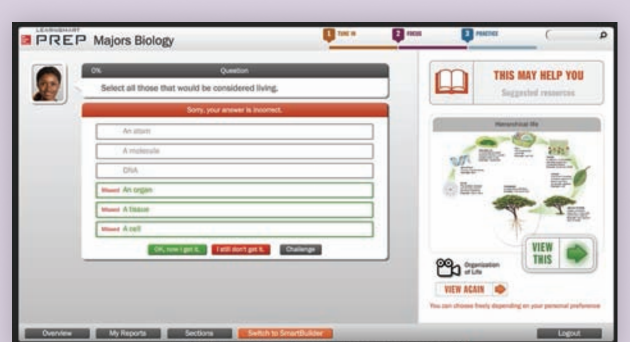
PREPARE FOR THE COURSE

Many biology students struggle the first few weeks of class. Many institutions expect students to start majors biology having a working knowledge of basic chemistry and cellular biology. *LearnSmart Prep* is now available in Connect. Professors can assign modules in LearnSmart Prep to help students get up to speed on core concepts or students can access LearnSmart Prep directly through the LearnSmart Prep link.

LearnSmart Prep is an adaptive learning tool designed to increase student success and aid retention through the first few weeks of class. Using this digital tool, Majors Biology students can master some of the most fundamental and challenging principles of biology before they begin to struggle in the first few weeks of class



1 A diagnostic establishes your baseline comprehension and knowledge; then the program generates a learning plan tailored to your academic needs and schedule.



2 As you work through the learning plan, the program asks you questions and tracks your mastery of concepts. If you answer questions about a particular concept incorrectly, the program will provide a learning resource (ex. animation or tutorial) on that concept, then ensure that you understand the concept by asking you more questions. Didn't get it the first time? Don't worry—*LearnSmart Prep* will keep working with you!

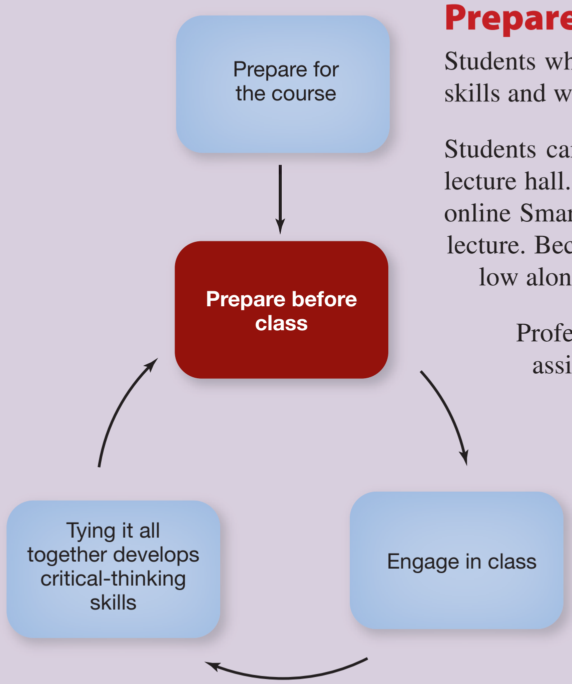
3 Using *LearnSmart Prep*, you can identify the content you don't understand, focus your time on content you need to know but don't, and therefore improve your chances of success in your majors biology course.

Prepare Before Class

Students who are most successful in college are those who have developed effective study skills and who use those skills, before, during, and after class.

Students can maximize time in class by previewing the material before stepping into the lecture hall. *Biology,* 4th edition, is available in two formats: the printed text as well as the online SmartBook. Students can use either of these options to preview the material before lecture. Becoming familiar with terminology and basic concepts will allow students to follow along in class and engage in the content in a way that allows for better retention.

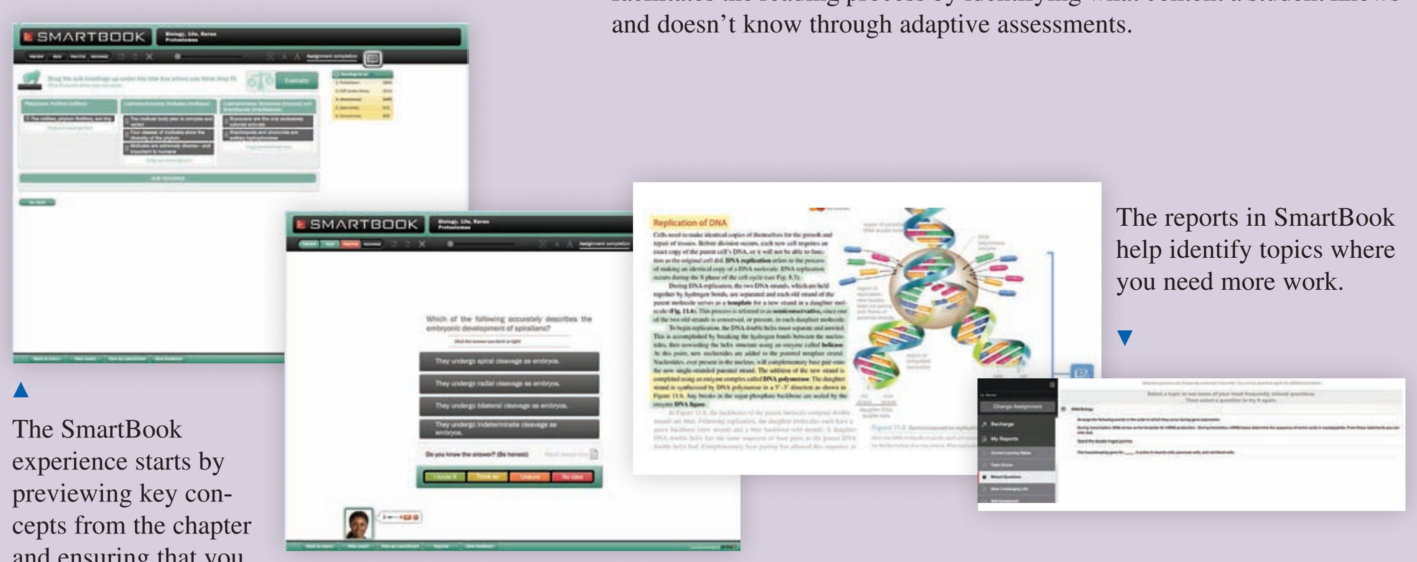
Professors can help students prepare for class by making assignments—SmartBook assignments are effective for introducing terminology and general concepts.



SmartBook provides a personalized, adaptive reading experience.

SMARTBOOK®

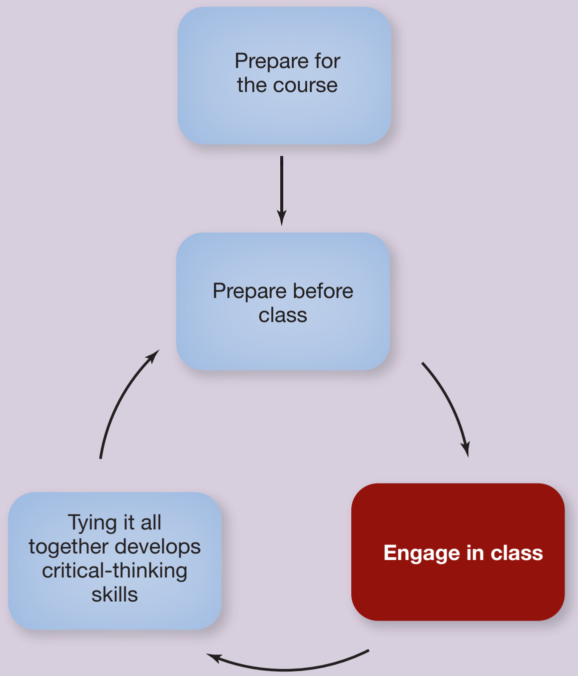
Powered by an intelligent diagnostic and adaptive engine, SmartBook facilitates the reading process by identifying what content a student knows and doesn't know through adaptive assessments.



The SmartBook experience starts by previewing key concepts from the chapter and ensuring that you understand the big ideas.

SmartBook asks you questions that identify gaps in your knowledge. The reading experience then continuously adapts in response to the assessments—highlighting the material you need to review based on what you don't know.

The reports in SmartBook help identify topics where you need more work.



Engage in Class

McGraw-Hill Connect provides online presentation, assignment, and assessment solutions. It connects students with the tools and resources they'll need to achieve success. A robust set of questions and activities is presented in the Question Bank and a separate set of questions to use for exams are presented in the Test Bank. Instructors can edit existing questions and author entirely new problems. Track individual student performance—by question, assignment, or in relation to the class overall—with detailed grade reports.

1 Pre-class assignments to help students engage in the content during class.

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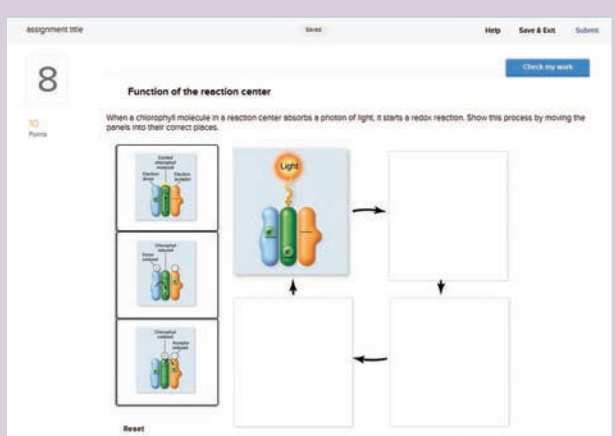
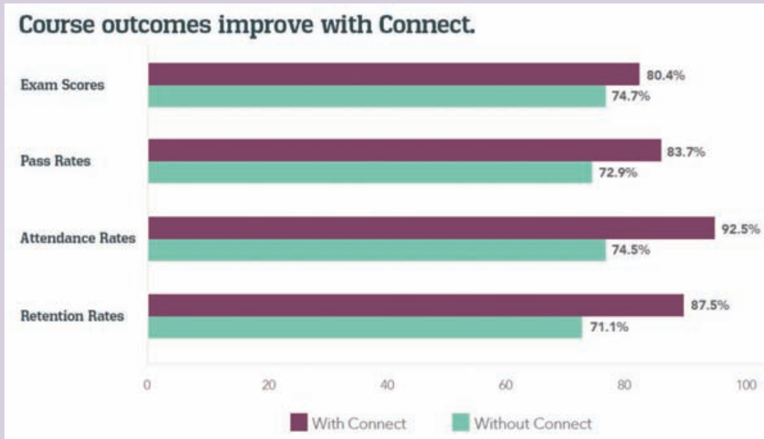
Assignments are accessed through Connect and could include homework assignments, quizzes, SmartBook assignments, and other resources. ▶



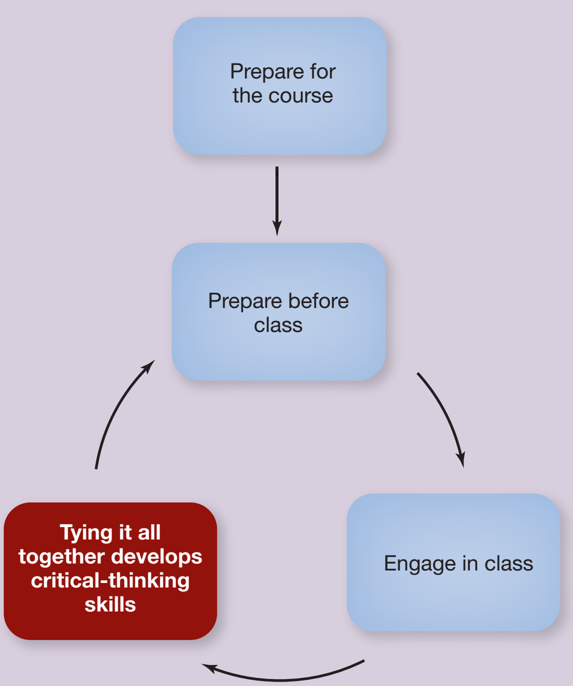
◀ Interactive and traditional questions help assess your knowledge of the material.

2 Connect Insight is Connect's visual analytics dashboard for instructors and students.



◀ Provides at-a-glance student performance on assignments. Instructors can use the information for a just-in-time approach to teaching.

◀ Connect Insight presents data that empowers students to improve performance that is efficient and effective.



Tying It All Together

Follow up class with assessment that helps students develop problem solving skills. Set up assignments from the various assessment banks in Connect.

The Question and Test Banks contain higher order critical thinking questions that require students to demonstrate a more in-depth understanding of the concepts—instructors can quickly and easily filter the banks for these questions using higher level Blooms tags.

◀ **Detailed Feedback** All higher level Blooms questions, that involve problem solving, contain detailed feedback in Connect. The feedback walks students through the steps of the problem solving process and helps them evaluate their scientific thinking skills.

Many chapters also contain a **Quantitative Question Bank.** These are more challenging algorithmic questions, intended to help your students practice their quantitative reasoning skills. Hints and guided solution options step students through a problem. ▶

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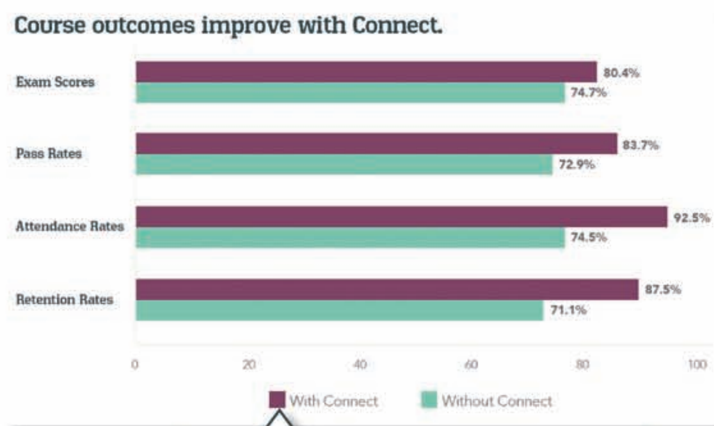

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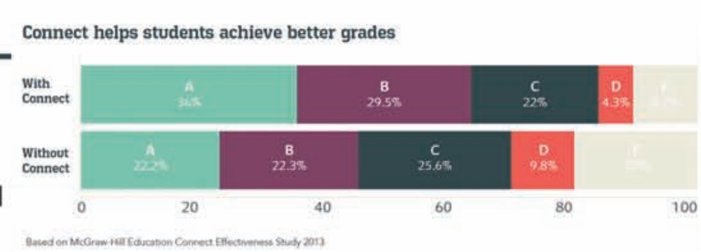
Analytics



Connect Insight®

Connect Insight is Connect's new one-of-a-kind visual analytics dashboard—now available for both instructors and students—that provides at-a-glance information regarding student performance, which is immediately actionable. By presenting assignment, assessment, and topical performance results together with a time metric that is easily visible for aggregate or individual results, Connect Insight gives the user the ability to take a just-in-time approach to teaching and learning, which was never before available. Connect Insight presents data that empowers students and helps instructors improve class performance in a way that is efficient and effective.

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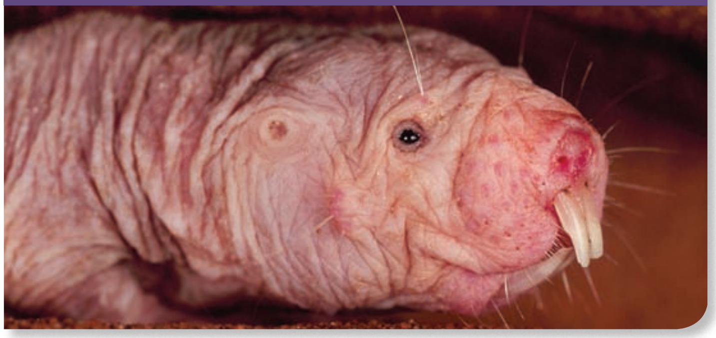

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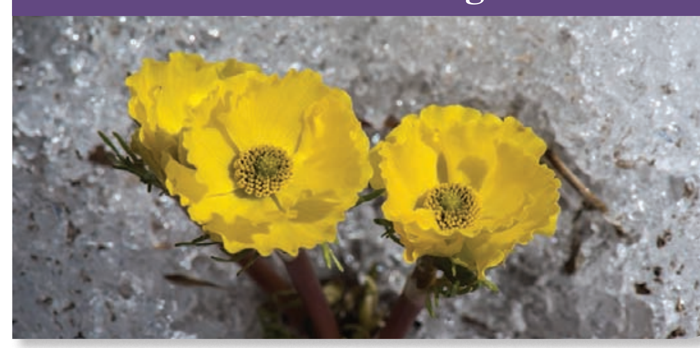

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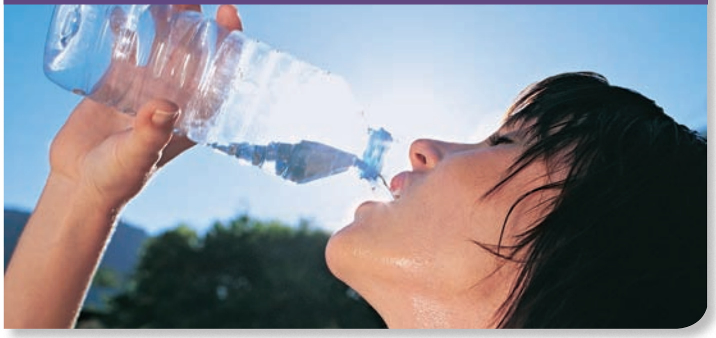

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1 An Introduction to Biology

CHAPTER OUTLINE

Gypsy moth (*Lymantria dispar*). The gypsy moth progresses through different stages, including a caterpillar, to become an adult moth. As discussed later in this chapter, the caterpillar can be infected with a virus, which alters its behavior into that of a "zombie."

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 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, scientists developed drugs to treat high blood pressure (**Figure 1.1**).

Biologists have discovered that plants can communicate with each other. For example, the beautiful umbrella thorn acacia (*Vachellia tortillis*), shown in **Figure 1.2**, emits volatile organic molecules when it is attacked by herbivores. These molecules warn other nearby acacia trees that herbivores are in the area, and those trees release toxins to protect themselves.

In the 20th 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**).

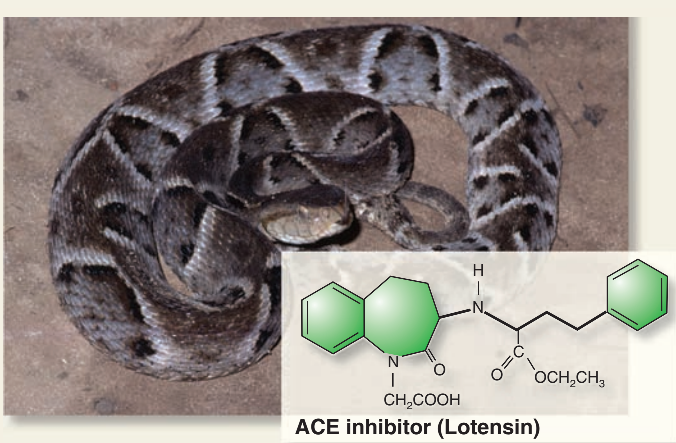


Figure 1.1 The Brazilian arrowhead viper and inhibitors of high blood pressure. Derivatives of a chemical, called an angiotensin-converting enzyme (ACE) inhibitor, are found in the venom of the Brazilian arrowhead viper and are commonly used to treat high blood pressure.

Figure 1.2 Plant communication. If attacked by herbivores, this acacia tree will emit molecules that will warn other acacia trees in the area.

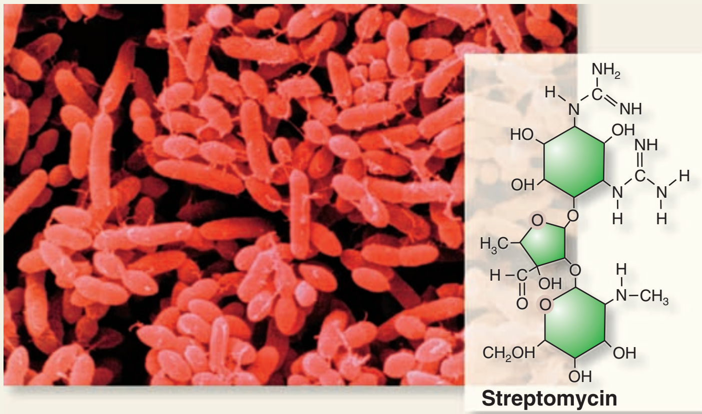


Figure 1.3 **The soil bacterium *Streptomyces griseus*, which naturally produces the antibiotic streptomycin, kills competing bacteria in the soil.** Doctors administer streptomycin to treat bacterial infections.

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 medicines 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?

Future biologists will continue to make important advances. Biologists are scientific explorers looking for answers to some of life'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 trying to preserve the environment and protect 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 principles that underlie the characteristics of all living organisms and the fields of biology. We will then take a deeper look at the process of evolution and how it has led to the development of genomes—the entire genetic compositions of living organisms—which explains the unity and diversity that we observe among living species. Finally, we will explore the general approaches that scientists follow when making new discoveries.

1.1 Principles of Biology and the Levels of Biological Organization

Learning Outcomes:

1. Describe the principles of biology.
2. Explain how life can be viewed at different levels of biological complexity.

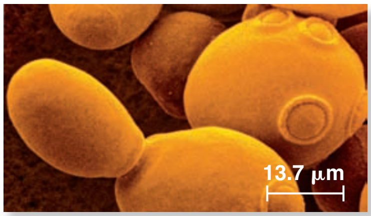
Because biology is the study of life, a good way to begin a biology textbook is to distinguish living organisms from nonliving objects. At first, the distinction might seem obvious. A person is alive, but a rock is not. However, the distinction between living and nonliving may seem less obvious when we consider microscopic entities. Is a bacterium alive? What about a virus or a chromosome? In this section, we will examine the principles that underlie the characteristics of all forms of life and explore other broad principles in biology. We will then consider the levels of organization that biologists study, ranging from atoms and small molecules to very large geographical areas.

The Study of Life Has Revealed a Set of Unifying Principles

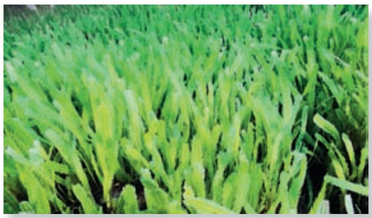
Biologists have studied many different species and learned that a set of principles applies to all fields of biology. Twelve broad principles are described in **Figure 1.4**. The first eight principles are often used as criteria to define the basic features of life. You will see these twelve principles at many points as you progress through this textbook, and they are indicated with the icon. In particular, we will draw your attention to them at the beginning of each unit, and we will refer to them within particular figures in Chapters 3 through 60. It should be noted that the principles of biology are also governed by the laws of chemistry and physics, which are discussed in Chapters 2, 3, and 6.

Principle 1: Cells are the simplest units of life. The term **organism** can be applied to all living things. Organisms maintain an internal order that is separated from the environment (Figure 1.4a). The simplest unit of such organization is the **cell**, which we will examine in Unit II. One of the foundations of biology is the **cell theory**, which states that (1) all organisms are composed of cells, (2) cells are the smallest units of life, and (3) new 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 an internal order, and the cells within the organism have specific arrangements and functions.

Principle 2: Living organisms use energy. The maintenance of organization requires energy. Therefore, all living organisms acquire 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



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



(b) Living organisms use energy: 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) Living organisms interact with their environment: Organisms respond to environmental changes. These plants are growing toward the light.

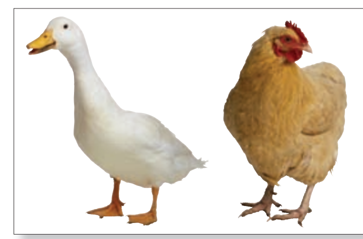
(d) Living organisms maintain homeostasis: Organisms regulate their cells and bodies, maintaining relatively stable internal conditions, a process called homeostasis. For example, this bird maintains its internal body temperature on a cold day.

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

(f) The genetic material provides a blueprint for 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.

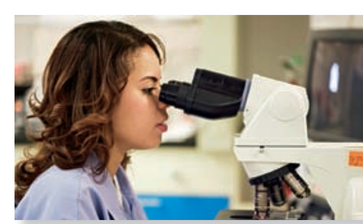
(g) Populations of organisms evolve from one generation to the next: Populations of organisms change over the course of many generations. Evolution results in traits that promote survival and reproductive success.

(h) All species (past and present) are related by an evolutionary history: The three mammal species shown here share a common ancestor, which was also a mammal.



(i) Structure determines function: In the example seen here, webbed feet (on ducks) function as paddles for swimming. Nonwebbed feet (on chickens) function better for walking on the ground.

(j) New properties of life emerge from complex interactions: Our ability to see is an emergent property due to interactions among many types of cells in the eye and neurons that send signals to the brain.



(k) Biology is an experimental science: The discoveries of biology are made via experimentation, which leads to theories and biological principles.

(l) Biology affects our society: Many discoveries in biology have had major effects on our society. For example, biologists developed Bt-corn, which is resistant to insect pests and widely planted by farmers.

Figure 1.4 Twelve principles of biology. The first eight principles are often used as criteria for defining the basic features of life. Note: The twelve principles described here were modeled after the themes and core competencies described in *Vision and Change in Undergraduate Biology*, a report that was published in 2009 and organized by the American Association for the Advancement of Science. *Vision and Change* proposed five themes. We have divided them into ten principles to make them more accessible to beginning biology students. The five *Vision and Change* themes are related to our principles in the following manner: 1. Evolution (principles g and h); 2. Structure and Function (principle i); 3. Information Flow, Exchange, and Storage (principles e and f); 4. Pathways and Transformations of Energy and Matter (principles b, c, and d); 5. Systems (principles a and j). The last two principles are modeled after two core competencies described in *Vision and Change*: Ability to Apply the Process of Science (principle k) and Ability to Understand the Relationship between Science and Society (principle l).

BioConnections: *Look ahead to Figure 52.11. Which of these principles is this figure emphasizing?*

harness light energy to produce their own nutrients in the process of **photosynthesis** (Figure 1.4b). They are the 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.

Principle 3: Living organisms interact with their environment. To survive, living organisms must be able to interact with their environment, which includes other organisms they may encounter. All organisms must respond to environmental changes. In the winter, many species of mammals develop a thicker coat of fur that protects them from the cold temperatures. Plants respond to changes in the angle of the sun. If you place a plant in a window, it will grow toward the light (Figure 1.4c).

Principle 4: Living organisms maintain homeostasis. 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 1.4d), whereas reptiles and amphibians tolerate a wider fluctuation in body temperature. By comparison, all organisms continually regulate their cellular metabolism so nutrient molecules are used at an appropriate rate and new cellular components are synthesized when they are needed.

Principle 5: Living organisms grow and develop. All living organisms grow and develop. **Growth** produces more or larger cells. In plants and animals, a fertilized egg undergoes multiple cell divisions to develop into a mature organism with many cells. Among unicellular organisms such as bacteria, new cells are relatively small, and they increase in volume by the synthesis of additional cellular components. **Development** is a series of changes in the state of a cell, tissue, organ, or organism, eventually resulting in organisms with a defined set of characteristics (Figure 1.4e).

Principle 6: The genetic material provides a blueprint for reproduction. All living organisms have a finite life span. To sustain life, organisms must **reproduce**, or generate offspring (Figure 1.4f). 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. DNA is **heritable**, which means that offspring inherit DNA from their parents.

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.

Principle 7: Populations of organisms evolve from one generation to the next. 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**, or simply **evolution**, which refers to a heritable change in a population of organisms from generation to generation. As a result of evolution, 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 1.4g). Over the course of many generations, the fossil record indicates that the long snout occurred via biological evolution in which modern anteaters evolved from populations of organisms with shorter snouts.

Principle 8: All species (past and present) are related by an evolutionary history. Principle 7 considers evolution as an ongoing process that happens from one generation to the next. Evidence from a variety of sources, including the fossil record and DNA sequences, also indicates that all organisms on Earth share a common ancestry. For example, the three species of mammals shown in Figure 1.4h shared a common ancestor in the past, which was also a mammal. We will discuss evolutionary relationships later in Section 1.2 and more thoroughly in Units IV and V.

As described later in this chapter, biologists often view evolution within the context of genomes and proteomes. The term **genome** refers to the complete genetic composition of an organism or species. Because most genes encode proteins, these genetic changes are often associated with changes in the **proteome**, which is the complete protein composition of a cell or organism. By studying how evolution affects genomes and proteomes, biologists can better understand how the changes that occur during evolution affect the characteristics of species. Because evolution is a core unifying principle in biology, we will draw your attention to it in Chapters 4 through 60 by including a brief topic that we call "Genomes & Proteomes Connection." This topic connects the principle of evolution to the subject matter in each chapter.

Principle 9: Structure determines function. In addition to the preceding eight characteristics of life, biologists have identified other principles that are important in all fields of biology. The principle "structure determines function" pertains to very tiny biological molecules and to very large biological structures. For example, at the microscopic level, a cellular protein called actin naturally assembles into structures that are long filaments. The function of these filaments is to provide support and shape to cells. At the macroscopic level, let's consider the feet of different birds (Figure 1.4i). Aquatic birds have webbed feet that function as paddles for swimming. By comparison, the feet of nonaquatic birds are not webbed and are better adapted for grasping food, perching on branches, and running along the ground. In this case, the structure of a bird's feet, webbed versus nonwebbed, is a critical feature that affects their function.

Principle 10: New properties of life emerge from complex interactions. In biology, when individual components in an organism interact with each other or with the external environment to create novel structures and functions, the resulting characteristics are called **emergent properties**. For example, the human eye is composed of many different types of cells that are organized to sense incoming light and transmit signals to the brain (Figure 1.4j). Our ability to see is an emergent property of this complex arrangement of different cell types. As discussed later in this chapter, biologists use the term **systems biology** to describe the study of how new properties of life arise by complex interactions of its components.

Principle 11: Biology is an experimental science. Biology is an inquiry process. Biologists are curious about the characteristics of living organisms and ask questions about those characteristics. For example, a cell biologist may wonder why a cell produces a specific protein when it is confronted with high temperature. An ecologist may ask herself why

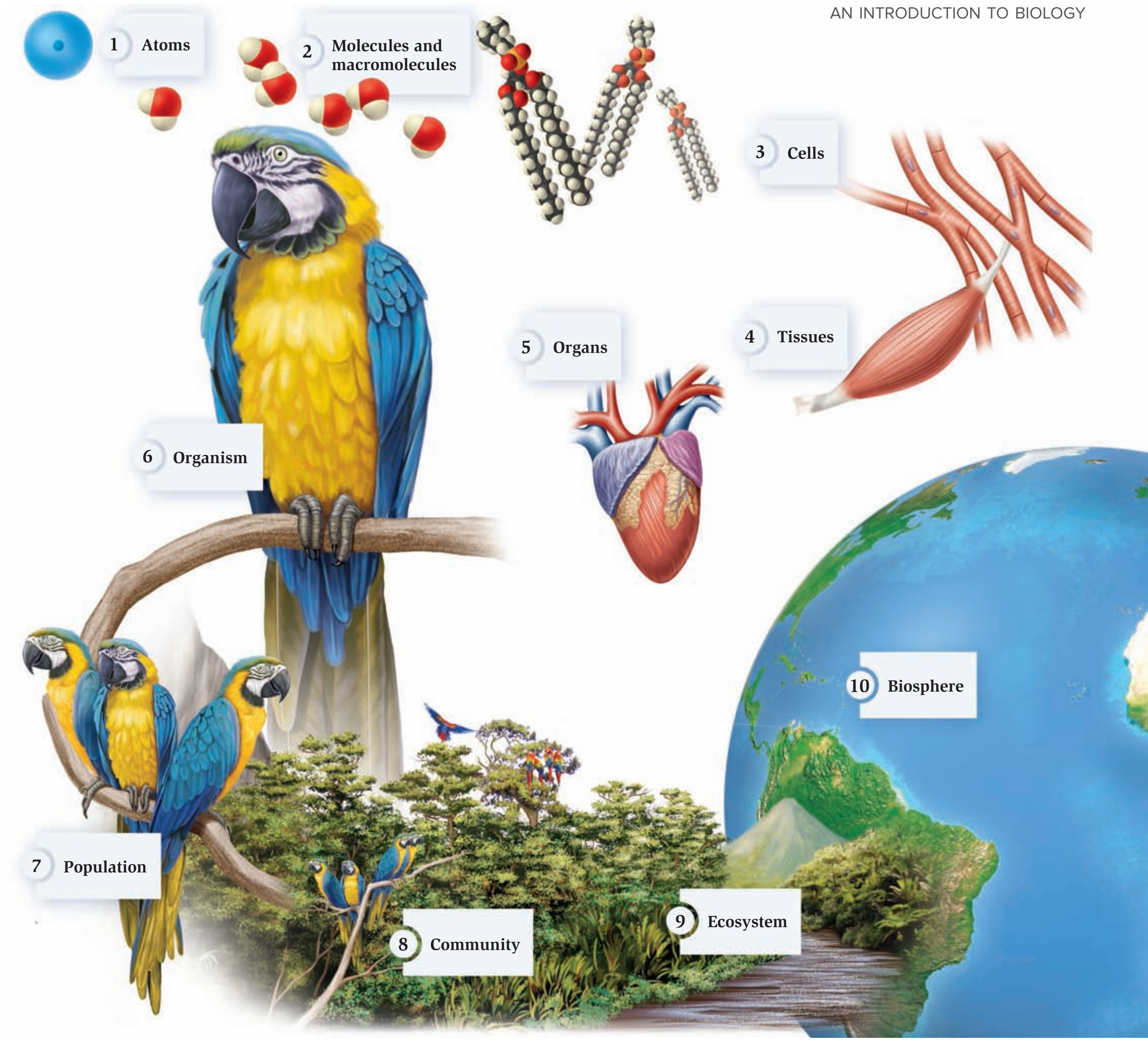


Figure 1.5 **The levels of biological organization.**

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

a particular bird eats insects in the summer and seeds in the winter. To answer such questions, biologists typically gather additional information and ultimately form a hypothesis, which is a proposed explanation for a natural phenomenon. The next stage is to design one or more experiments to test the validity of a hypothesis (Figure 1.4k).

Like our emphasis on evolution, experimentation is such a key aspect of biology that the authors of this textbook have highlighted it in every chapter. As discussed later, a consistent element in Chapters 2 through 60 is a "Feature Investigation"—an actual study by current or past researchers that showcases the experimental approach.

Principle 12: Biology affects our society. The influence of biology is not confined to textbooks and classrooms. The work of biologists has far-reaching effects in our society. For example, biologists have discovered drugs that are used to treat many different human diseases. Likewise, biologists have created technologies that have many uses. Examples include the use of microorganisms to make medical products, such as human insulin, and the genetic engineering of crops to make them resistant to particular types of insect pests (Figure 1.4l).

Living Organisms Are Studied at Different Levels of Organization

The organization of living organisms can be analyzed at different levels of biological complexity, starting with the smallest level of organization and progressing to levels that are physically much larger and more complex. **Figure 1.5** depicts a scientist's view of the levels of biological organization.

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 (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 surrounded by a membrane and contains a variety of molecules and macromolecules. A cell is the simplest unit of life.
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.
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**. 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 physical 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 Unity and Diversity of Life

Learning Outcomes:

1. Explain the two basic mechanisms by which evolutionary change occurs: vertical descent with mutation and horizontal gene transfer.
2. Outline how organisms are classified (taxonomy).
3. Describe how changes in genomes and proteomes underlie evolutionary changes.

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. Life on Earth is united by an evolutionary past in which modern organisms have evolved from populations of 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 different environments the Earth has to offer. In this section, we will begin to examine the unity and diversity that exists within the biological world.

Modern Forms of Life Are Connected by an Evolutionary History

Life began on Earth as primitive cells about 3.5–4 billion years ago (bya). Since that time, populations of living organisms underwent evolutionary changes that ultimately gave rise to the species we see today. Understanding the evolutionary history of species can provide key insights into the structure and function of an organism's body, because evolutionary change frequently involves modifications of characteristics in pre-existing populations. Over long periods of time, populations may change so that structures with a particular function 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. Evidence from the fossil record indicates that both structures were modified from a limb that was used for walking in a pre-existing ancestor (**Figure 1.6**).

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.

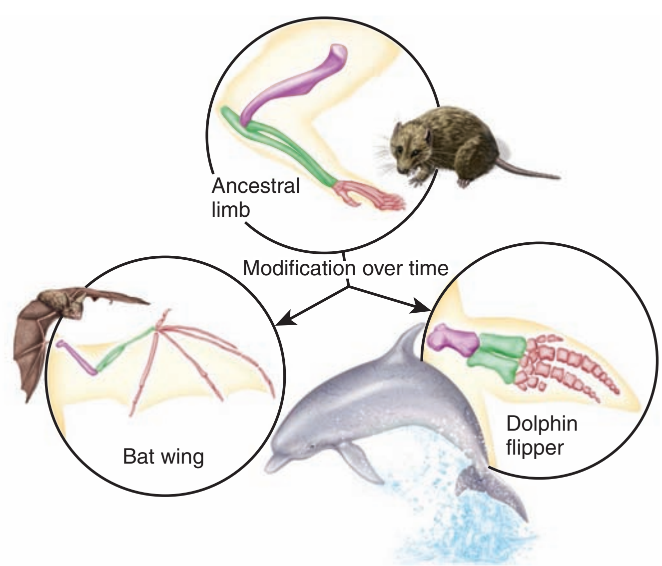


Figure 1.6 An example showing a modification that has occurred as a result of biological evolution. The wing of a bat and the flipper of a dolphin are modifications of a limb that was used for walking in a pre-existing ancestor.

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

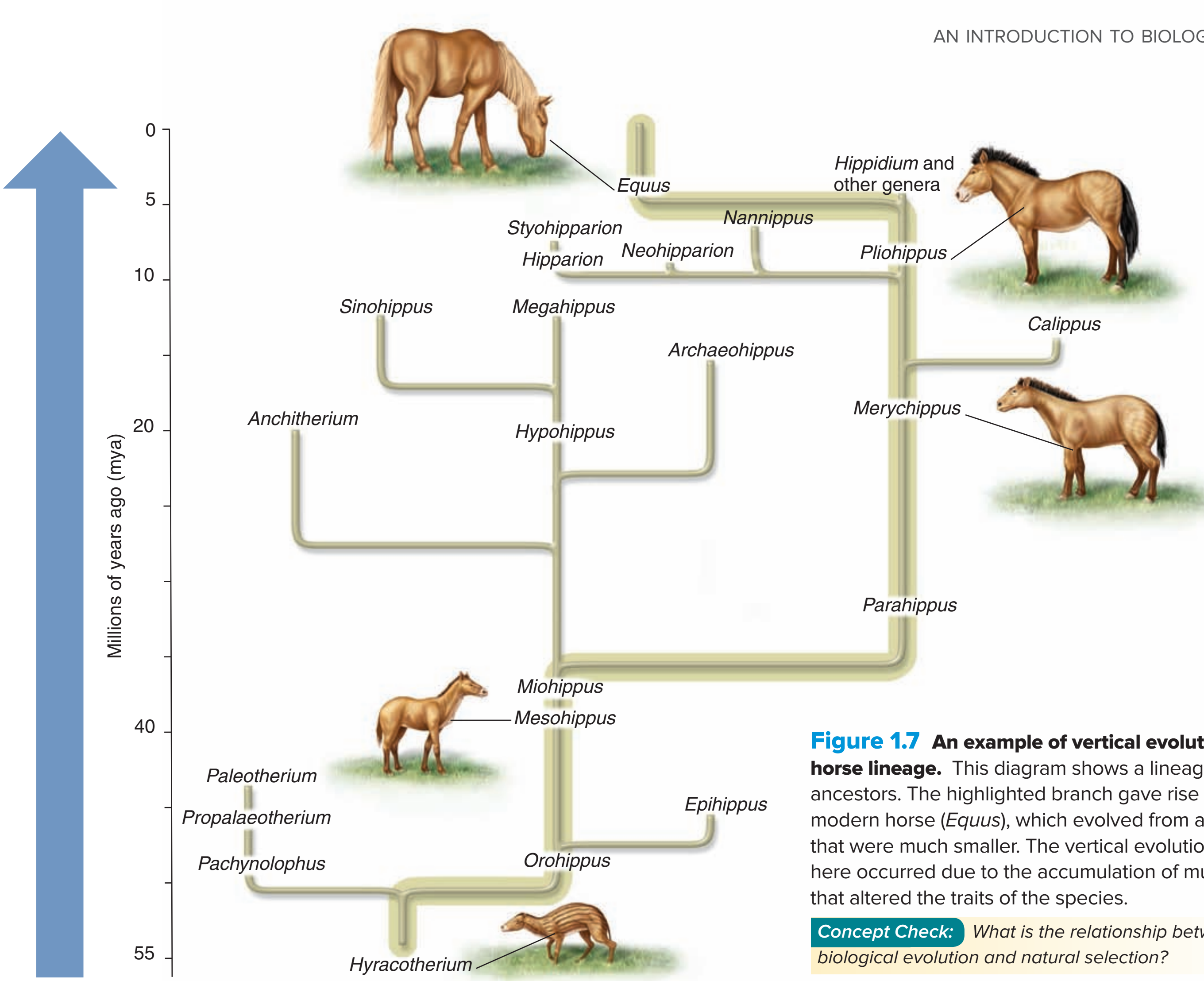


Figure 1.7 An example of vertical evolution: The horse lineage. This diagram shows a lineage of ancestors. The highlighted branch gave rise to the modern horse (*Equus*), which evolved from ancestors that were much smaller. The vertical evolution shown here occurred due to the accumulation of mutations that altered the traits of the species.

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

Vertical Descent with Mutation The traditional way to study evolution is to examine a progression of changes in a series of ancestors. Such a series is called a **lineage**. **Figure 1.7** 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 1.7. In this mechanism of evolution, new species evolve from pre-existing ones by the accumulation of **mutations**, which are heritable 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 topic is discussed in Units IV and V. Evolution also involves the accumulation of neutral changes that do not benefit or harm a species, and evolution sometimes involves rare changes that may be harmful.

With regard to the horses shown in Figure 1.7, 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 with 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, in that changing global climates favored the survival and reproduction of horses with certain types of traits. Over North America, where much of horse evolution occurred, large areas changed from dense forests to grasslands. Horses with genetic variation that made them larger were more likely to escape predators and travel greater distances in search of food. The changes seen in horses' teeth are consistent with a dietary shift from eating 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**, which is the transfer of genetic material from one organism to another organism that is not its offspring. 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,

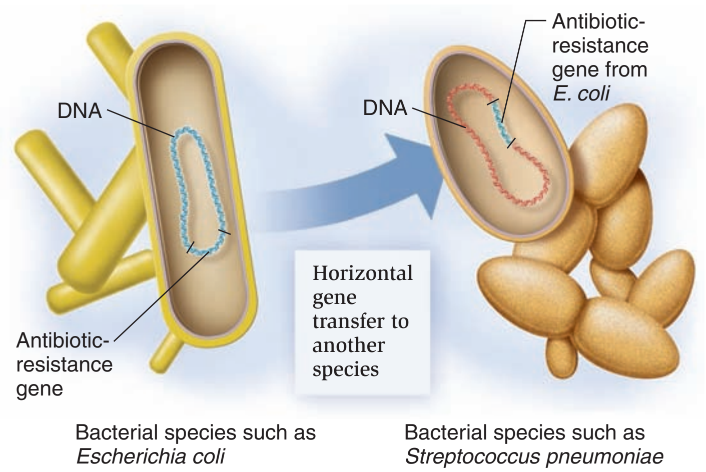


Figure 1.8 An example of horizontal gene transfer: Antibiotic resistance. One bacterial species may transfer a gene to a different bacterial species, such as a gene that confers resistance to an antibiotic.

genes that confer antibiotic resistance are sometimes transferred between different bacterial species (**Figure 1.8**).

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 1.9**). 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 type of evolutionary tree was shown earlier in Figure 1.7. 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 to describe it as a "web of life," as shown in Figure 1.9, which accounts for both vertical evolution and horizontal gene transfer.

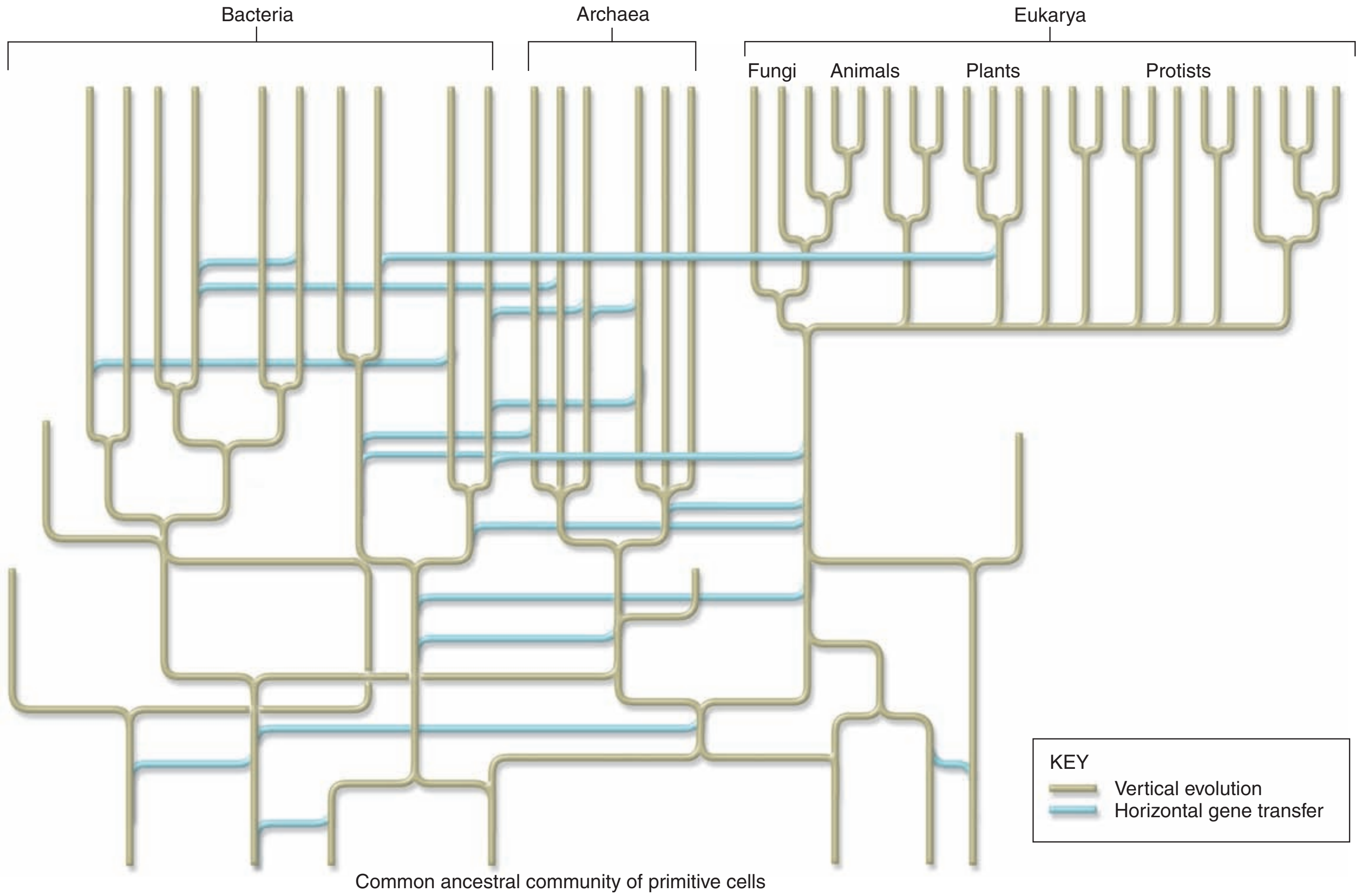


Figure 1.9 The web of life, showing both vertical evolution and horizontal gene transfer. This diagram of evolution includes both of these important mechanisms in the evolution of life on Earth. Note: Archaea are unicellular species that are similar in cell structure to bacteria.

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

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 into groups based on their evolutionary history. This is a difficult task because researchers estimate that the Earth has between 5 and 50 million different species! The rationale for categorization is based on vertical descent. Species with a recent common ancestor are grouped together, whereas species whose common ancestor was 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 1.9 showed three main groups of organisms. From an evolutionary perspective, all forms of life can be placed into those three large categories, or domains, called **Bacteria**, **Archaea**, and **Eukarya** (**Figure 1.10**). 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 were once 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 became invalid as biologists gathered new information regarding the evolutionary relationships of these organisms. We now know the protists do not form a single kingdom but instead are divided into several broad categories called supergroups.

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, a popular saltwater aquarium fish (**Figure 1.11**). Several species of clownfish have been identified. One species of clownfish, which is orange with white stripes, has several common names, including Ocellaris clownfish. The broadest grouping for this clownfish is the domain, namely, Eukarya, followed by progressively smaller divisions, from supergroup (Opisthokonta), to kingdom (Animalia), and eventually 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, including 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 the genomes of modern species.

As mentioned, the term genome refers to the complete genetic composition of an organism or species (**Figure 1.12a**). The genomes of bacteria and archaea usually contain a few thousand genes, whereas those of eukaryotes may contain tens of thousands. 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 for producing 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.

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.