
BIOLOGY
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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

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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.

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.

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

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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.

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