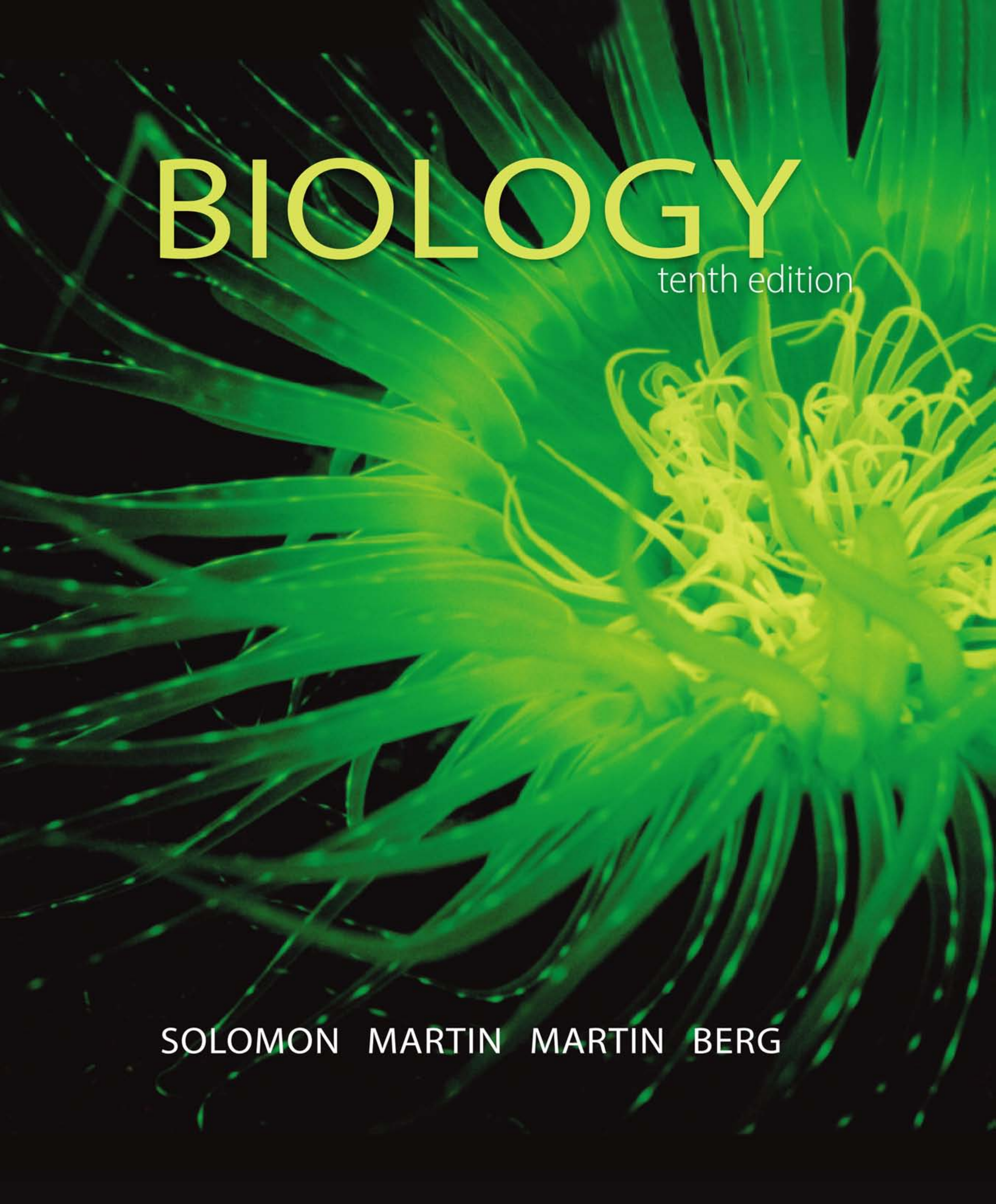
BIOLOGY

tenth edition



SOLOMON MARTIN MARTIN BERG

BIOLOGY

TENTH EDITION

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Biology, Tenth Edition
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Cover Image: Tube anemone (*Cerianthus* sp.) showing green fluorescence. The tube anemone is a solitary anthozoan that lives in a long tube that it constructs from sand and mucus. When attacked, this animal can retract rapidly into its tube. Tube anemones feed on plankton, small fish, and crustaceans. They capture and paralyze prey using their tentacles, which are equipped with stinging cells. Photographed in Alor, Indonesia. © altrendo nature/Getty Images

Library of Congress Control Number: 2013952376

College Edition:
ISBN-13: 978-1-285-42358-6
ISBN-10: 1-285-42358-5

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Printed in Canada
2 3 4 5 17 16 15 14

DEDICATION

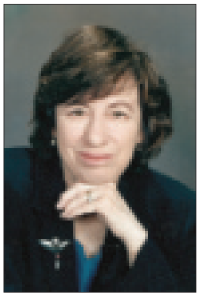
To our families, friends, and colleagues who gave freely of their love, support, knowledge, and time as we prepared this tenth edition of *Biology,* and in appreciation of all who teach and learn.

Especially to
My mother, Freda M. Brod, and to Kathleen, Mical, Karla, Amy, Belicia, and Neal

Professors Emeritus A. Gib DeBusk
and Guy A. Thompson Jr.

Alan and Jennifer

About the Authors



Eldra P. Solomon has written several leading college textbooks in biology and in human anatomy and physiology. Her books have been translated into more than ten languages. She earned an M.S. from the University of Florida and an M.A. and Ph.D. from the University of South Florida. Dr. Solomon taught biology and nursing students for more than 20 years.

In addition to being a biologist and science author, Dr. Solomon is a biopsychologist with a special interest in the neurophysiology of traumatic experience. Her research has focused on the neurological, endocrine, and psychological effects of trauma, including complex posttraumatic stress disorder and development of maladaptive coping strategies.

Dr. Solomon has presented her research at numerous national and international conferences, and her work has been published in leading professional journals. She has been profiled more than 30 times in leading publications, including *Who's Who in America, Who's Who in Science and Engineering, Who's Who in Medicine and Healthcare, Who's Who in American Education, Who's Who of American Women,* and *Who's Who in the World.*

Charles E. Martin is professor emeritus of cell biology and neuroscience at Rutgers University. He received his Ph.D. in genetics from Florida State University and engaged in postdoctoral research in genetics and membrane biology at the University of Texas at Austin. He has taught general biology as well as undergraduate and graduate level courses in genetics and molecular cell biology throughout his career at Rutgers. An award-winning teacher for more than 30 years, in 2011 Dr. Martin was named Professor of the Year by the Molecular Biosciences Graduate Student Association.

His research on gene regulation of membrane protein enzyme systems in yeast and other fungi illustrates the interdisciplinary nature of the life sciences. He is most proud of the many generations of undergraduate, graduate, and postdoctoral students who contributed to this research and have gone on to productive careers. He continues to be committed to teaching and is grateful for the opportunities to pursue a teaching and research career in what continues to be the most exciting era of the biological sciences.

Diana W. Martin is professor emeritus and former director of general biology in the Division of Life Sciences at Rutgers University. Dr. Martin received an M.S. from Florida State University, where she studied the chromosomes of related plant species to understand their evolutionary relationships. She earned a Ph.D. from the University of Texas at Austin, where she studied the genetics of the fruit fly, *Drosophila melanogaster,* and then conducted postdoctoral research at Princeton University.

Dr. Martin taught general biology and other courses at Rutgers for more than 30 years and has been involved in writing textbooks since 1988. She is immensely grateful that her decision to study biology in college has led to a career that allows her many ways to share her excitement about all aspects of biology.

Linda R. Berg is an award-winning teacher and textbook author. She received a B.S. in science education, an M.S. in botany, and a Ph.D. in plant physiology from the University of Maryland. Her research focused on the evolutionary implications of steroid biosynthetic pathways in various organisms.

Dr. Berg taught at the University of Maryland at College Park for 17 years and at St. Petersburg College in Florida for 8 years. During her career, she taught introductory courses in biology, botany, and environmental science to thousands of students. At the University of Maryland, she received numerous teaching and service awards. Dr. Berg is also the recipient of many national and regional awards, including the National Science Teachers Association Award for Innovations in College Science Teaching, the Nation's Capital Area Disabled Student Services Award, and the Washington Academy of Sciences Award in University Science Teaching.

During her career as a professional science writer, Dr. Berg has authored or coauthored several leading college science textbooks. Her writing reflects her teaching style and love of science.

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Preface

This tenth edition of Solomon, Martin, Martin, and Berg's *Biology* conveys our vision of the dynamic science of biology and how it affects every aspect of our lives, from our own health and behavior to the challenging global environmental issues that confront us. New discoveries in the biological sciences continue to increase our understanding of both the unity and diversity of life's processes and adaptations. With this understanding, we become ever more aware of our interdependence with the vast diversity of organisms with which we share planet Earth.

BIOLOGY: THE STUDENT-FRIENDLY BIOLOGY BOOK

We want beginning students to experience learning biology as an exciting journey of discovery. In the tenth edition of *Biology,* we explore Earth's diverse organisms, their remarkable adaptations to the environment, and their evolutionary and ecological relationships. We present the workings of science and the contributions of scientists whose discoveries not only expand our knowledge of biology but also help shape and protect the future of our planet. *Biology* provides insight into what science is, how scientists work, what scientists have contributed, and how scientific knowledge affects daily life.

Since the first edition of *Biology,* we have worked very hard to present the principles of biology in an integrated way that is accurate, interesting, and conceptually accessible to students. In this tenth edition of *Biology,* we continue this tradition. We also continue to present biology in an inquiry-based framework. Some professors interpret inquiry as a learning method that takes place in the laboratory as students perform experiments. Laboratory research is certainly an integral part of inquiry-based learning, but inquiry is also a way of learning in which the student actively pursues knowledge outside the laboratory. In *Biology* we have always presented the history of scientific advances, including scientific debates, to help students understand that science is a process—that is, a field of investigative inquiry—as well as a body of knowledge, the product of inquiry. In the tenth edition of *Biology,* we make a concerted effort to further integrate inquiry-based learning into the textbook with the introduction of new features and the expansion of several others (discussed in the following sections).

Throughout the text we stimulate interest by relating concepts to experiences within the student's frame of reference. By helping students make such connections, we facilitate their mastery of general concepts. We hope the combined effect of an engaging writing style and interesting features will motivate and excite students in their study of biology.

THE SOLOMON/MARTIN/MARTIN/BERG LEARNING SYSTEM

In the tenth edition, we have continued to refine our highly successful *Learning System.* This system provides the student with the learning strategies needed to integrate biological concepts and demonstrate mastery of these concepts. Learning biology is challenging because the subject of biology is filled with so many new terms and so many facts that must be integrated into the framework of general biological principles. To help students focus on important principles and concepts, we provide *Learning Outcomes* for the course and *Learning Objectives* for each major section of every chapter. At the end of each section, we provide *Checkpoint* questions based on the *Learning Objectives* so that students can assess their level of understanding of the material presented in the section. At the end of each chapter, we include a *Summary: Focus on Learning Objectives* that is organized around the *Learning Objectives* and emphasizes key terms in context. The *Summary* is followed by *Test Your Understanding,* a set of questions organized according to Bloom's taxonomy. Questions include *Know and Comprehend* multiple-choice exercises as well as a variety of questions that encourage the student to *Apply and Analyze* and *Evaluate and Synthesize* the topics in the chapter.

Students are directed to **www.cengagebrain.com,** a powerful online tool that offers access to course materials such as *Aplia for Biology* and other companion resources. See the Resources for Students section of the Preface for details.

Pedagogical Features

Our *Learning System* includes numerous learning strategies that help students increase their success:

- ***NEW*** An updated and expanded *art program* reinforces concepts discussed in the text and presents complex processes in clear steps. This edition expands the number of *Key Experiment* figures, which encourage students to evaluate investigative approaches that scientists have taken. *Key Experiment* figures emphasize the scientific process in both classic and modern research; Figure 4-12 is a new example. Also included in this edition are newly designed *Key Point* figures, in which important concepts are stated in process diagrams of complex topics; new examples include Figures 4-11 and 4-15. Many of the *Key Point* figures have numbered parts that show sequences of events in biological processes or life cycles.

- Numerous photographs, both alone and combined with line art, help students grasp concepts by connecting the "real" to the "ideal." The line art uses features such as *orientation icons* to help students put the detailed figures into the broader context. We use symbols and colors consistently throughout the book to help students connect concepts. For example, the same four colors and shapes are used throughout the book to identify guanine, cytosine, adenine, and thymine. Similarly, the same colors are used consistently in illustrations and tables to indicate specific clades of organisms. *Research Method* figures describe why biologists use a particular method and explain how the method is executed. New examples include Figures 4-7 and 15-7.
- ***NEW*** Many questions have been added, and several types of questions carry special designations: *Predict; Connect; Visualize; Evolution Link; Interpret Data;* or *Science, Technology, and Society.* These questions emphasize that learning is enhanced by many diverse approaches.
- *Inquiring About* boxes explore issues of special relevance to students, such as the effects of smoking, how traumatic experiences affect the body, and breast cancer. These boxes also provide a forum for discussing some interesting topics in more detail, such as the smallest ancient humans, ancient plants and coal formation, hydrothermal vent communities, declining amphibian populations, and stratospheric ozone depletion.
- A list of *Key Concepts* at the beginning of each chapter provides a chapter overview and helps the student focus on important principles discussed in the chapter.
- *Learning Objectives* at the beginning of each major section in the chapter indicate, in behavioral terms, what the student must do to demonstrate mastery of the material in that section.
- Each major section of the chapter is followed by a series of *Checkpoint* questions that assess comprehension by asking the student to describe, explain, compare, contrast, or illustrate important concepts. The *Checkpoint* questions are based on the section *Learning Objectives.*
- *Concept Statement Subheads* introduce sections, previewing and summarizing the key idea or ideas to be discussed in that section.
- *Sequence Summaries* within the text simplify and summarize information presented in paragraph form. For example, paragraphs describing blood circulation through the body or the steps by which cells take in certain materials are followed by a *Sequence Summary* listing the sequence of structures or steps.
- Numerous *tables,* many illustrated, help the student organize and summarize material presented in the text. Many tables are color-coded.
- A *Summary: Focus on Learning Objectives* at the end of each chapter is organized around the chapter *Learning Objectives.* This summary provides a review of the material, and because selected key terms are boldfaced in the summary, students learn vocabulary words within the context of related concepts.
- ***NEW*** *Test Your Understanding* end-of-chapter questions are now organized according to Bloom's taxonomy, providing students with the opportunity to evaluate their understanding of the material in the chapter. *Know and Comprehend* multiple-choice questions reinforce important terms and concepts. *Apply and Analyze* questions challenge students to integrate their knowledge. Higher-level *Evaluate and Synthesize* questions encourage students to apply the concepts just learned to new situations or to make connections among important concepts. Each chapter has one or more *Evolution Link* questions, and many chapters contain one or more *Interpret Data* questions that require students to actively interpret experimental data presented in the chapter. Also included are *Predict, Connect, Visualize,* and *Science, Technology, and Society* questions. Answers to the *Test Your Understanding* questions are provided in Appendix E.
- The *Glossary* at the end of the book, the most comprehensive glossary found in any biology text, provides precise definitions of terms. The *Glossary* is especially useful because it is extensively cross-referenced and includes pronunciations for many terms. The vertical green bar along the margin facilitates rapid access to the *Glossary.* The companion website also includes glossary flash cards with pronunciations.

Course Learning Outcomes

At the end of a successful study of introductory biology, the student can demonstrate mastery of biological concepts by responding accurately to the following *Course Learning Outcomes:*

- Design an experiment to test a given hypothesis, using the procedure and terminology of the scientific method.
- Cite the cell theory and relate the structure of organelles to their functions in both prokaryotic and eukaryotic cells.
- Describe the mechanisms of evolution, explain why evolution is the principal unifying concept in biology, and discuss natural selection as the primary agent of evolutionary change.

- Explain the role of genetic information in all species and discuss applications of genetics that affect society.
- Describe several mechanisms by which cells and organisms transfer information, including the use of nucleic acids in genetic transmission of information, signal transduction, chemical signals (such as hormones and pheromones), electrical signals (such as neural transmission), sounds, and visual displays.
- Provide examples (at various levels of complexity) of interactions among biological systems that illustrate the interdependence of these systems.
- Explain how any given structure is related to its function.
- Argue for or against the classification of organisms in three domains and several kingdoms or supergroups, characterizing each of these clades; based on your knowledge of genetics and evolution, give specific examples of the unity and diversity of organisms in different domains and supergroups.
- Compare the structural adaptations, life processes, and life cycles of a prokaryote, protist, fungus, plant, and animal.
- Define *homeostasis* and give examples of regulatory mechanisms, including feedback systems.
- Trace the flow of matter and energy through a photosynthetic cell and a nonphotosynthetic cell and through the biosphere, comparing the roles of producers, consumers, and decomposers.
- Describe the study of ecology at the levels of an individual organism, a population, a community, and an ecosystem.

WHAT'S NEW: AN OVERVIEW OF *BIOLOGY*, TENTH EDITION

Five themes are interwoven throughout *Biology:* the evolution of life, the transmission of biological information, the flow of energy through living systems, interactions among biological systems, and the inter-relationship of structure and function. As we introduce the concepts of modern biology, we explain how these themes are connected and how life depends on them.

Educators present the major topics of an introductory biology course in a variety of orders. For this reason, we carefully designed the eight parts of this book so that they do not depend heavily on preceding chapters and parts. This flexible organization means that an instructor can present the 57 chapters in any number of sequences with pedagogical success. Chapter 1, which introduces the student to the major principles of biology, provides a comprehensive springboard for future discussions, whether the professor prefers a "top-down" or "bottom-up" approach.

In this edition as in previous editions, we examined every line of every chapter for accuracy and currency, and we made a careful attempt to update every topic and verify all new material. Our efforts have been enhanced by an updated art program with many new illustrations. The following brief summary provides a general overview of the organization of *Biology* and some changes made to the tenth edition.

Part 1 The Organization of Life

The six chapters that make up Part 1 provide basic principles of biology and the concepts of chemistry and cell biology that lay the foundation upon which the remaining parts of the book build. We begin Chapter 1 with a discussion of the promise and challenges of stem cell research. We then introduce the main themes of the book: evolution, information transfer, energy transfer, interactions in biological systems, and the interrelationship of structure and function. Chapter 1 examines several fundamental concepts in biology and the nature of the scientific process, including a discussion of systems biology. Chapters 2 and 3, which focus on the molecular level of organization, establish the foundations in chemistry necessary for understanding biological processes. Chapters 4, 5, and 6 focus on the cellular level of organization, including cell structure and function, cell membranes, and cell signaling. We have revised these chapters to place greater emphasis on the interdisciplinary nature of cell research and have expanded coverage of transport between the nucleus and cytoplasm as well as the routing of proteins through the endomembrane system.

Part 2 Energy Transfer Through Living Systems

Because all living cells need energy for life processes, the flow of energy through living systems—that is, capturing energy and converting it to usable forms—is a basic theme of *Biology*. Chapter 7 examines how cells capture, transfer, store, and use energy. Chapters 8 and 9 discuss the metabolic adaptations by which organisms obtain and use energy through cellular respiration and photosynthesis.

Part 3 The Continuity of Life: Genetics

We have updated and expanded the eight chapters of Part 3 for the tenth edition. We begin this unit by discussing mitosis and meiosis in Chapter 10. Chapter 11 builds on this foundation as it considers Mendelian genetics and related patterns of inheritance. We then turn our attention to the structure and replication of DNA in Chapter 12. The discussion of RNA and protein synthesis in Chapter 13 includes new insights into how the small percentage of DNA that codes for polypeptides relates to the much larger percentage of the genome that is expressed. We introduce new information derived from the ENCODE project establishing that much of the genome encodes different classes of non-protein-coding RNAs, including microRNAs and long noncoding RNAs. The newly discovered regulatory functions of these RNAs are further explored in Chapter 14, which also includes new information on eukaryotic promoters, enhancers, and silencers as well as on epigenetic inheritance. In Chapter 15 we focus on DNA technology and genomics, including an expanded discussion of rapid DNA sequencing, as well as the importance of gene databases as tools for understanding gene regulation, gene functions, and molecular evolution. These chapters build the necessary foundation for exploring human genetics and the human genome in Chapter 16, which includes new sections on genomic imprinting and on genome-wide association studies. In Chapter 17 we introduce the role of genes in development, emphasizing studies on specific model organisms that have led to spectacular advances in this field; changes include new material on induced pluripotent stem cells as well as a comprehensive view of cancer and its relationship to cell signaling that has developed through the application of genome-wide association studies and whole genome sequencing.

Part 4 The Continuity of Life: Evolution

Although we explore evolution as the cornerstone of biology throughout the book, Part 4 discusses evolutionary concepts in depth. We provide the history behind the discovery of the scientific theory of evolution, the mechanisms by which it occurs, and the methods by which it is studied and tested. Chapter 18 introduces the Darwinian concept of evolution and presents several kinds of evidence that support the scientific theory of evolution. In Chapter 19 we examine evolution at the population level. Chapter 20 describes the evolution of new species and discusses aspects of macroevolution. Chapter 21 summarizes the evolutionary history of life on Earth. In Chapter 22 we recount the evolution of primates, including humans. New molecular and fossil findings, including those relating to recently discovered human relatives such as the Denisovans (a sister species to the Neandertals) and *Australopithecus sediba,* are explored.

Part 5 The Diversity of Life

Emphasizing the cladistic approach, we use an evolutionary framework to discuss each group of organisms. We present current hypotheses of how groups of organisms are related. Chapter 23 has been updated to reflect the effect of recent research on systematics. In this chapter we discuss *why* organisms are classified and provide insight into the scientific process of deciding *how* they are classified. New advances have enabled us to further clarify the connection between evolutionary history and systematics in the tenth edition. Chapter 24 focuses entirely on viruses and subviral agents. Information has been updated and expanded on giant viruses, viral origins, evolutionary importance of viruses, and recent research on viruses. Chapter 25 is devoted to the prokaryotes, both bacteria and archaea. Information about the evolution, structure, ecology, and phylogeny of archaea has been expanded. Implications of research on the human microbiome are discussed and discussion of antibiotic resistance has been expanded. Chapter 26 describes the protists in the context of five "supergroups" of eukaryotes. Chapters 27 and 28 present the members of the plant kingdom. Chapter 27 considers the evolution of land plants and the evolution of seedless vascular plants. Discussion of the origin and early evolution of angiosperms is included in Chapter 28. Chapter 29 describes the fungi. In Chapters 30 through 32, we discuss the diversity of animals. We have updated the discussions of phylogenetic relationships to reflect recent research.

Part 6 Structure and Life Processes in Plants

Part 6 introduces students to the fascinating plant world. Here we stress relationships between structure and function in plant cells, tissues, organs, and individual organisms. In Chapter 33 we consider plant structure, growth, and differentiation in the context of cell division, cell expansion, cell differentiation, tissue culture, morphogenesis, pattern formation, positional information, and *Arabidopsis* mutants. Chapters 34 through 36 discuss the structural and physiological adaptations of leaves, stems, and roots; these chapters include special consideration of plant transport systems. Chapter 37 describes reproduction in flowering plants, including asexual reproduction, flowers, fruits, and seeds. Chapter 38 focuses on growth responses and regulation of growth, including the latest findings generated by the continuing explosion of knowledge in plant biology, particularly at the molecular level.

Part 7 Structure and Life Processes in Animals

In Part 7 we provide a strong emphasis on comparative animal physiology, showing the structural, functional, and behavioral adaptations that help animals meet environmental challenges. We use a comparative approach to examine how various animal groups have solved both similar and diverse problems. In Chapter 39 we discuss the basic tissues and organ systems of the animal body, homeostasis, and the ways that animals regulate their body temperature. Chapter 40 focuses on different types of body coverings, skeletons, and muscles, and discusses how they function. In Chapters 41 through 43, we discuss neural signaling, neural regulation, and sensory reception. In Chapters 44 through 51, we compare how different animal groups carry on life processes, such as internal transport, internal defense, gas exchange, digestion, reproduction, and development. Each chapter in this part considers the human adaptations for the life processes being discussed. Part 7 ends with a discussion of behavioral adaptations in Chapter 52. Reflecting recent research findings, we have updated or added new material on many topics, including neurotransmitters, cardiovascular disease, evolution of immunity in invertebrates, chronic inflammation, HIV, nutrition, regulation of appetite and energy metabolism, endocrine function, ovarian stem cells, contraception, sexually transmitted infections, and social learning and transmission of culture in vertebrates. The art program has been updated and improved, and new photographs and photomicrographs have been added.

Part 8 The Interactions of Life: Ecology

Part 8 focuses on the dynamics of populations, communities, and ecosystems and on the application of ecological principles to disciplines such as conservation biology. Chapters 53 through 56 give the student an understanding of the ecology of populations, communities, ecosystems, and the biosphere, and Chapter 57 focuses on global environmental issues. Among the many new and updated topics discussed in this unit are Antarctic tundra; the role of archaea in the carbon cycle, nitrogen cycle, and climate change; the Cross River gorilla (*Gorilla gorilla diehli*) as an example of a critically endangered species; new research on global climate change; updated information on stratospheric ozone depletion; and the effect of humans on the biosphere.

A COMPREHENSIVE PACKAGE FOR LEARNING AND TEACHING

A carefully designed supplement package is available to further facilitate learning. In addition to the usual print resources, we are pleased to present student multimedia tools that have been developed in conjunction with the text.

Resources for Students

MindTap, a fully online, highly personalized learning experience built on Cengage Learning content. MindTap combines student learning tools—readings, multimedia, activities, and assessments—into a singular Learning Path that guides students through their course. Instructors personalize the experience by customizing authoritative Cengage Learning content and learning tools, including the ability to add their own content in the Learning Path via apps that integrate into the MindTap framework seamlessly with Learning Management Systems.

MindTap for Biology is easy to use and saves instructors time by allowing them to:

- Seamlessly deliver appropriate content and technology assets from a number of providers to students, as they need them.
- Break course content down into movable objects to promote personalization, encourage interactivity, and ensure student engagement.
- Customize the course—from tools to text—and make adjustments "on the fly," making it possible to intertwine breaking news into their lessons and incorporate today's teachable moments.
- Bring interactivity into learning through the integration of multimedia assets.
- Track students' use, activities, and comprehension in real time, which provides opportunities for early intervention to influence progress and outcomes. Grades are visible and archived so that students and instructors always have access to current standings in the class.

Aplia offers a way to stay on top of coursework with regularly scheduled homework assignments. Interactive tools and additional content are provided to further increase engagement and understanding. Students, ask your instructor about Aplia!

Study Guide to accompany *Biology,* Tenth Edition, by Jennifer Aline Metzler of Ball State University and Robert Yost of Indiana University and Purdue University, Indianapolis. Updated for this edition, the study guide provides the student with many opportunities to review chapter concepts. Multiple-choice study questions, coloring-book exercises, vocabulary-building exercises, and many other types of active-learning tools are provided to suit different cognitive learning styles.

A Problem-based Guide to Basic Genetics by Donald Cronkite of Hope College. This brief guide provides students with a systematic approach to solving genetics problems along with numerous solved problems and practice problems.

Spanish Glossary. This Spanish glossary of biology terms is available to Spanish-speaking students.

Audio Study Tools. This tenth edition of *Biology* is accompanied by useful study tools, which contain valuable information such as reviews of important concepts, key terms, questions, and study tips. Students can download the audio study tools.

Virtual Biology Laboratory 4.0. Now with an upgraded user interface, these 14 online laboratory experiments allow students to "do" science by acquiring data, performing simulated experiments, and using data to explain biological concepts. Assigned activities automatically flow to the instructor's grade book. Self-designed activities ask students to plan their procedures around an experimental question and write up their results.

Additional Resources for Instructors

The instructors' examination copy for this edition lists a comprehensive package of print and multimedia supplements, including online resources, available to qualified adopters. Please ask your local sales representative for details.

Instructor Companion Site. Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via **www.cengage.com/login.** Access and download PowerPoint presentations, images, instructor's manual, videos, and more.

Cengage Learning Testing Powered by Cognero. A flexible, online system that allows you to import, edit, and manipulate test bank content from the test bank or elsewhere, including your own favorite test questions; create multiple test versions in an instant; and deliver tests from your LMS, your classroom, or wherever you want.

Aplia is a Cengage Learning online homework system dedicated to improving learning by increasing student effort and engagement. Aplia makes it easy for instructors to assign frequent online homework assignments. Aplia provides students with prompt and detailed feedback to help them learn as they work through the questions, and features interactive tutorials to fully engage them in learning course concepts. Automatic grading and powerful assessment tools give instructors real-time reports of student progress, participation, and performance, while Aplia's easy-to-use course management features let instructors flexibly administer course announcements and materials online. With Aplia, students will show up to class fully engaged and prepared, and instructors will have more time to do what they do best . . . teach.

Brooks/Cole Video Library (Featuring BBC Motion Gallery Video Clips). The Brooks/Cole Video Library contains many high-quality videos that can be used alongside the text. A wide range of video topics offer professors a great tool to engage students and help them connect the material to their lives outside of the classroom. Available on the Instructor Companion Site.

ACKNOWLEDGMENTS

The development and production of the tenth edition of *Biology* required extensive interaction and cooperation among the authors and many individuals in our family, social, and professional environments. We thank our editors, colleagues, students, family, and friends for their help and support. Preparing a book of this complexity is challenging and requires a cohesive, talented, and hardworking professional team. We appreciate the contributions of everyone on the editorial and production staff at Brooks/Cole–Cengage Learning who worked on this tenth edition of *Biology*. We thank our senior product team manager, Yolanda Cossio, for her commitment to *Biology* and for working closely with us throughout the entire process of development and production. We greatly appreciate the help of Suzannah Alexander, our very talented content developer, who was a critical part of our team. Suzannah expertly coordinated many aspects of this challenging project, including the complex new art rendered for this edition. She made herself available to advise and help us whenever we needed her, including late at night and during weekends.

We thank Tom Ziolkowski, our market development manager, and Nicole Hamm, our brand manager, whose expertise ensured that you would know about our new edition.

We appreciate the help of content project manager Hal Humphrey, who expertly guided overall production of the project.

We are grateful to product assistant Victor Luu for quickly providing us with resources whenever we needed them.

We thank creative director Rob Hugel, senior art director and cover designer John Walker, and text designer Jeanne Calabrese.

We appreciate the work of Lauren Oliveira, media developer, who coordinated the many high-tech components of the computerized aspects of our *Learning System*. We thank content coordinator Kellie Petruzzelli for coordinating the print supplements.

We are grateful to our production editor, Whitney Thompson of Lachina Publishing Services, for coordinating the many editors involved in the preparation of this edition and bringing together the thousands of complex pieces of the project that together produced *Biology,* Tenth Edition. We value the careful work of our copy editor, Kathleen Lafferty of Roaring Mountain Editorial Services, who helped us maintain consistency and improve the manuscript. We thank the artists at Lachina Publishing Services, Precision Graphics, and Dragonfly Media Group for greatly improving the art program for this book. We appreciate the efforts of photo research manager Jill Reichenbach of Bill Smith Group in helping us find excellent images. We appreciate the help, patience, and hard work of our production team. Our schedule for this project was very demanding. At times, it seemed like the team worked around the clock. When we sent e-mails late at night or during weekends, we often received immediate responses.

These dedicated professionals and many others on the Brooks/Cole team provided the skill, attention, patience, and good humor needed to produce *Biology,* Tenth Edition. We thank them for their help and support throughout this project.

We appreciate the help of obstetrician/gynecologist Dr. Amy Solomon for her input regarding the most recent information on pregnancy, childbirth, contraception, and sexually transmitted infections. We are grateful to Mical Solomon for his computer help. We thank Dr. David Axelrod for insightful discussions on the genetics and biology of cancer.

We thank our families and friends for their understanding, support, and encouragement as we struggled through many revisions and intense deadlines. We especially thank Dr. Kathleen M. Heide, Freda Brod, Alan Berg, Jennifer and Pat Roath, and Margaret Martin for their support and input.

Our colleagues and students who have used our book have provided valuable input by sharing their responses to past editions of *Biology*. We thank them and ask again for their comments and suggestions as they use this new edition. We can be reached via our website at **www.cengagebrain.com** or through our editors at Brooks/Cole, a division of Cengage Learning.

We greatly appreciate and want to acknowledge the participation and help of our contributors:

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We express our thanks to the many biologists who have read the manuscript during various stages of its development and provided us with valuable suggestions for improving it. Tenth edition reviewers include the following:

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Bruce Stallsmith, University of Alabama in Huntsville
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Robert Yost, Indiana University and Purdue University Indianapolis

We would also like to thank the hundreds of reviewers of previous editions, both professors and students, who are too numerous to mention. They asked thoughtful questions, provided new perspectives, offered alternative wordings to clarify difficult passages, and informed us of possible errors. We are truly indebted to their excellent feedback. Their suggestions have helped us improve each edition of *Biology*.

To the Student

We have learned a great deal from tens of thousands of students who have taken on the challenge of learning biology. Although they have varied in their life goals and academic preparation, most have found that they needed to modify their approach to learning to be successful.

You already know that memorization and cramming are unsuccessful, and you probably also know that many students fall back on these methods as default strategies. So, what really works?

Use the Wealth of Learning Aids That Accompany *Biology*

The *Learning System* we use in this book is described in the Preface. Using the strategies of the *Learning System* will help you master the language and concepts of biology. You will also want to use the many online tools available to *Biology* students. These tools, described in the Resources for Students section of the Preface, include *Aplia for Biology* and *MindTap* available at **www.cengagebrain.com.** In addition to these learning strategies, you can make the task of learning biology easier by using approaches that have been successful for a broad range of our students over the years.

Be Open to Many Learning Styles

There is a popular belief that each person has an innate "learning style" that is most successful for them. In fact, there is very little scientific evidence to support this view. What works will depend on the nature of the material being learned, and in most cases a mix of activities and a variety of sensory inputs will be most effective. *Biology* includes many kinds of questions to encourage you to think and learn in different ways. Make learning a part of your life as you think, listen, draw, write, argue, describe, speak, observe, explain, and experiment.

Know Your Professor's Expectations

Determine what your professor wants you to know and how your learning will be assessed. Some professors test almost exclusively on material covered in lecture. Others rely on their students' learning most of, or even all, the content assigned in chapters. Find out what your professor's requirements are because the way you study will vary accordingly.

If lectures are the main source of examination questions, make your lecture notes as complete and organized as possible. Before going to class, skim over the chapter, identifying key terms and examining the main figures, so that you can take effective lecture notes. Spend no more than 1 hour on this. Within 24 hours after class, type (or rewrite) your notes. Before typing them, however, read the notes and make marginal notes about anything that is not clear. Then read the corresponding material in your text. Do not copy the information; instead, process it and write out an explanation in your own words. Read the entire chapter, including parts that are not covered in lecture. This extra information will give you breadth of understanding and will help you grasp key concepts. In addition, you should make an effort to employ as many of the techniques described in the next paragraphs as possible.

If the assigned readings in the text are going to be tested, you must use your text intensively. After reading the chapter introduction, read the list of *Learning Objectives* for the first section. These objectives are written in behavioral terms; that is, they ask you to "do" something to demonstrate mastery. The objectives give you a concrete set of goals for each section of the chapter. At the end of each section, you will find *Checkpoint* questions keyed to the *Learning Objectives.* Carefully examine each figure, making certain that you understand what it is illustrating. Answer the question at the end of each *Key Point* figure and at the end of each *Key Experiment.*

Read each chapter section actively. Highlighting and underlining are not always active learning techniques; sometimes they postpone learning. ("This part is important; I'll learn it later.") An active learner always has questions in mind and is constantly making connections. For example, there are many processes that must be understood in biology. Don't try to blindly memorize them; instead, think about causes and effects so that every process becomes a story. Eventually, you'll see that many processes are connected by common elements.

To master the material, you will probably have to read each chapter more than once. Each time will be much easier than the previous time because you'll be reinforcing concepts that you have already partially learned.

Write a chapter outline and flesh out your outline by adding important concepts and boldface terms with definitions in your own words (not copied from the book or cut and pasted). Use this outline when preparing for the exam.

Now it is time to test yourself. Answer the *Test Your Understanding* questions (*Know and Comprehend, Apply and Analyze,* and *Evaluate and Synthesize*) at the end of the chapter. You will sharpen your thinking if you take the time to type or write out your answers. The answers are in Appendix E, but do not be too quick to check them. Think about them and discuss them with your fellow students if possible. Consider each question as a kind of springboard that leads to other questions. Finally, review the *Learning Objectives* in the *Summary* and try to answer them before reading the summary provided.

Learn the Vocabulary

One stumbling block for many students is learning the many terms that make up the language of biology. In fact, it would be much more difficult to learn and communicate if we did not have this terminology because words are really tools for thinking. Learning terminology generally becomes easier if you realize that most biological terms are modular. They consist of mostly Latin and Greek roots; once you learn many of these roots, you will have a good idea of the meaning of a new word even before it is defined. For this reason, we have included Appendix C, Understanding Biological Terms. To be sure that you understand the precise definition of a term, use the Index and the Glossary. The more you use biological terms in speech and writing, the more comfortable you will be with the language of biology.

Develop a Framework for Your Learning

Always aim to get the big picture before adding details. When attempting to learn a complex process, a struggling student will typically begin with the first part, try to learn all the details, and then give up. Instead, begin by making sure that you have a basic understanding of what is happening in the overall process. To encourage you in this way of thinking, we have modeled this approach in *Biology.* As just one example out of many, glycolysis is a multistep process covered in Chapter 8. Before presenting all the details, we provide an overview figure that emphasizes what the process accomplishes.

Form a Study Group

Active learning is facilitated if you do some of your studying collaboratively in a small group. In a study group, the roles of teacher and learner can be interchanged: a good way to learn material is to teach, through a process that cognitive scientists describe as *elaborative rehearsal* (not to be confused with memorization). A study group has other advantages: it can make learning more fun, lets you meet challenges in a nonthreatening environment, and can provide some emotional support. When combined with individual study of text and lecture notes, study groups can be effective learning tools.

Eldra P. Solomon
Charles E. Martin
Diana W. Martin
Linda R. Berg

A View of Life

1

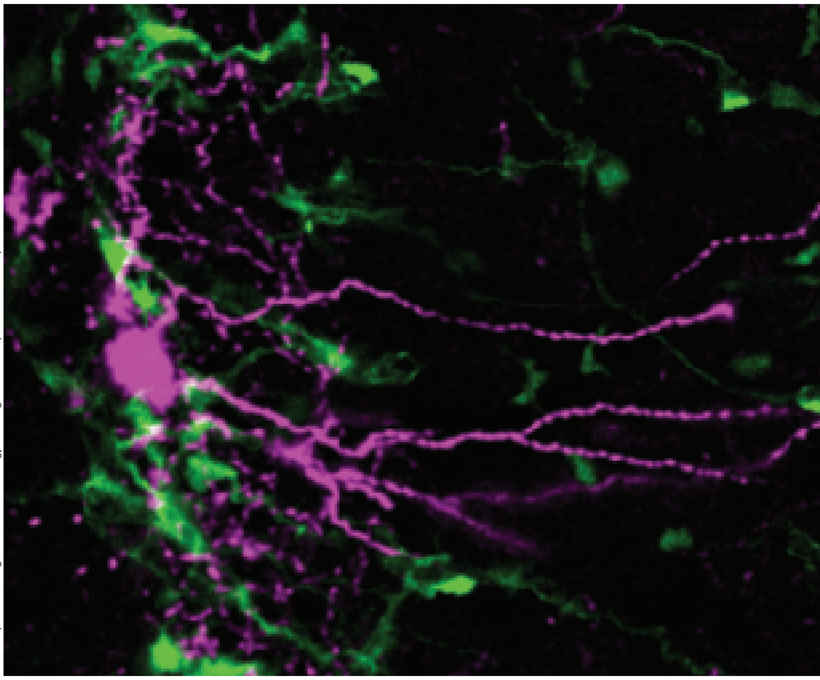
This is an exciting time to study **biology**, the science of life. Biologists are making remarkable new discoveries that affect every aspect of our lives, including our health, food, safety, relationships with humans and other organisms, and the environment of our planet. New knowledge provides new insights into the human species and the millions of other organisms with which we share planet Earth. Biology affects our personal, governmental, and societal decisions.

One of the most exciting areas of current research is stem cell biology. **Stem cells** are unspecialized cells that have the capacity to divide, giving rise to more stem cells *and* to one or more specialized types of cell. For example, stem cells in the bone marrow differentiate to produce the various types of blood cells. Stem cells also allow the body to repair injury as well as to recover from normal wear and tear. For example, stem cells in the skin continuously divide, and some differentiate to replace skin cells that are constantly worn off from the body's surface.

Basic research in stem cell biology has helped scientists understand how unspecialized cells differentiate to become specific types of cells such as skin cells, white blood cells, or cells lining the intestine. Combined with technological advances, stem cell biology has led to exciting new advances and possibilities in such diverse fields as clinical medicine and ecology. For example, patients with leukemia and certain other cancers are often treated with radiation that destroys blood-producing stem cells in the bone marrow. Thousands of lives are saved each year using procedures in which stem cells are transplanted into the patient's bone marrow.

Researchers are developing methods for using stem cells to treat infertility and to repair spinal cord injury. In the future, stem cells may be used to cure genetic diseases and to treat diseases such as arthritis, Alzheimer's disease, Parkinson's disease, multiple sclerosis, and macular degeneration. Tissue may someday be cultured from a patient to replace organs that are diseased. For example, a diabetic patient may be given a new pancreas.

Biologists continue to discover new types of stem cells within the bodies of plants, humans, and research animals. The most versatile stem cells, called **pluripotent** stem cells, can give rise to all the tissues of the body. Biologists have discovered how to



Courtesy Juan Song, Gerald Sun, Hongjun Song, Johns Hopkins University School of Medicine

Neural stem cells in the brain. Neural stem cells (*green*) in the hippocampus gather around a neuron (*purple*). Neural stem cells appear to receive and respond to signals transmitted from one neuron to another.

KEY CONCEPTS

1.1 Basic themes of biology include evolution, interactions of biological systems, inter-relationships of structure and function, information transfer, and energy transfer.

1.2 Characteristics of life include cellular structure, growth and development, self-regulated metabolism, response to stimuli, and reproduction.

1.3 Biological organization is hierarchical and includes chemical, cell, tissue, organ, organ system, and organism levels; ecological organization includes population, community, ecosystem, and biosphere levels.

1.4 Information transfer includes DNA transfer of information from one generation to the next, chemical and electrical signals within and among the cells of every organism, and sensory receptors and response systems that allow organisms to communicate with one another and interact with their environment.

1.5 Individual organisms and entire ecosystems depend on a continuous input of energy. Energy is transferred within cells and from one organism to another.

1.6 Evolution is the process by which populations of organisms change over time, adapting to changes in their environment; the tree of life includes three major branches, or domains.

1.7 Biologists ask questions, develop hypotheses, make predictions, and collect data by careful observation and experiment; based on their results, they come to conclusions and then share their work with other scientists and with the public.

induce pluripotent stem cells by reprogramming the genome of certain adult cells. These *induced pluripotent stem cells (iPSCs)* are similar in many ways to embryonic stem cells. An important advantage of iPSCs is that they give rise to tissues that are genetically identical to those of the patient.

Stem cells may also be used in the future to save endangered species. Researchers have already produced iPSCs from the tissues of an adult snow leopard, a jaguar, a Bengal tiger, and a serval (a medium-sized, slender cat, native to Africa). In the future they hope to clone the iPSCs and to produce eggs and sperm from them.

Recently, the journal *Nature* reported that researchers at the Johns Hopkins University School of Medicine have discovered that neural stem cells in the brain "listen in" on the chemical signals that neurons use to communicate with one another (see photograph). When necessary, the stem cells differentiate into neurons or glial cells, or signal the brain to produce new cells.

The 2012 Nobel Prize in Physiology or Medicine was awarded to John B. Gurdon and Shinya Yamanaka for their contributions to the development of stem cell research. In the 1960s, Gurdon transplanted differentiated cell nuclei taken from tadpoles into frog egg cells. He found that a few of these eggs developed into tadpoles (see Fig. 17-3). More than forty years later Yamanaka and his colleagues identified a combination of four genes from embryonic stem cells that could reprogram certain mature cells to become pluripotent stem cells.

Stem cell research is just one of hundreds of exciting areas of biological research that bring together science, technology, and society. Whatever your college major or career goals, knowledge of biological concepts is a vital tool for understanding our world and for meeting many of the personal, societal, and global challenges that confront us. Among these challenges are the expanding human population, decreasing biological diversity, diminishing natural resources, global climate change, and prevention and cure of diseases, such as heart disease, cancer, diabetes, and Alzheimer's disease. Meeting these challenges will require the combined efforts of biologists and other scientists, health professionals, educators, politicians, and biologically informed citizens.

This book is a starting point for your exploration of biology. It will provide you with the basic knowledge and the tools to become a part of this fascinating science as well as a more informed member of society.

1.1 MAJOR THEMES OF BIOLOGY

LEARNING OBJECTIVE

1 Describe five basic themes of biology.

In this first chapter we introduce five major themes of biology. These themes are interconnected with one another and with almost every concept that we discuss in this book.

1. **Biological systems interact.** Every organism is a biological system made up of millions of other biological systems. Each of its cells is a biological system, as is each organ (e.g., heart and liver) and body system (e.g., cardiovascular system and digestive system). Each of the multitude of microorganisms (e.g., bacteria) that inhabit an organism is also a biological system. Making this concept even more interesting, an organism cannot survive on its own. Every organism is a biological system that is interdependent with many other biological systems. Clearly, scientists can study biological systems and their interactions at many different levels.
2. **Structure and function are inter-related in all biological systems.** The structure of neurons that function to transmit information is very different from the structure of red blood cells, which function to transport oxygen. Similarly, on the level of organisms, the canine teeth of carnivorous mammals are adapted for stabbing their prey and ripping flesh. In contrast, horses and other herbivorous mammals have teeth adapted for cutting off bits of vegetation and grinding plant material. In each case, structure and function are inter-related.
3. **Information must be transmitted within organisms and among organisms.** Each organism must be able to receive information from the surrounding environment. The survival and function of every cell and every organism depend on the orderly transmission of information. As we will learn, evolution depends on the transmission of genetic information from one generation to another.
4. **Life depends on a continuous input of energy from the sun because every activity of a living cell or organism requires energy.** Energy from the sun flows through individual organisms and through ecosystems. Within living cells energy is continuously transferred from one chemical compound to another.
5. **Evolution is the process by which populations of organisms change over time.** Scientists have accumulated a wealth of evidence showing that the diverse life-forms on this planet are related and that populations have *evolved*—that is, have changed over time—from earlier forms of life. The process of *evolution* is the framework for the science of biology and is a major theme of this book.

The interaction of biological systems, the inter-relationship of structure and function, information transfer, energy transfer, and the process of evolution are forces that give life its unique characteristics. You will find reference to one or more of these unifying themes in every chapter of *Biology.* We begin our study of biology by developing a more precise understanding of the fundamental characteristics of living systems and of the levels of biological organization. We then take a closer look at some of the major themes of biology. We end Chapter 1 with a discussion of the process of science.

CHECKPOINT 1.1

- *Why are information transmission, energy transfer, and evolution considered basic to life?*
- CONNECT *What are some ways in which an organism is dependent on other biological systems?*

1.2 CHARACTERISTICS OF LIFE

LEARNING OBJECTIVE

2 Distinguish between living systems and nonliving things by describing the features that characterize living organisms.

We easily recognize that a pine tree, a butterfly, and a horse are living systems, whereas a rock is not. Despite their diversity, the organisms that inhabit our planet share a common set of characteristics that distinguish them from nonliving things. These features include a precise kind of organization, growth and development, self-regulated metabolism, the ability to respond to stimuli, reproduction, and adaptation to environmental change.

Organisms are composed of cells

Although they vary greatly in size and appearance, all organisms consist of basic units called **cells.** New cells are formed only by the division of previously existing cells. As will be discussed in Chapter 4, these concepts are expressed in the **cell theory**, another fundamental unifying concept of biology.

Some of the simplest life-forms, such as protozoa, are *unicellular* organisms, meaning that each consists of a single cell (FIG. 1-1a). In contrast, the body of a maple tree or a buffalo is made of billions of cells (FIG. 1-1b). In such complex *multicellular* organisms, life processes depend on the coordinated functions of component cells that are organized to form tissues, organs, and organ systems.

Every cell is enveloped by a protective **plasma membrane** that separates it from the surrounding external environment. The plasma membrane regulates passage of materials between the cell and its environment. Cells have specialized molecules that contain genetic instructions and transmit genetic information. In most cells, the genetic instructions are encoded in deoxyribonucleic acid, more simply known as **DNA.** Cells typically have internal structures called **organelles** that are specialized to perform specific functions.

There are two fundamentally different types of cells: prokaryotic and eukaryotic. *Prokaryotic cells* are exclusive to bacteria and to microscopic organisms called *archaea*. Prokaryotic cells do not have a nucleus or other membrane-enclosed organelles. All other organisms are characterized by their *eukaryotic cells*. These cells typically contain a variety of organelles enclosed by membranes, including a **nucleus,** which houses DNA.

Mike Abbey/Visuals Unlimited, Inc.

(a) Unicellular organisms consist of one cell that performs all the functions essential to life. Ciliates, such as this *Paramecium*, move about by beating their hairlike cilia.

McMurray Photography

(b) Multicellular organisms, such as this African buffalo (*Syncerus caffer*) and the plants on which it grazes, may consist of billions of cells specialized to perform specific functions.

Figure 1-1 Unicellular and multicellular life-forms

Organisms grow and develop

Biological growth involves an increase in the size of individual cells of an organism, in the number of cells, or in both. Growth may be uniform in the various parts of an organism, or it may be greater in some parts than in others, causing the body proportions to change as growth occurs. Some organisms—most trees, for example—continue to grow throughout their lives. Many animals have a defined growth period that terminates when a characteristic adult size is reached. An intriguing aspect of the growth process is that each part of the organism typically continues to function as it grows.

Organisms develop as well as grow. **Development** includes all the changes that take place during an organism's life. The structures and body form that develop are exquisitely adapted to the functions the organism must perform. Like many other organisms, every human begins life as a fertilized egg that then grows and develops.

Organisms regulate their metabolic processes

Within all organisms, chemical reactions and energy transformations occur that are essential to nutrition, the growth and repair of cells, and the conversion of energy into usable forms. The sum of all the chemical activities of the organism is its **metabolism.**

Metabolic processes occur continuously in every organism, and they must be carefully regulated to maintain **homeostasis,** an appropriate, balanced internal environment. The term *homeostasis* also refers to the automatic tendency of the organism to maintain a steady state. When a particular substance is required, cell processes that produce it must be turned on. When enough of a cell product has been made, its manufacture must be decreased or turned off. These *homeostatic mechanisms* are self-regulating control systems that are remarkably sensitive and efficient.

The regulation of glucose (a simple sugar) concentration in the blood of complex animals is a good example of a homeostatic mechanism. Your cells require a constant supply of glucose molecules, which they break down to obtain energy. The circulatory system delivers glucose and other nutrients to all the cells. When the concentration of glucose in the blood rises above normal limits, glucose is stored in the liver and in muscle cells. When you have not eaten for a few hours, the glucose concentration begins to fall. Your body mobilizes stored glucose. If necessary, the body converts other stored nutrients to glucose, bringing the glucose concentration in the blood back to normal levels. When the glucose concentration decreases, you also feel hungry and can restore nutrients by eating.

Organisms respond to stimuli

All forms of life respond to **stimuli,** physical or chemical changes in their internal or external environment. Stimuli that evoke a response in most organisms are changes in the color, intensity, or direction of light; changes in temperature, pressure, or sound; and changes in the chemical composition of the surrounding soil, air, or water. Responding to stimuli involves movement, although not always locomotion (moving from one place to another).

In simple organisms, the entire individual may be sensitive to stimuli. Certain unicellular organisms, for example, respond to bright light by retreating. In some organisms, locomotion is achieved by the slow oozing of the cell, the process of *amoeboid movement.* Other organisms move by beating tiny, hairlike extensions of the cell called **cilia** or longer structures known as **flagella** (FIG. 1-2). Some bacteria move by rotating their flagella.

Most animals move very obviously. They wiggle, crawl, swim, run, or fly by contracting muscles. Sponges, corals, and oysters have free-swimming larval stages, but most are **sessile** as adults, meaning that they do not move from place to place. In fact, they may remain firmly attached to a surface, such as the sea bottom or a rock. Many sessile organisms have cilia or flagella that beat rhythmically, bringing them food and oxygen in the surrounding water. Complex animals, such as grasshoppers, lizards, and humans, have highly specialized cells that respond to specific types of stimuli. For example, cells in the retina of the vertebrate eye respond to light.

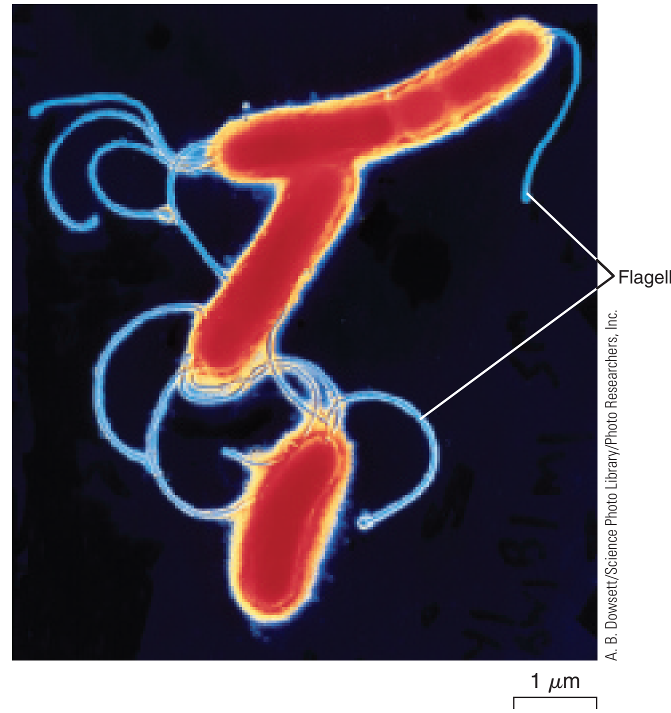


Figure 1-2 Biological movement
These bacteria (*Helicobacter pylori*), equipped with flagella for locomotion, have been linked to stomach ulcers. The photograph was taken using a scanning electron microscope. The bacteria are not really red and blue. Their color has been artificially enhanced.

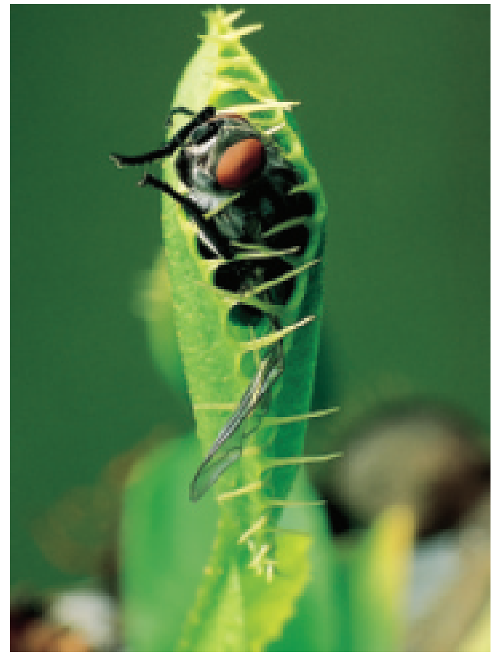
Although their responses may not be as obvious as those of animals, plants do respond to light, gravity, water, touch, and other stimuli. For example, plants orient their leaves to the sun and grow toward light. Many plant responses involve different growth rates of various parts of the plant body. A few plants, such as the Venus flytrap of the Carolina swamps, are very sensitive to touch and catch insects (FIG. 1-3). Their leaves are hinged along the midrib, and they have a scent that attracts insects. Trigger hairs on the leaf surface detect the arrival of an insect and stimulate the leaf to fold. When the edges come together, they interlock, preventing the insect's escape. The leaf then secretes enzymes that kill and digest the insect. The Venus flytrap usually grows in nitrogen-deficient soil. The plant obtains part of the nitrogen required for its growth from the insects it "eats."

Organisms reproduce

At one time, people thought worms arose spontaneously from horsehair in a water trough, maggots from decaying meat, and frogs from the mud of the Nile. Thanks to the work of a great many scientists, beginning with pioneering studies by Italian physician Francesco Redi in the 17th century and French chemist Louis Pasteur in the 19th century, we know that organisms arise only from previously existing organisms.

David M. Dennis

(a) When hairs on the leaf surface of the Venus flytrap (*Dionaea muscipula*) detect the touch of an insect, the leaf responds by folding.



David M. Dennis

(b) The edges of the leaf come together and interlock, preventing the fly's escape. The leaf then secretes enzymes that kill and digest the insect.

Figure 1-3 Plants respond to stimuli

Simple organisms, such as amoebas, perpetuate themselves by **asexual reproduction** (FIG. 1-4a). When an amoeba has grown to a certain size, it reproduces by splitting in half to form two new amoebas. Before an amoeba divides, its hereditary material (set of *genes*) is duplicated, and one complete set is distributed to each new cell. Except for size, each new amoeba is similar to the parent cell. The only way that variation occurs among asexually reproducing organisms is by genetic *mutation*, a permanent change in the genes.

In most plants and animals, **sexual reproduction** is carried out by the fusion of an egg and a sperm cell to form a fertilized egg (FIG. 1-4b). The new organism develops from the fertilized egg. Offspring produced by sexual reproduction are the product of the interaction of various genes contributed by the mother and the father. This genetic variation is important in the vital processes of evolution and adaptation.

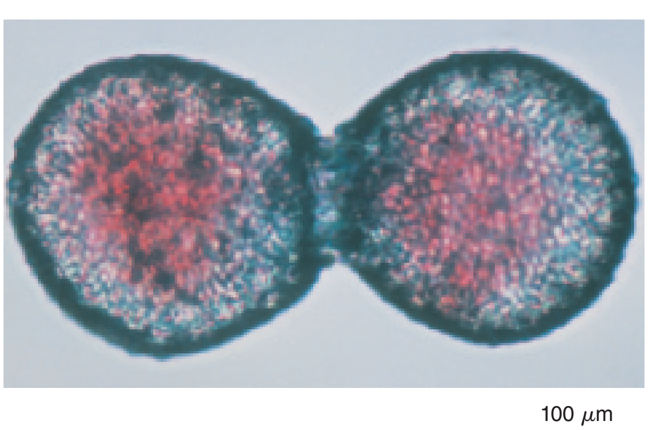
Populations evolve and become adapted to the environment

The ability of a population to evolve over many generations and adapt to its environment equips it to survive in a changing world. **Adaptations** are inherited characteristics that enhance an organism's ability to survive in a particular environment. The long, flexible tongue of the frog is an adaptation for catching insects. The feathers and lightweight bones of birds are adaptations for flying, and their thick fur coats allow polar bears to survive in frigid temperatures. Adaptations may be structural, physiological, biochemical, behavioral, or a combination of all four (FIG. 1-5). Every biologically successful organism is a complex collection of coordinated adaptations produced through evolutionary processes.

CHECKPOINT 1.2

- *What characteristics distinguish a living organism from a rock?*
- PREDICT *What would be the consequences to an organism if its homeostatic mechanisms failed? Explain your answer.*

Figure 1-4 Asexual and sexual reproduction



Cabisco/Visuals Unlimited, Inc.

(a) Asexual reproduction. One individual gives rise to two or more offspring that are similar to the parent. *Difflugia*, a unicellular amoeba, is shown dividing to form two amoebas.

L. E. Gilbert/Biological Photo Service

(b) Sexual reproduction. Typically, each of two parents contributes a gamete (sperm or egg). Gametes fuse to produce the offspring, which has a combination of the traits of both parents. A pair of tropical flies is shown mating.

Figure 1-5 Adaptations

These Burchell's zebras (*Equus burchelli*), photographed in Tanzania, are behaviorally adapted to position themselves to watch for lions and other predators. Stripes are thought to be an adaptation for visual protection against predators. They serve as camouflage or to break up form when spotted from a distance. The zebra stomach is adapted for feeding on coarse grass passed over by other grazers, an adaptation that helps the animal survive when food is scarce.

1.3 LEVELS OF BIOLOGICAL ORGANIZATION

LEARNING OBJECTIVE

3 Construct a hierarchy of biological organization, including levels characteristic of individual organisms and levels characteristic of ecological systems.

Whether we study a single organism or the world of life as a whole, we can identify a hierarchy of biological organization (**FIG. 1-6**). At every level, structure and function are precisely coordinated. One way to study a particular level is by looking at its components. Biologists can gain insights about cells by studying atoms and molecules. Learning about a structure by studying its parts is called **reductionism.** However, the whole is more than the sum of its parts. Each level has **emergent properties,** characteristics not found at lower levels. For example, populations of organisms have emergent properties such as population density, age structure, and birth and death rates. The *individuals* that make up a population do not have these characteristics. Consider also the human brain. The brain is composed of billions of neurons (nerve cells). However, we could study every one of these individual neurons and have no clue about the functional capacities of the brain. Only when the neurons interact are the emergent properties, such as the capacity for thought, judgment, and motor coordination, evident.

Organisms have several levels of organization

The chemical level, the most basic level of organization, includes atoms and molecules. An **atom** is the smallest unit of a chemical element that retains the characteristic properties of that element. For example, an atom of iron is the smallest possible amount of iron. Atoms combine chemically to form **molecules.** Two atoms of hydrogen combine with one atom of oxygen to form a single molecule of water. Although composed of two types of atoms that are gases under conditions found on Earth, water can exist as a gas, liquid, or solid. The properties of water are very different from those of its hydrogen and oxygen components, an example of emergent properties.

At the cellular level, many types of atoms and molecules associate with one another to form *cells*. However, a cell is much more than a heap of atoms and molecules. Its emergent properties make it the basic structural and functional unit of life, the simplest component of living matter that can carry on all the activities necessary for life.

During the evolution of multicellular organisms, cells associated to form **tissues.** For example, most animals have muscle tissue and nervous tissue. Plants have epidermis, a tissue that serves as a protective covering, and vascular tissues that move materials throughout the plant body. In most complex organisms, tissues organize into functional structures called **organs**, such as the heart and stomach in animals and roots and leaves in plants. In animals, each major group of biological functions is performed by a coordinated group of tissues and organs called an **organ system.** The circulatory and digestive systems are examples of organ systems. Functioning together with great precision, organ systems make up a complex, multicellular **organism.** Again, emergent properties are evident. An organism is much more than its component organ systems.

Several levels of ecological organization can be identified

Organisms interact to form still more complex levels of biological organization. All the members of one species living in the same geographic area at the same time make up a **population.** The populations of various types of organisms that inhabit a particular area and interact with one another form a **community.** A community can consist of hundreds of different types of organisms.

A community together with its nonliving environment is an **ecosystem.** An ecosystem can be as small as a pond (or even a puddle) or as vast as the Great Plains of North America or the Arctic tundra. All Earth's ecosystems together are known as the **biosphere.** The biosphere includes all systems of Earth that are inhabited by living organisms: the atmosphere, the hydrosphere (water in any form), and the lithosphere (Earth's crust). The study of how organisms relate to one another and to their physical environment is called **ecology** (derived from the Greek *oikos*, meaning "house").

CHECKPOINT 1.3

- *What are the levels of organization within an organism?*
- **PREDICT** *At which level do you think more biological systems would be interacting: organism, population, or ecosystem? Justify your answer.*

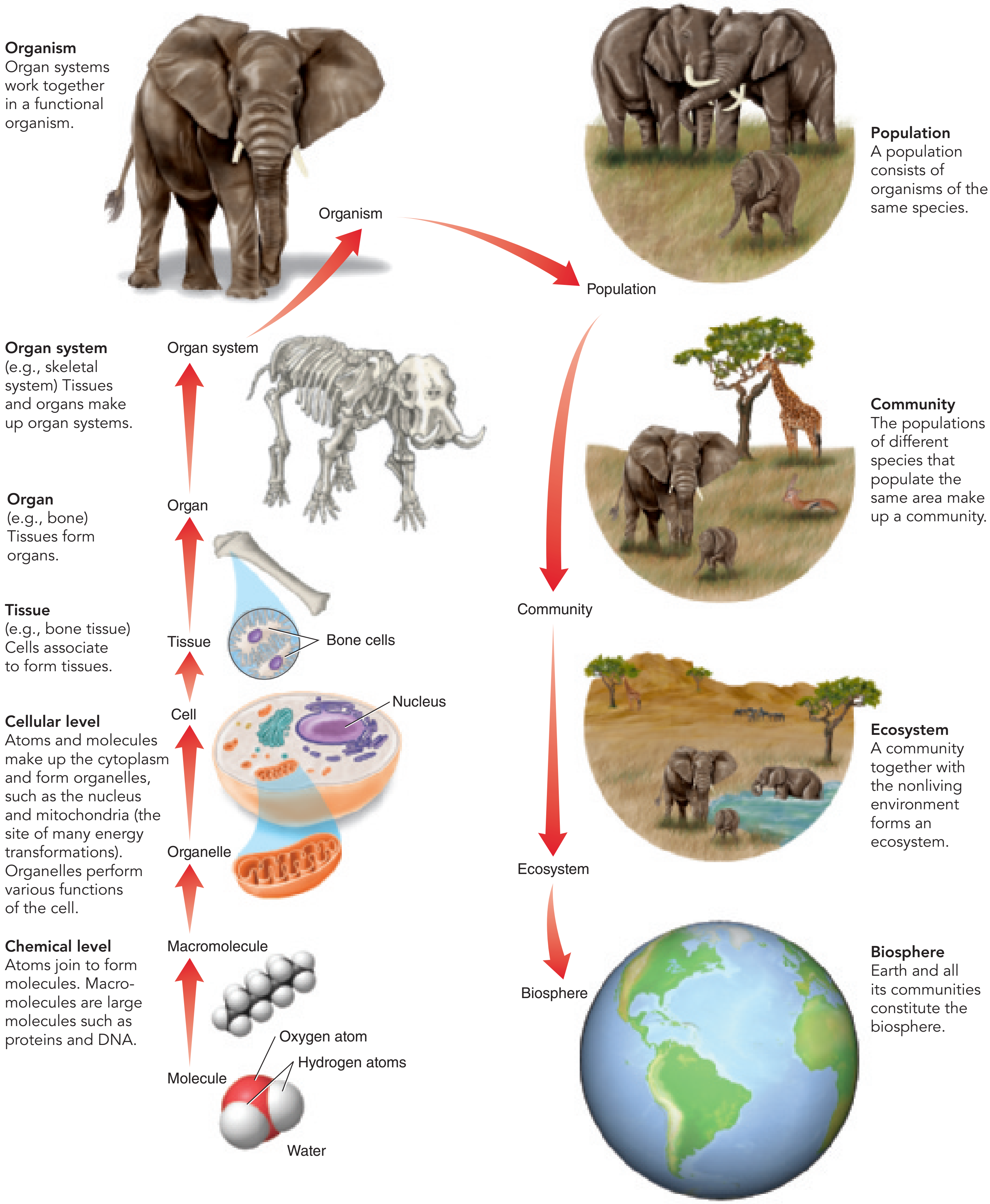


Figure 1-6 ***Animation*** **The hierarchy of biological organization**

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1.4 INFORMATION TRANSFER

LEARNING OBJECTIVE

4 Summarize the importance of information transfer within and between living systems, giving specific examples.

Biological systems receive and respond to information. They also store information. An organism inherits the information it needs to grow, develop, carry on self-regulated metabolism, respond to stimuli, and reproduce. Each organism must also have precise instructions for making the molecules necessary for its cells to communicate. The information an organism requires to carry on these life processes is coded and transmitted in the form of chemical substances and electrical impulses.

DNA transmits information from one generation to the next

Humans give birth only to human babies, not to giraffes or rosebushes. In organisms that reproduce sexually, each offspring is a combination of the traits of its parents. In 1953, James Watson and Francis Crick worked out the structure of DNA, the large molecule that makes up the **genes,** units of hereditary information (FIG. 1-7). A DNA molecule consists of two chains of atoms twisted into a helix. As will be described in Chapter 3, each chain is made up of a sequence of chemical subunits called **nucleotides.** There are four types of nucleotides in DNA, and each sequence of three nucleotides is part of the genetic code.

Watson and Crick's work led to the understanding of the genetic code. The information coded in sequences of nucleotides in DNA transmits genetic information from generation to generation. The code works somewhat like an alphabet. The nucleotides can "spell" an amazing variety of instructions for making organisms as diverse as bacteria, frogs, and redwood trees. The genetic code is universal—that is, virtually identical in all organisms—and is a dramatic example of the unity of life.

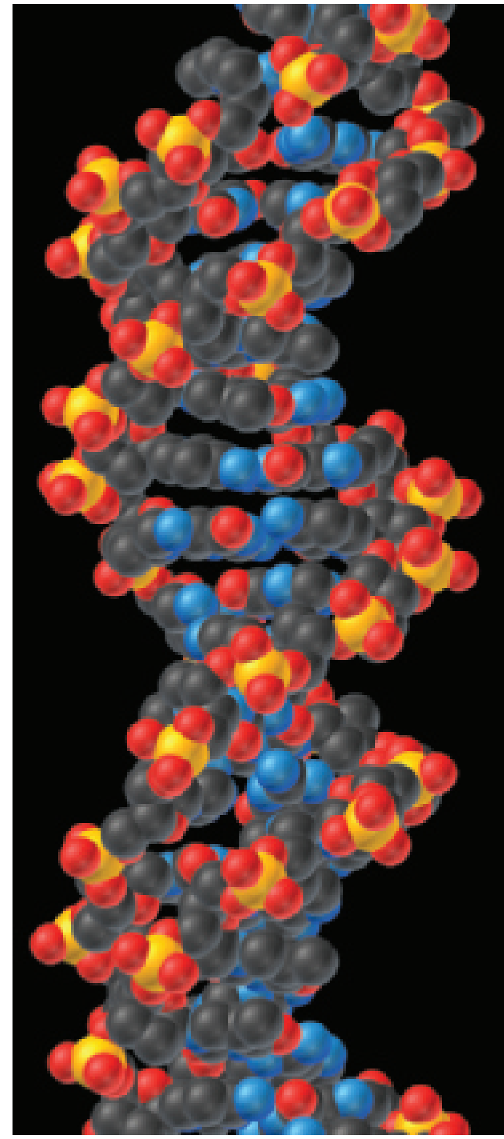

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Figure 1-7 DNA

DNA is the hereditary material that transmits information from one generation to the next. As shown in this model, DNA is a macromolecule that consists of two chains of atoms twisted into a helix. Each chain consists of subunits called nucleotides. The sequence of nucleotides makes up the genetic code.

Information is transmitted by chemical and electrical signals

Genes control the development and functioning of every organism. As you will learn in later chapters, the information carried by the DNA that makes up the genes has many functions, including providing the "recipes" for making all the proteins required by the organism. **Proteins** are large molecules important in determining the structure and function of cells and tissues. For example, brain cells differ from muscle cells in large part because they have different types of proteins. Some proteins are important in communication within and among cells. Certain proteins on the surface of a cell serve as markers so that other cells "recognize" them. Other cell-surface proteins serve as receptors that combine with chemical messengers.

Cells use proteins and many other types of molecules to communicate with one another. In a multicellular organism, cells produce chemical compounds, such as **hormones,** that signal other cells. Hormones and other chemical messengers can signal cells in distant organs to secrete a particular required substance or change some metabolic activity. In this way chemical signals help regulate growth, development, and metabolic processes. The mechanisms involved in **cell signaling** often involve complex biochemical processes.

Cell signaling is currently an area of intense research. A major focus has been the transfer of information among cells of the immune system. A better understanding of how cells communicate promises new insights into how the body protects itself against disease organisms. Learning to manipulate cell signaling may lead to new methods of delivering drugs into cells and new treatments for cancer and other diseases.

Many organisms use electrical signals to transmit information. Most animals have nervous systems that transmit information by way of both electrical impulses and chemical compounds known as **neurotransmitters**. Information transmitted from one part of the body to another is important in regulating life processes. In complex animals, the nervous system gives the animal information about its outside environment by transmitting signals from sensory receptors such as the eyes and ears to the brain.

Organisms also communicate information to one another

Organisms communicate information to other organisms by releasing chemicals, sounds, and visual displays. Typically, organisms use a combination of several types of communication signals. A dog may signal aggression by growling, using a particular facial expression, and laying its ears back. Many animals perform complex courtship rituals in which they display parts of their bodies, often elaborately decorated, to attract a mate.

Seaweed algae compete with coral for light and space. Marine biologists studying endangered coral reefs have discovered that certain seaweed algae secrete chemical compounds that kill coral. Researchers have reported that some coral can fight back. When they come into contact with toxic seaweed, the coral release chemical compounds that signal certain species of goby fish. In response to this chemical signal, the fish eat the seaweed. This action helps preserve their coral reef habitat.

CHECKPOINT 1.4

- *What is the function of DNA?*
- *How does a nervous system transmit information?*

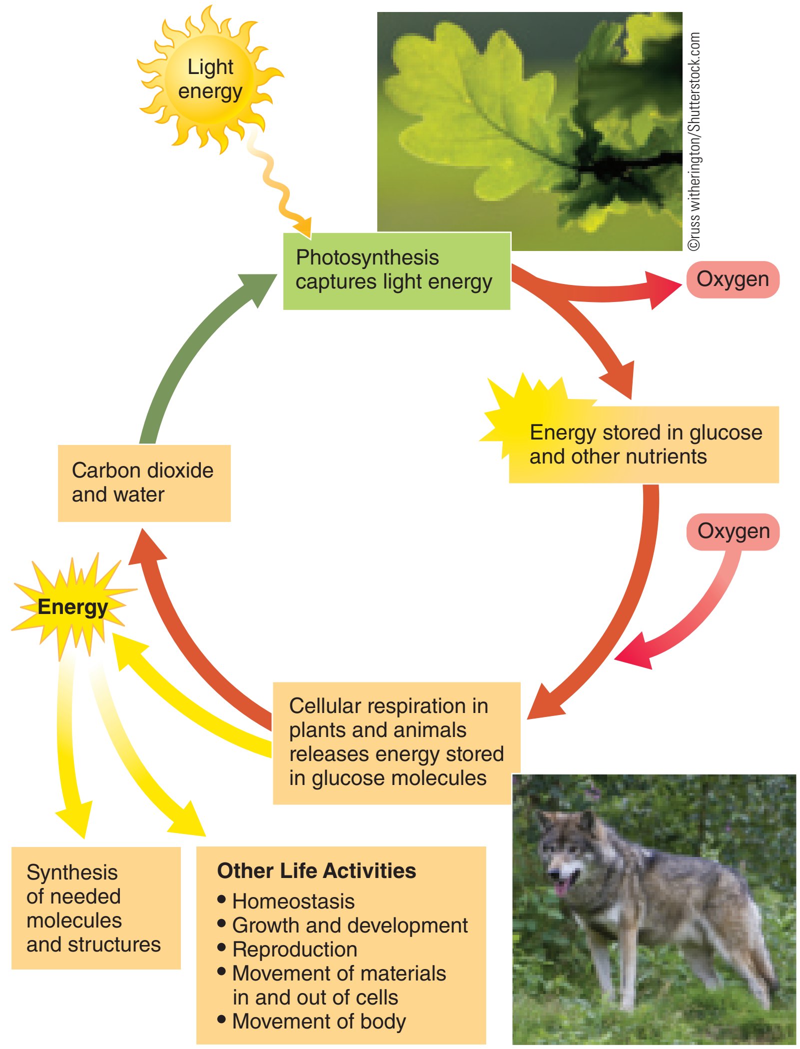

Figure 1-8 *Animation* **Energy flow within and among organisms**
Algae and certain plant cells carry on photosynthesis, a process that uses light energy to produce glucose from carbon dioxide and water. Energy is stored in the chemical bonds of glucose and other nutrients produced from glucose. Through the process of cellular respiration, cells of all organisms, including algae and plant cells, then break down glucose and other nutrients. The energy released can be used to produce needed molecules and to fuel other life activities.
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1.5 THE ENERGY OF LIFE

LEARNING OBJECTIVE

5 Summarize the flow of energy through ecosystems and contrast the roles of producers, consumers, and decomposers.

The sun provides most of the energy that powers life on Earth. All life processes, including thousands of chemical transactions that maintain life's organization, require a continuous input of energy. Organisms can neither create energy nor use it with complete efficiency. During every energy transaction, some energy is converted to heat and dispersed into the environment. Energy flows through individual organisms and through ecosystems.

A self-sufficient ecosystem consists of a physical environment inhabited by three types of organisms: producers, consumers, and decomposers. These organisms depend on one another and on the environment for nutrients, energy, oxygen, and carbon dioxide. Plants, algae, and certain bacteria are **producers,** or **autotrophs**, organisms that produce their own food from simple raw materials. Most of these organisms carry on **photosynthesis**, the process during which autotrophs use carbon dioxide, water, and light energy to synthesize complex molecules such as glucose and other sugars (**FIG. 1-8**):

$$\text{carbon dioxide} + \text{water} + \text{light energy} \longrightarrow \text{glucose} + \text{oxygen}$$

The light energy is transformed into chemical energy, which is stored within the chemical bonds of the glucose and other food molecules produced. Oxygen, which is required by the cells of most organisms including plant cells, is produced as a byproduct of photosynthesis.

Recall that all the energy transformations and chemical processes that occur within an organism are referred to as its *metabolism.* Energy is necessary to carry on the metabolic