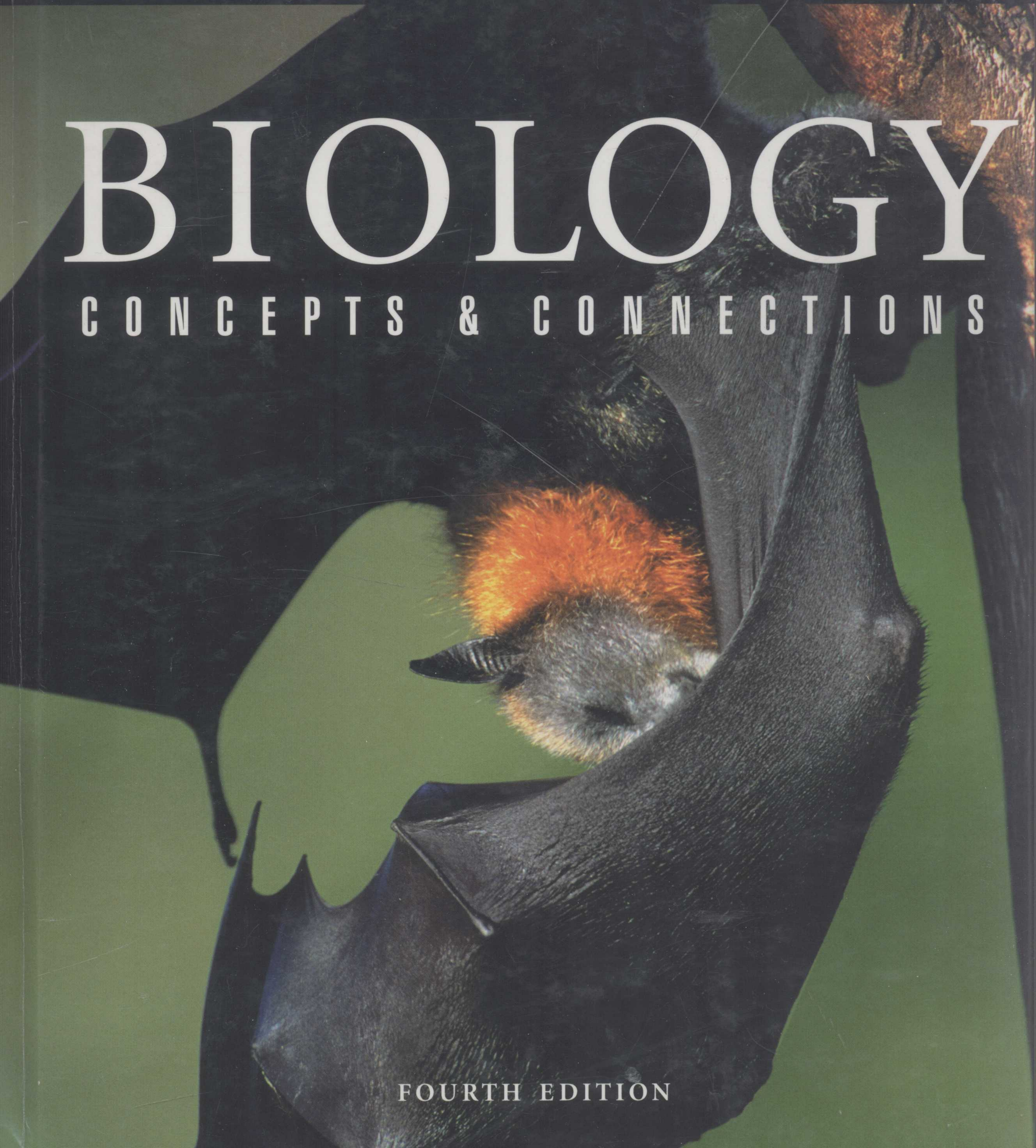
CAMPBELL · REECE · MITCHELL · TAYLOR

# BIOLOGY

## CONCEPTS & CONNECTIONS



FOURTH EDITION

# BIOLOGY

## CONCEPTS & CONNECTIONS

Fourth Edition

Neil A. Campbell
Jane B. Reece
Lawrence G. Mitchell
Martha R. Taylor

Benjamin Cummings

San Francisco • Boston • New York
Cape Town • Hong Kong • London • Madrid • Mexico City
Montreal • Munich • Paris • Singapore • Sydney • Tokyo • Toronto

Executive Editor: Beth Wilbur
Developmental Manager, Text and Media: Pat Burner
Senior Project Editor: Ginnie Simione Jutson
Developmental Editor: Kim Johnson Krummel
Developmental Editor: Evelyn Dahlgren
Developmental Artist: Carla Simmons
Senior Art Editor: Donna Kalal
Photo Image Manager: Travis Amos
Associate Editor, Media: Aaron Gass
Publishing Assistant: Krystina Sibley
Marketing Manager: Josh Frost
Senior Producer, Art and Media: Russell Chun
Production: Jonathan Peck and Joan Keyes, Dovetail Publishing Services
Manufacturing Buyer: Vivian McDougal
Manager, Production and Manufacturing: Diane Southworth
Copyeditors: Janet Greenblatt, John Burner, Pete Shanks
Text Designer: Frances Baca
Cover Designer: Yvo Riezebos
Indexer: Charlotte Shane
Proofreaders: Linda Smith, Pete Shanks
Illustrations: Precision Graphics
Compositor and Prepress: Dovetail Publishing Services, Thompson Type
Cover Printer: Phoenix Color
Printer: Von Hoffmann Press, Inc.

*On the cover:* Photograph of a gray-headed flying fox (*Pteropus poliocephalus*), Queensland, Australia, © Getty/Theo Allofs

Credits continue in Appendix 4.



**Library of Congress Cataloging-in-Publication Data**

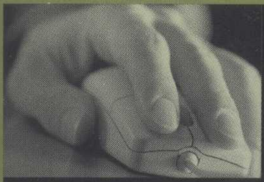
Campbell, Neil A., 1946–
Biology : concepts & connections / Neil A. Campbell . . . [et al.].—4th ed.
p. cm.
Includes bibliographical references (p. ).
ISBN 0-8053-6627-X
1. Biology. I. Campbell, Neil A., 1946–

QH308.2.B56448 2002
570—dc21 2002073633

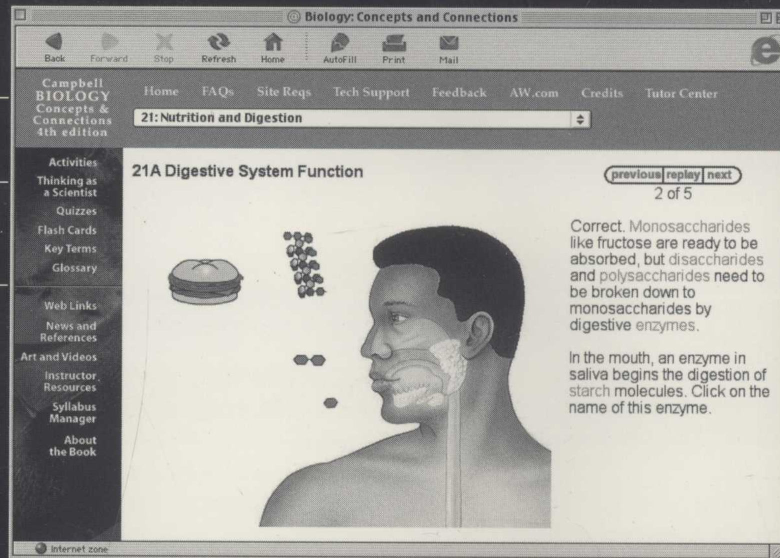
3 4 5 6 7 8 9 10—VHP—06 05 04

High School Binding distributed by
Scott Foresman-Addison Wesley, Glenview, Illinois
ISBN 0-8053-0013-9

Benjamin Cummings
1301 Sansome Street
San Francisco, CA 94111
www.aw.com/bc



# Free Student Aid.




**Log in.**

**Explore.**

**Succeed.**

To help you succeed in introductory biology, every new copy of ***Biology: Concepts & Connections***, Fourth Edition, comes with great media resources on an interactive CD-ROM and web site. See the back of this insert for a description of the media resources designed to help you learn biology.

**Got technical questions?**
For technical support, go to
http://247.aw.com/mediaform

**Minimum system requirements:**

WINDOWS
166 MHz Intel Pentium processor
Windows 95, 98, NT4, 2000, or XP
32 MB RAM installed
800 x 600 screen resolution
Browser: Internet Explorer 5.0 or higher or Netscape Communicator 4.7
Plug-Ins: Shockwave Player 8, Flash Player 5, QuickTime 4
4x CD-ROM drive (for CD-ROM)
Internet connection with 56K modem (for web site)

MACINTOSH
120 MHz PowerPC
OS 8.6 or higher
24 MB RAM available
800 x 600 screen resolution, thousands of colors
Browser: Internet Explorer 5.0 or higher (web only) or Netscape Communicator 4.7
Plug-Ins: Shockwave Player 8, Flash Player 5, QuickTime 4
4x CD-ROM drive (for CD-ROM)
Internet connection with 56K modem (for web site)

**Here's your personal ticket to success:**

**How to log in to *Biology: Concepts & Connections* web site**

1. Go to www.campbellbiology.com
2. Click the book cover for *Biology: Concepts & Connections*, Fourth Edition.
3. Click "Register."
4. Enter your pre-assigned access code exactly as it appears below.
5. Complete the online registration form to create your own personal Login Name and Password.
6. Once your personal Login Name and Password are confirmed by e-mail, go to www.campbellbiology.com and click on your book cover. Type in your personal Login Name and Password and click "Log In."

**Your Access Code is:**

Record your personal Login Name and Password on the back of this card. Cut out this card and keep it handy. It's your ticket to valuable information.

If you have purchased a used copy of this book, this access code may not be valid. You may purchase a subscription to the web site at www.campbellbiology.com.

**Important:** Please read the License Agreement located on the "Welcome" screen before using the *Biology: Concepts & Connections* web site or CD-ROM. By using the web site or CD-ROM, you indicate that you have read, understood, and accepted the terms of this agreement.

0-8053-6627-X / 0-321-10679-2

## Features of the Web Site and Student CD-ROM for *Biology: Concepts & Connections*, Fourth Edition

### Activities
Explore approximately 200 activities, including animations, interactive review exercises, and videos. Test your knowledge with Activities Quizzes that can be e-mailed to instructors.

### Thinking as a Scientist
Perform 56 virtual investigations that develop scientific thinking skills such as data collection, analysis, and communication of results. Answer questions in a Lab Report that can be e-mailed. With a subscription to Biology Labs On-Line, link to 12 more extensive virtual labs and complete assignments that can be e-mailed.

### Quizzes
Assess understanding with over 3,000 multiple-choice questions. Each chapter includes a Pre-Test to diagnose current knowledge (10 questions per chapter), an Activities Quiz with graphics that tests understanding of the media Activities in the chapter (20 questions per chapter on average), and a comprehensive Chapter Quiz (50 questions per chapter on average). Each quiz has hints, immediate feedback, grading, and e-mailable results.

### Flash Cards
Use electronic flash cards to test your knowledge of the key terms and definitions for each chapter or multiple chapters. Includes audio pronunciations for selected terms.

### Key Terms
Study the list of key terms for each chapter, looking up definitions and hearing selected audio pronunciations. Word roots are also provided to improve vocabulary skills.

### Glossary
Look up definitions of boldface terms and hear selected audio pronunciations.

## Additional Features of the Web Site

### Web Links
Each chapter includes links to relevant web sites with descriptions of the sites.

### News and References
Access news links on recent developments in biology, organized by chapter. Consult an archive of relevant biology news articles and lists of further readings for each chapter.

### Art and Videos
View art from the textbook and 85 videos. The art is provided both with and without labels. The art can be printed out to take to class for note-taking and the version without labels can be used as a self-quiz.

**Your Login Name**

______________________

**Your Password**

______________________

Your subscription to the *Biology: Concepts & Connections* web site is good for 12 months from registration.

### How to Start the Student CD-ROM

WINDOWS:

1. Insert the Student CD-ROM into the CD-ROM drive. If you have autorun turned on, the installer should launch automatically. If it does not, follow these steps:
   a) Navigate through My Computer to your default CD-ROM drive.
   b) Double-click on the CD-ROM icon.
   c) Double-click on the Windows_Installer.exe icon and follow the instructions in the dialog boxes.
2. Click the "Check Browser" button to launch your default browser and see if it meets the minimum system requirements.
3. If you need to install a new browser, click the "Install Browser" button and select a browser to install.
4. After you have a browser that meets the minimum requirements, click on the "Install Plug-ins" button and launch each of the installers for the required plug-ins.
5. Once all plug-ins have been installed, return to the Main Screen and click the "Launch" button to begin using the CD-ROM.

Once you have a valid browser and have installed all the required plug-ins you can skip the above steps and click on the "Launch" button directly to begin using the CD-ROM. Or, if you have the valid browser and plug-ins installed and you don't have autorun installed, you can click on Bio_Concepts_&_Connections.html to skip the installation process.

MACINTOSH:

1. Insert the Student CD-ROM into the CD-ROM drive. Double-click the Macintosh_Installer.
2. Click the "Check Browser" button to launch your default browser and see if it meets the minimum system requirements.
3. If you need to install a new browser, click the "Install Browser" button and select a browser to install.
4. After you have a browser that meets the minimum requirements, click on the "Install Plug-ins" button and launch each of the installers for the required plug-ins.
5. Once all plug-ins have been installed, return to the Main Screen and click the "Launch" button to begin using the CD-ROM.

Once you have a valid browser and have installed all the required plug-ins you can skip these steps and click on the "Launch" button to begin using the CD-ROM. Or, if you have the valid browser and plug-ins installed, you can click on Bio_Concepts_&_Connections.html to skip the installation process.

# ABOUT THE AUTHORS

Left to right, authors Campbell, Reece, Mitchell, and Taylor

**Neil A. Campbell** has taught general biology for 30 years, and with Dr. Reece, has coauthored *Biology*, Sixth Edition, the most widely used text for biology majors. His enthusiasm for sharing the fun of science with students stems from his own undergraduate experience. He began at Long Beach State College as a history major, but switched to zoology after general education requirements "forced" him to take a science course. Following a B.S. from Long Beach, he earned an M.A. in Zoology from UCLA and a Ph.D. in Plant Biology from the University of California, Riverside. He has published numerous articles on how certain desert plants thrive in salty soil and how the sensitive plant (*Mimosa*) and other legumes move their leaves. His diverse teaching experiences include courses for non-biology majors at Cornell University, Pomona College, and San Bernardino Valley College, where he received the first Outstanding Professor Award in 1986. Dr. Campbell is currently a visiting scholar in the Department of Botany and Plant Sciences at UC Riverside, which recognized him as the university's Distinguished Alumnus for 2001. In addition to *Biology*, Sixth Edition, he is the coauthor of *Essential Biology*.

**Jane B. Reece** has worked in biology publishing since 1978, when she joined the editorial staff of Benjamin Cummings. Her education includes an A.B. in Biology from Harvard University, an M.S. in Microbiology from Rutgers University, and a Ph.D. in Bacteriology from the University of California, Berkeley. At UC Berkeley and later as a postdoctoral fellow in genetics at Stanford University, her research focused on genetic recombination in bacteria. Dr. Reece taught biology at Middlesex County College (New Jersey) and Queensborough Community College (New York). During her 12 years as an editor at Benjamin Cummings, she played major roles in a number of successful textbooks. Subsequently, she was a coauthor of *The World of the Cell*, Third Edition, with W. M. Becker and M. F. Poenie. With Dr. Campbell, she coauthors *Biology*, Sixth Edition, and *Essential Biology*.

**Lawrence G. Mitchell** has 21 years of experience teaching a broad range of life science courses at both undergraduate and graduate levels. He holds a B.S. in Zoology from Pennsylvania State University and a Ph.D. in Zoology and Microbiology from the University of Montana. Following postdoctoral research with the National Institute of Allergy and Infectious Diseases, Dr. Mitchell joined the biology faculty at Iowa State University in 1971. He received the Outstanding Teacher Award at Iowa State in 1982. In addition to numerous research publications in aquatic parasitology, Dr. Mitchell has coauthored the textbook *Zoology*, two laboratory manuals, and a study guide for introductory biology. He has also developed television courses in general biology and has written, produced, and narrated programs on wildlife biology for public television. Dr. Mitchell is a full-time writer.

**Martha R. Taylor** has been teaching biology for over 20 years. She earned her B.A. in Biology from Gettysburg College and her M.S. and Ph.D. in Science Education from Cornell University. She was Assistant Director of the Office of Instructional Support at Cornell for seven years. She has taught introductory biology for both majors and non-majors at Cornell University for many years and is currently a visiting lecturer in Cornell's introductory biology laboratory course. Based on her experiences working with students from high school and community college through university, in both classrooms and tutorials, Dr. Taylor is committed to helping students create their own knowledge of and appreciation for biology. She has been the author of the *Student Study Guide* for all six editions of *Biology*, by Drs. Campbell and Reece.

# Introduce yourself to the chapter.

**Find out where you're going.**
Use the *chapter outline* to preview the chapter.

CHAPTER 6



*How Is a Marathoner Different from a Sprinter?*

**ATHLETES WHO PARTICIPATE** in track competitions usually have a favorite event in which they excel. For some runners, this event may be a sprint, a short race of only 100 or 200 meters. For others, it may be a race of 1,000, 5,000, or even 10,000 meters. It is unusual to find a runner who competes equally well in both 100-meter and 10,000-meter races; runners just seem to feel more comfortable running races of particular lengths. But why? Is it a matter of habit?

Could it be that runners' bodies "tell" them which races are best for them? There are indications that this is indeed the case. The muscles that move our legs contain two main types of muscle fibers, called slow and fast muscle fibers. Slow muscle fibers (also called "slow-twitch" fibers) are muscle cells that can sustain repeated, long contractions but don't generate a lot of quick power for the body. They perform better in endurance exercises, like long-distance running, which requires slow, steady muscle activity. Fast muscle fibers ("fast-twitch" fibers) are cells that can contract more quickly and powerfully than slow fibers but fatigue much more easily; they function best for short bursts of intense activity, like weight lifting or sprinting.

All human muscles contain both slow and fast fibers, but muscles differ in the percentage of each. The percentage of each fiber type in a particular muscle also varies from person to person. For example, in the quadriceps muscles of the legs, most marathon runners have about 80% slow fibers, whereas sprinters have about 60% fast fibers. These differences, which are genetically determined, undoubtedly help account for our differing athletic capabilities. Training can't usually turn one kind of runner into another!

# Focus on what's most important.

**Get the big picture.**
Look for the *main headings* (orange bars) that organize the chapter into major sections.

**Understand biology, one concept at a time.**
Each module features a *central concept*, announced in its heading.

**Use both text and figures as you study.**
The *figures* illuminate the text and vice versa. Text and figures are always together—you'll never have to turn a page to find what you need.

INTRODUCTION TO CELLULAR RESPIRATION

## 6.1 Breathing supplies oxygen to our cells and removes carbon dioxide

We often use the word *respiration* as a synonym for "breathing," the meaning of its Latin root. In this sense, respiration refers to an exchange of gases: An organism obtains $O_2$ from its environment and releases $CO_2$ as a waste product. Biologists also define respiration as the aerobic harvesting of energy from food molecules by cells. This process is called cellular respiration to distinguish it from breathing.

Breathing and cellular respiration are closely related. As the gymnast in Figure 6.1 goes through her routine, her lungs take up $O_2$ from the air and pass it to her bloodstream. The bloodstream carries the $O_2$ to her muscle cells. Mitochondria in the muscle cells use the $O_2$ in cellular respiration, harvesting energy from sugar and other organic molecules the gymnast obtained from food several hours before. The energy is used to generate ATP, which the muscle cells then use to contract. Simultaneous contraction of many thousands of muscle cells, precisely controlled by the nervous system, makes the gymnast's body move. Her bloodstream and lungs also perform the vital function of disposing of the $CO_2$ waste produced by cellular respiration in the muscle cells.

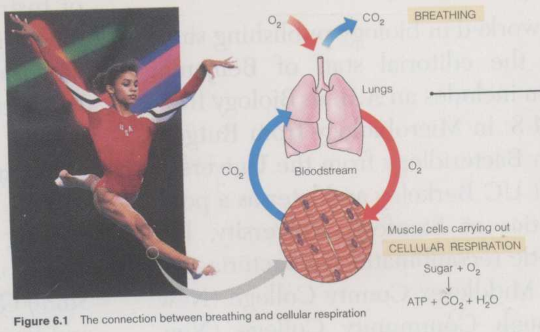



**Figure 6.1** The connection between breathing and cellular respiration

? How is your breathing related to your cellular respiration?

In breathing, your lungs exchange $CO_2$ and $O_2$ between your body and the atmosphere. In cellular respiration, your cells consume the $O_2$ in extracting energy from food and release $CO_2$ as a waste product.

# How Cells Harvest Chemical Energy

But what makes these two types of muscle fibers perform so differently? An important part of the answer is that they use different processes for making ATP (see Module 5.4), the substance that supplies the energy for muscle contraction. While both types of muscle cells break down sugar (chiefly glucose) to make chemical energy available for ATP production, slow fibers do it *aerobically*, using oxygen ($O_2$), while fast fibers work *anaerobically*, without oxygen.

Fast muscle (white meat) and slow muscle (dark meat) from a turkey.

A closer look at the differing structures of these two kinds of muscle cells helps explain their differing functions. The structure of slow fibers supports their aerobic function in three ways: First, the fibers are thin, maximizing their surface area and hence their contact with blood vessels carrying oxygen. Second, the fibers have many mitochondria, the organelles where aerobic ATP production occurs. And third, the fibers contain many molecules of myoglobin, a red protein related to hemoglobin that, like hemoglobin, is a carrier of $O_2$ molecules. The myoglobin gives slow muscle fibers a reddish color. You've undoubtedly seen this color in the "dark meat" of cooked turkeys, whose leg muscles are composed mostly of myoglobin-rich slow fibers. The aerobic harvesting of energy from sugar by muscle cells (or other cells) is called **cellular respiration.** This process yields carbon dioxide ($CO_2$), water ($H_20$), and a large amount of ATP—perfect for sustaining long muscle contractions.

Fast muscle fibers, on the other hand, have a structure that allows for a quicker energy-harvesting process that doesn't require $O_2$ but produces much less ATP per glucose molecule. Fast fibers are thicker than slow ones, have fewer mitochondria, and have much less myoglobin, making them pale in color. (Turkey breast muscles, specialized for quick bursts of flight, consist of fast fibers—"white meat.") The thickness of fast fibers enhances their power. But when oxygen is not available, they can't completely break down glucose. Instead of producing $CO_2$, they produce lactic acid, a larger molecule that makes muscles ache and fatigue. This is why fast muscle fibers are best at supplying short bursts of power. Anaerobic ATP production in our muscles is only effective for a minute or so.

Muscle cells are not the only cells in our body that break down sugars and other food molecules for ATP production. Nearly all our cells harvest chemical energy from food—as do the cells of all other organisms, eukaryotic and prokaryotic alike. Most cells of most organisms function like slow muscle fibers in that they carry out the aerobic process of cellular respiration. We begin this chapter with a look at how our own cells obtain $O_2$ for cellular respiration and dispose of $CO_2$.

89

**Discover.**
The *opening essays* introduce the chapter topic through stories that will pique your curiosity.

## 5.6 A specific enzyme catalyzes each cellular reaction

As a protein, an enzyme has a unique three-dimensional shape, and that shape determines which chemical reaction the enzyme catalyzes. A substance that an enzyme acts on—a reactant in a chemical reaction—is called the enzyme's **substrate.** Each enzyme recognizes only the specific substrate or substrates of the reaction it catalyzes. Thus, it takes many different kinds of enzymes to catalyze all the reactions in a cell.

In catalyzing a reaction, an enzyme binds to its substrate. While the two are joined, the substrate changes into the product (or products) of the reaction. Only a small part of an enzyme molecule, called the **active site,** actually binds to substrate. The active site is typically a pocket or groove on the surface of the enzyme. The enzyme is specific because its active site fits only one kind of substrate molecule.

The figure here illustrates how an enzyme works. We use the enzyme sucrase as an example. Its specific substrate is table sugar (sucrose), and the reaction it catalyzes is the hydrolysis of sucrose to glucose and fructose. ① Sucrase starts with an empty active site. ② Sucrose enters the active site, attaching by weak bonds. The interaction with sucrose induces the enzyme to change shape slightly so that the active site fits even more snugly around the sucrose. This "induced fit" is like a clasping handshake. It holds the substrate in a position that facilitates the reaction, and ③ the substrate is converted to the products glucose and fructose. ④ The enzyme releases the products and emerges unchanged from the reaction. Its active site is now available for another substrate molecule, and another round of the cycle can begin. A single enzyme molecule may act on thousands or even millions of substrate molecules per second.

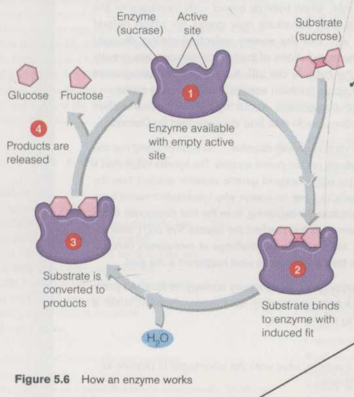



**Figure 5.6** How an enzyme works

Web/CD Activity 5D *How Enzymes Work*

? What is meant by "induced fit"?

Induced fit is the slight change in shape of the active site of an enzyme as it embraces its substrate. In its new shape, the active site catalyzes the reaction.

**Never get lost.**
Figures describing a process take you through a series of *numbered steps* keyed to explanations in the text.

**Interact.**
*Media references* direct you to related activities and investigations on the CD-ROM and web site.

**Test yourself.**
Get immediate feedback with a *checkpoint question* at the end of each module.

# Learn about biology in your world.

**Make a connection.**
*Connection modules* relate biology to your life and interests—from how coffee affects your nervous system to stem cell research.

CONNECTION

## 28.9 Many drugs act at chemical synapses

Many drugs, even common ones such as caffeine, nicotine, and alcohol, affect the action of neurotransmitters in the brain's billions of synapses. Caffeine, found in coffee, tea, chocolate, and many soft drinks, keeps us awake by countering the effects of inhibitory neurotransmitters. Nicotine acts as a stimulant by binding to and activating the neurotransmitter acetylcholine's receptors. Alcohol is a strong depressant. Its precise effect on the nervous system is not yet known, but it seems to increase the inhibitory effects of the neurotransmitter GABA.

Many prescription drugs used to treat psychological disorders also alter the effects of neurotransmitters. The antidepressant drug fluoxetine (Prozac®) blocks the removal of serotonin from a synapse, increasing the amount of this mood-altering neurotransmitter available to receiving cells. Tranquilizers such as Valium® and Xanax® activate the receptors for GABA, increasing the effect of this inhibitory neurotransmitter. In other cases, a drug may bind to and block a receptor, reducing a neurotransmitter's effect. For instance, some antipsychotic drugs used to treat schizophrenia block dopamine receptors.

What about illegal drugs? Stimulants such as amphetamines and cocaine increase the release and availability of norepinephrine and dopamine at synapses. Abuse of these drugs can produce symptoms resembling schizophrenia. LSD and mescaline may produce their hallucinatory effects by activating serotonin and dopamine receptors. Opiates—morphine, codeine, and heroin—bind to endorphin receptors, reducing pain and producing euphoria. Not surprisingly, opiates are commonly used medicinally for pain relief. However, abuse of any of these narcotics may permanently change the brain's chemical synapses and reduce the normal synthesis of neurotransmitters. As explained in Module 28.15, these drugs are also highly addictive.

The drugs discussed here are used for a variety of purposes, both medicinal and recreational. While they have the ability to increase alertness and sense of well-being or to reduce physical and emotional pain, they also have the potential to act like sledgehammers in the brain's finely tuned neural pathways, altering the chemical balances that are the product of millions of years of evolution.

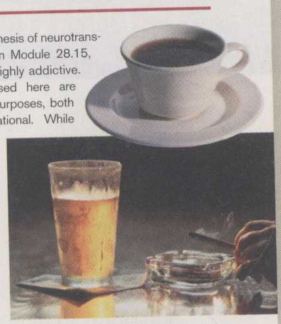


**Figure 28.9** Caffeine, alcohol, and nicotine alter the effects of neurotransmitters

? When people say that "alcohol lowers a person's inhibitions," it is a behavioral description. At the neurological level, it is probably more accurate to say that "alcohol raises inhibitions." Why?

Alcohol probably depresses the brain by enhancing the inhibitory effects of GABA.

TALKING ABOUT SCIENCE

## 14.9 Peter and Rosemary Grant study the evolution of Darwin's finches

**Figure 14.9** Peter and Rosemary Grant

Some theories wait a long time to be tested. Such was the case with Darwin's 150-year-old hypothesis that the beaks of the diverse Galápagos finch species had adapted to different food sources through natural selection. Then came the classic research of Peter and Rosemary Grant (see Module 13.5). For almost 30 years, the Grants (Figure 14.9) have been documenting natural selection acting on finches.

How did the Grants come to work with Darwin's finches? They were looking for a pristine, undisturbed place to study variation within populations. As we saw in Module 14.4, islands, with their isolated populations, make ideal laboratories in which to study evolution. And the Grants knew from other researchers that the Galápagos were promising. In 1973, Peter banded about 60 medium ground finches on Daphne Major, a tiny island in the Galápagos. When he returned 8 months later with Rosemary and their young daughters, they were able to find all but two of the banded birds. With such an opportunity to study a small, isolated population, they decided to research these birds for 3 years. One evolutionary question led to another, and for the past 29 years they have spent up to 3 months a year on the rather inhospitable island of Daphne. Here is how Peter Grant describes their rugged and isolated research site:

> There is no beach on Daphne. There's just steep rocks. To land on the island, you have to find some little platform that the waves have cut out of the rock and then climb on from the boat when there are no waves. Then you climb up until you reach a slope where you can actually stand up and walk. And you have to get supplies up there too—something on the order of 30 5-gallon water jugs, cans of food, packets of rice, sugar . . . plus a stove and cylinder of gas for cooking as well as other camping supplies.

What were some of the evolutionary questions that kept the Grants on this rocky island for so many years? One was the occasional interbreeding between the medium ground finch and the cactus finch (see Figure 14.4A). They found that this happens when a male learns to sing the song of the other species. Nestlings (whose father died or did not sing much) may learn a neighbor's song, even if the neighbor is a different finch species. Thus, a medium ground finch might breed with a cactus finch because he sings her song.

To find out whether these interspecies couples would create a new hybrid species, the Grants followed the survival of their offspring. They found that the hybrids have intermediate bill sizes and thus can only survive during wet years when there are plenty of soft, small seeds. During dry years, the hybrids can't crack the larger, harder seeds that the medium ground finches can eat and can't compete with cactus finches for cactus seeds. As Rosemary Grant explains:

> There is this occasional hybridization through a breakdown of a learned cultural trait, the song. And so you get this balance between an input of genes and then selection, during drought years, keeping the populations on divergent trajectories in spite of the episodes of hybridization.

In other words, when hybrids breed with members of the parent species, they introduce new genes on which natural selection can act. But the severe selection during drought years (when the populations of both finch species are greatly reduced and the hybrids die off), keeps the medium ground finch and the cactus finch on separate evolutionary paths.

Peter Grant conjectures about hybrid finches and their adaptive radiation, which was first documented by Darwin:

> Perhaps hybrids occasionally disperse . . . to another island that has neither the hybrids nor the parent species. The hybrids could start a new population with a range of genetic variation different from the parent species. . . . I see no reason why hybridization hasn't been important right from the beginning, from the first divergence of the ancestral finch stock that reached the islands. We don't have the early stages, but that's the big challenge of evolutionary biology—trying to infer from modern clues what happened in the past.

Another challenge of evolutionary biology, at least as practiced by the Grants, is to enjoy field research, even when it means camping on the rocks.

? Despite the rocks, what were the advantages of Daphne as a research site?

The resident finch populations were small and isolated, and individual birds and their offspring could be followed over several years.

**Meet the people behind the science.**
Hear scientists discuss their investigations—in the lab and in the field—in *Talking About Science* modules.

# Feel confident going into the test.

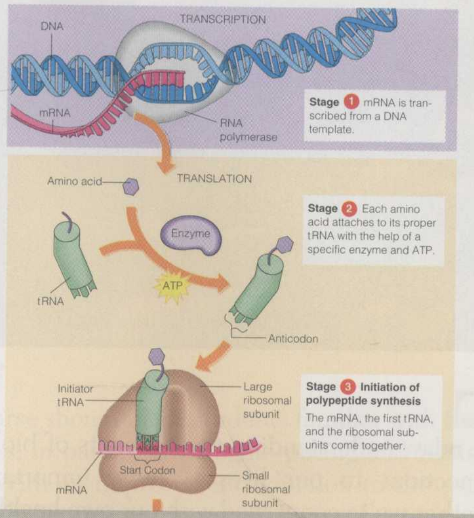
## 10.15 Review: The flow of genetic information in the cell is DNA → RNA → protein

Figure 10.15 summarizes the main stages in the flow of genetic information from DNA to protein. In transcription (DNA → RNA), the RNA is synthesized on a DNA template (stage ①). In eukaryotic cells, transcription occurs in the nucleus, and the messenger RNA must travel from the nucleus to the cytoplasm.

Translation (RNA → protein) can be divided into four stages (②–⑤), all of which occur in the cytoplasm. When the polypeptide is complete, the two ribosomal subunits come apart, and the tRNA and mRNA are released (not shown in this figure). Translation is rapid; a single ribosome can make an average-sized polypeptide in less than a minute. Typically, an mRNA molecule is translated simultaneously by a number of ribosomes. Once the start codon emerges from the first ribosome, a second ribosome can attach to it; thus, several ribosomes may trail along on the same mRNA molecule.

Each polypeptide coils and folds, assuming a three-dimensional shape, its tertiary structure. Several polypeptides may come together, forming a protein with quaternary structure (see Module 3.18).

What is the overall significance of transcription and translation? These are the processes whereby genes control the structures and activities of cells, or, more broadly, the way the genotype produces the phenotype. The chain




**Remind yourself** how all the details fit together with *overview modules* and *review modules.*

**Review the main points.** *Chapter Summaries* review all the key concepts, referring you back to the appropriate module if you need more detail.

### Chapter Review

**CHAPTER SUMMARY**

Ecology is the scientific study of the interactions of organisms with their environment. Most organisms are solar powered. Those living where there is no light are powered by energy from Earth's interior **(Introduction).** Ecologists study environmental interactions at the organism, population, community, and ecosystem levels. Ecosystem interactions involve living (biotic) communities and nonliving (abiotic) components, such as energy, nutrients, and water **(34.1).**

**The Biosphere (34.2–34.6)**

The global ecosystem is called the biosphere: all life on Earth and where it lives. Except for energy obtained from the sun and heat lost to space, the biosphere is self-contained. Patchiness characterizes the biosphere, with each habitat having a unique community of species **(34.2).** Human activities, including the widespread use of chemicals, affect all parts of the

696 UNIT VII *Ecology*

Climatic differences, mainly temperature and rainfall, shape the major biomes that cover Earth's land surface **(34.9).** Several kinds of tropical forests occur in the warm, moist belt along the equator. The tropical rain forest is the most diverse ecosystem on Earth. Large-scale human destruction of these forests endangers many species and may alter world climate **(34.10).** The Luquillo Experimental Forest allows ecologists to study the effects of disruption on tropical forests **(34.11).** Drier tropical areas and some nontropical areas are characterized by the savanna, a grassland with scattered trees. Grazing by large herbivores and fire help maintain savannas **(34.12).** Deserts are the driest biomes. The misuse of surrounding land is contributing to the growth of some deserts **(34.13).** The chaparral biome is a shrubland with cool, rainy winters and dry, hot summers, when fires often occur **(34.14).** Temperate grasslands are found in the interiors of the continents, where winters are cold. Drought, fires, and grazing animals prevent trees from growing. Farms have replaced most of North America's temperate grasslands **(34.15).** Forests of broadleaf deciduous trees grow in some temperate areas. North America's deciduous forests have been drastically altered by agriculture and urban development **(34.16).** The northern coniferous forest, or taiga, is an extensive biome of the far north and high mountains. Taiga occurs where there are short summers and long, snowy winters. Coastal coniferous forests of the Pacific Northwest are actually temperate rain forests **(34.17).** Arctic tundra, a treeless biome characterized by extreme cold, wind, and permafrost, lies between the taiga and the permanently frozen polar regions. Alpine tundra occurs above the treeline on high mountains. The vegetation of the tundra includes shrubs, grasses, mosses, and lichens **(34.18).**

**TESTING YOUR KNOWLEDGE**

**Multiple Choice**

1. Changes in the seasons are caused by
   a. the tilt of Earth's axis toward or away from the sun.
   b. annual cycles of temperature and rainfall.
   c. variation in the distance between Earth and the sun.
   d. an annual cycle in the sun's energy output.
   e. the periodic buildup of heat energy at the equator.
2. What makes the Gobi Desert of Asia a desert?
   a. The growing season there is very short.
   b. Its vegetation is sparse.
   c. It is hot.
   d. Temperatures vary little from summer to winter.
   e. It is dry.
3. Andrea was a passenger on a plane that flew over temperate deciduous forest, then grassland and desert, finally landing at an airport in chaparral. The route of Andrea's flight was between
   a. New York and Denver.
   b. Philadelphia and San Francisco.
   c. Denver and Los Angeles.
   d. Washington, D.C., and Phoenix.
   e. Seattle and Washington, D.C.

**Prepare for the test** with *Multiple Choice* questions.

**Test your understanding** with *Describing, Comparing, and Explaining* questions. If you can restate a concept in your own words, you've probably learned it!

| | |
|---|---|
| 4. Spruce, fir, pine, and hemlock trees | d. temperate grassland |
| 5. Home of zebras, baboons, and lions | e. chaparral |
| 6. The steppes, pampas, and plains | f. tundra |
| 7. The most complex and diverse biome | g. taiga |

**Describing, Comparing, and Explaining**

1. Explain how the following factors change from the source of a river to its mouth: nutrient content, current, sediments, temperature, oxygen content, food sources.
2. Choose any animal or plant in your geographic area and write a paragraph describing how it is adapted to abiotic and biotic factors in its environment.
3. What climatic conditions allow tropical rain forests to grow along the equator in places such as Brazil and Southeast Asia, but create deserts like the Sahara 30° north and south of the equator?

**THINKING AS A SCIENTIST**

The North American pronghorn looks and acts like the antelopes of Africa. But the pronghorn is really the only survivor of a family of mammals restricted to North America. Propose a hypothesis to explain how these widely separated animals came to be so much alike.

**SCIENCE, TECHNOLOGY, AND SOCIETY**

Near Lawrence, Kansas, there was, until 1990, a rare patch of the original North American temperate grassland that had never been plowed. It was home to numerous native grasses, annual plants, and grassland animals. Among the species present were two endangered plants. Environmental activists thought the area should be set aside as a nature preserve, and they started to raise money to save it. In 1990, the owner of the land plowed it, stating that there are no federal laws protecting endangered plants on private grasslands, and that he did not want to be told what he could do with his property. What issues and values are in conflict in this situation? How could this story have had a more satisfactory ending for all concerned?

**Answers to all questions can be found in Appendix 3.**

**MEDIA RESOURCES**

For further review, go to the web site (www.campbellbiology.com) or student CD-ROM for Activities, Thinking as a Scientist investigations, Connections, Pre-Tests, Chapter Quizzes, Activities Quizzes, Flash Cards, Word Roots, Key Terms, and a Glossary with selected audio pronunciations. The web site also offers Web Links, News Links, News Archives, Further Readings, art with and without labels, videos, and Instructor Resources.

**Practice science** using the *Thinking as a Scientist* questions.

**Get involved.** *Science, Technology, and Society* questions help you connect biology to your life and society.

Today, understanding the concepts of biology and their connections to our lives is more important than ever. Whether we're concerned with our own health or the health of our planet, a familiarity with biology is essential. This basic knowledge and an appreciation for how science works have become elements of good citizenship in an era when informed evaluations of health issues, environmental problems, and applications of new technology are critical.

The "connections" to which the title of this book refers include many such practical applications of biology—and go beyond them. Biology has important connections with the other natural sciences and with the humanities and social sciences as well. And the study of life has no coherence without an understanding of the connections among the different areas of biology and an appreciation of the grand unifying theme of evolution. From its first edition, the hallmarks of this book have included an emphasis on connections within biology and between biology and other fields, along with a focus on engaging students from a wide variety of majors. In this fourth edition, we have increased the emphasis on connections to our everyday world in both the chapter opening essays and the newly labeled "Connection" modules.

We could not have hoped to meet our ambitious goals for this book without extensive discussions with teaching colleagues throughout the world and feedback from many of the hundreds of instructors and hundreds of thousands of students who have used our earlier editions. We have been gratified by their enthusiastic responses and have paid close attention to their thoughtful suggestions for improvement. For this edition, we set out to create a book that would be an even more effective tool for learning biology. In addition, we worked to ensure that the book would integrate smoothly with the rich program of supporting materials on the CD-ROM and web site that accompany the book.

How can we help students learn—and enjoy—biology? How can we help instructors teach biology? Our responses to these questions are reflected in the teaching strategies we bring to the book. In this new edition, we build on the approach that has been so successful in earlier editions. Below we describe our main teaching strategies as they are embodied in *Biology: Concepts & Connections*, Fourth Edition.

## Focus Students on the Main Ideas of Biology

Biology is a vast subject that gets bigger every year, but a general biology course is still only one or two terms long. In that brief time, we explore all of life, from molecules to ecosystems, while also trying to share the excitement of important research breakthroughs. For beginning biology students confronting this avalanche of information, it can seem as important to memorize all the scientific terms and facts as it is to master and apply the major ideas. This situation changes, however, when students acquire a framework of key biological concepts into which they can fit the many new things they learn. It is this framework of concepts that will serve them long after they have forgotten specific facts and terms.

**Concept Modules** *Biology: Concepts & Connections* was the first introductory biology textbook to use concept modules to help students recognize and focus on the main ideas of each chapter. The heading of each module is not simply a topic name but a carefully crafted statement of a biological concept. Printed in large type, each concept heading serves as a focal point for a module, and all of the module's text and illustrations converge on that concept with explanation and, often, evidence. For example, "Sensory receptor cells convert stimuli into electrical energy" announces a key concept in Chapter 29 (Module 29.2). The text and illustrations introduce the general principles of sensory reception and transduction, using the human sense of taste as an example. In this and other modules, we integrate the words and pictures to an unprecedented degree: The text walks the student through the illustrations, just as an instructor would do in class. In teaching a sequential process, such as the functioning of the receptor cells of the taste buds (Figure 29.2A), we number the steps in the text to correspond to numbered steps in the figure. The synergy between a module's verbal and graphic components transforms the concept heading into an idea with meaning to the student.

**Integrated Media** Printed in red immediately following the text in many modules are one or more references to interactive Activities and Thinking as a Scientist investigations to be found on the student CD-ROM and web site. In this edition, we provide the titles of the activities on the text page.

**Checkpoint Questions** At the end of every module is a checkpoint question that reinforces the module's message. These questions encourage students to test themselves as they proceed through a chapter. Some questions simply ask the student to restate the main concept or a corollary; others test understanding of the supporting evidence or ask the student to connect the concept to another concept in the book; still others require the student to carry out a calculation using information in the module. Feedback is provided on the spot: The answer is printed upside down beneath the question. These questions are intended to make students think about the material they are studying and to build their confidence. In summary, each module provides everything a student needs to master a concept.

**General Headings** How do we help students see the connections between concepts? We group the modules under prominent general headings, printed on orange bars, which form an overarching framework for the chapter. Students first see these general headings and subordinated concepts and connections in the outline at the beginning of a chapter. At the end of the chapter, the general headings organize the Chapter Summary. To provide further help in tying concepts together, we make frequent use of overviews, reviews, and explanatory transitions at the beginnings or ends of modules. The modules of each chapter tell a continuous story.

## Relate Biological Concepts to Everyday Life

**Connection Modules** Students are more motivated to study biology when they can connect it to their own lives and interests—for example, to health issues, economic problems, environmental quality, ethical controversies, and social responsibility. In this edition, yellow "Connection" banners mark the numerous application modules that go beyond the core biological concepts. You can preview the Connection module headings on the front endpapers of the book.

**Introductory Essays** In this edition, the illustrated essays that open the chapters vary in approach. Over half of these essays are new, and many of them discuss topics that relate to daily life. For example, Chapter 10, "Molecular Biology of the Gene," now opens with an essay on herpes infections. Other introductory essays continue our earlier tradition of featuring a nonhuman organism and describing how it is adapted to its environment. One example is our new essay for Chapter 13, "How Populations Evolve," which focuses on the blue-footed boobies of the Galápagos Islands. Our hope is that essays like this one will nurture students' appreciation for biological diversity.

**Science, Technology, and Society Questions** At the end of each chapter, one or more "Science, Technology, and Society" questions encourage students to use the concepts they have learned in thinking about various social and environmental issues.

## Adapt This Book to Fit Your Course

Though a biology textbook's table of contents must be linear, biology itself is more like a web of related concepts without a single starting point or prescribed path. Courses can navigate this network starting with molecules, with ecology, or somewhere in between, and most courses omit some topics. *Biology: Concepts & Connections* is uniquely suited to serve this variety of courses. The seven units of the book are largely self-contained, and most of the chapters within a unit can be assigned in a different order without much loss of coherence. Moreover, the modular format of the chapters makes it easy to omit or to relocate modules within a syllabus.

## Relate Biological Concepts to the Unifying Theme of Evolution

The history of life on Earth goes back more than three and a half billion years, and this past is the key to the present diversity of organisms. As the unifying theme of this textbook, evolution elevates biology from a collection of facts to a coherent study of changing life on a changing planet. In *Biology: Concepts & Connections*, students study the structure, function, and behavior of organisms in an evolutionary context. And throughout the book, students learn to view the unity and diversity of life—the similarities and differences among organisms—as the dual consequences of descent with modification. Our enhanced coverage of evolution in Chapter 1 and Unit III of this edition strengthens this unifying theme.

## Help Students Understand the Process of Science

A biology course should make students familiar with the scientific process, in particular with the posing and testing of hypotheses. With an improved introduction to the process of science in Chapter 1, students will be better equipped to appreciate the many examples throughout the book of how scientific concepts emerge from observations and experimental evidence. The book also puts human faces on science with "Talking About Science" modules. A number of these profiles of interesting scientists are new to this edition.

In the review material that concludes each chapter, questions called "Thinking as a Scientist" give students some personal practice with science as a process. The CD-ROM and web site also provide interactive "Thinking as a Scientist" investigations. In fact, this book will work best for students who participate actively in learning about biological concepts and their applications.

■ ■ ■

Introductory biology is the only science course that many students will take during their college years. Long after today's students have forgotten most of the specific content of their biology course, they will be left with general impressions and attitudes about science and scientists. We hope this new edition of *Biology: Concepts & Connections* helps make those impressions positive and supports the instructor's goals for sharing the fun of biology. To help us produce an even better text in the next edition, please send your comments and suggestions to one of the following authors:

*Neil Campbell*
Department of Botany and Plant Sciences
University of California
Riverside, CA 92521

*Jane Reece*
Benjamin Cummings
1301 Sansome Street
San Francisco, CA 94111

*Martha Taylor*
Biological Sciences
Comstock Hall
Cornell University
Ithaca, NY 14853

# NEW CONCEPTS AND CONNECTIONS IN THE FOURTH EDITION

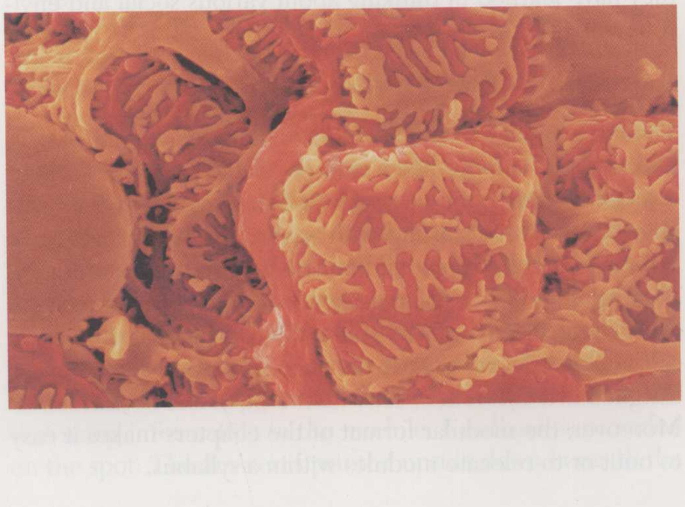
Chapter 1, "Introduction: The Scientific Study of Life," has a new opening essay on the Australian flying fox that is pictured on the cover of the book. The material on the process of science in Modules 1.2 and 1.3 has been heavily revised. Module 1.2 now introduces discovery (descriptive) science as well as hypothesis-driven science, and the explanation of hypothesis-driven science in Module 1.3 features a case study from everyday life as well as one from biological research on flies that mimic predatory spiders.

**Unit I, The Life of the Cell,** the book's introduction to the basic chemistry, structure, and energetics of cells, has a number of new chapter opening essays and Connection modules that relate core concepts to other areas of biology and to everyday life. The new chapter introductions discuss chemical communication in courtship and other aspects of chemical ecology (Chapter 2), the connections between art and biology (Chapter 4), slow-twitch and fast-twitch muscle fibers and their influence on athletic performance (Chapter 6), and the multiple roles of light in the lives of plants (Chapter 7). New and updated Connection modules in this unit cover topics such as the connection between molecular structure and sweet taste (3.6), the use of anabolic steroids and related chemicals by athletes (3.10), the possibility of extraterrestrial life (4.21), and global warming (7.13).

As in previous editions, **Unit II, Cellular Reproduction and Genetics** enlivens the core genetic concepts by integrating topics in human genetics throughout. Topics of human interest extend to the chapter introductions, including new ones on the genetics of Labrador retrievers (Chapter 9), herpesvirus infections (Chapter 10), and human cloning and stem cells (Chapter 11). New Connection modules discuss such topics as genetic testing (9.15), reproductive cloning of nonhuman mammals (11.4), DNA microarrays (12.9), and other applications of DNA technology to medicine, law, industry, and agriculture (12.15–12.19). There are two organizational improvements in the molecular biology chapters (Chapters 10–12): RNA processing is now introduced in Module 10.10, where it falls logically just after transcription; and in Chapter 11, the explanation of cellular differentiation and its basis in selective gene expression is now unified in one early module (11.2). Other highlights of the revision of Unit II include new micrographs of mitosis (Figure 8.6), a simplified presentation of the regulation of the later stages of gene expression (Module 11.10), updated coverage of the Human Genome Project (Module 12.14), and updated discussions of gene therapy (Module 12.19) and genetically modified (GM) crops (Modules 12.18 and 12.20). To the already strong coverage of the genetic basis of cancer (Modules 11.15–11.19) have been added a new figure on tumor-suppressor genes (Figure 11.15B) and updated cancer statistics (Module 11.19).

**Unit III, Concepts of Evolution,** has been extensively reorganized and updated, with new chapter introductions for all three chapters. Chapter 13 presents new examples of natural selection in action (Module 13.5), a discussion of the evolution of drug resistance in HIV (Module 13.14), and new modules on sexual selection (13.20), why natural selection does not lead to perfect organisms (13.21), and the evolution of antibiotic resistance in bacteria (13.22). In Chapter 14, the evolution of reproductive barriers in animal populations is discussed in Module 14.7, and a new Talking About Science Module 14.9 describes the work of Peter and Rosemary Grant with finches on a rugged island in the Galápagos. Module 15.7 has additional material on developmental genes and the new field of "evo-devo," and Module 15.12 has new information on mitochondrial DNA comparisons and the use of molecular clocks to date evolutionary divergence. The discussion of cladistics in Module 15.13 has also been improved and updated.

**Unit IV, The Evolution of Biological Diversity,** has updated science and enriched applications. Module 16.11 includes the surprising prevalence of archaea in the oceans. Modules 16.14 and 16.15, on pathogenic bacteria, are now followed by a new module on the use of bacteria—in particular, anthrax bacteria—as biological weapons (Module 16.16). Chapter 17 has two new modules: 17.12, on the importance of angiosperms in



agriculture, and 17.14, on the current endangerment of plant diversity. (Module 17.14 includes a table on medicinal plant products.) Chapter 18 has a new introduction and many new photos. A revised Module 18.23 compares the traditional phylogenetic tree for the animal kingdom to a new tree that takes into account molecular evidence; the latter tree includes the Ecdysozoan and Lophotrochozoan clades within the Protostomes. A new Module 18.24 uses Australia to illustrate how non-native species threaten biodiversity. The new introduction to Chapter 19 describes the scientific controversy over the place of Neanderthals in human evolution. An updated Module 19.6 compares the evidence for the multiregional and replacement hypotheses of the origin of modern humans.

New chapter introductions in **Unit V, Animals: Form and Function**, discuss such topics as how geckos climb walls (Chapter 20), winter dormancy in bears (Chapter 25), testosterone and male aggression (Chapter 26), and new possibilities for healing spinal-cord injuries (Chapter 28). Module 20.10 has updated information and photos of new imaging techniques. Revised Modules 23.8 and 23.10 provide current health information on heart attacks, blood pressure, and cardiovascular problems, and revised Module 23.17 discusses the use of stem cells to treat certain blood-cell diseases. Chapter 24, on the immune system, features updated information on HIV and AIDS. Updated modules in Chapter 25 include 25.6 on sweating and dehydration and 25.12 on causes and treatment of kidney failure. The explanations of the two main mechanisms of hormone action in Module 26.2 benefit from clearer text and new figures. Module 26.7 presents a more accurate account of calcium homeostasis. Chapter 27 has improved diagrams of spermatogenesis and oogenesis (Module 27.4) and updated Connection modules on contraception (27.8) and reproductive technology (27.19). In Chapter 28, an updated Module 28.9 describes how legal and illegal drugs affect the actions of neurotransmitters in the brain, and the new Module 28.17 explains how brain injuries and surgical operations have provided insight into brain functioning. Chapter 30 includes two new modules: 30.6 on the treatment of broken bones and 30.11 on aerobic and anaerobic conditioning.


The text and figures of **Unit VI, Plants: Form and Function,** have been fine-tuned for this edition. Module 31.15, on the use of vegetative reproduction in agriculture, has been expanded and updated. Chapter 32 has a new chapter introduction on plants that clean up poisons in the environment and a new discussion of organic farming (Module 32.10). The potential human health benefits of soy phytoestrogens are described in the new introduction to Chapter 33. In Talking About Science Module 33.13, researcher Joanne Chory discusses the effects of light and hormones on the model plant *Arabidopsis thaliana*.

**Unit VII, Ecology,** has been updated with current ecological data, fresh photos, and new and revised Talking About Science modules. Chapter 34 has a new chapter introduction featuring a newly discovered species of squid. Chapter 35 now includes more field data on the growth of populations (Module 35.4), a new diagram explaining field experiments on life history traits (Module 35.7), the concept of ecological footprint in estimating the carrying capacity of Earth (Module 35.8), and an explanation of the demographic transition and human population growth (Module 35.9). A new Connection module (Module 35.10) describes how principles of population ecology can be applied to resource management and pest control. Chapter 36 has new information on resource partitioning (Module 36.2) and the contribution of different ecosystems to primary production (Module 36.11). In Module 36.19, David Schindler discusses altered ecosystems and his experimental lakes project. In Chapter 37, the discussion of animal cognition and problem-solving behavior has been updated (Module 37.7), Jane Goodall describes reconciliation behavior in chimpanzees (Module 37.16), and the Talking About Science module featuring E. O. Wilson includes new material from his latest books (Module 37.21). Chapter 38 has updated statistics on energy consumption per capita, ozone thinning, and global warming. A reorganized Module 38.6 introduces the small-population and declining-population approaches to saving endangered species.

The saying that it takes a village to raise a child applies equally well to this biology textbook. *Biology: Concepts & Connections*, Fourth Edition, results from the combined efforts of a "village" of people, and the authors wish to extend heartfelt thanks to all those who contributed to this and previous editions. Our work on this edition was shaped by input from the biologists acknowledged in the Fourth Edition reviewer list on p. xiii, who shared with us their experiences teaching introductory biology and provided specific suggestions for improving the book. The unsolicited comments and suggestions we received from other biologists and from biology students were also very helpful. In addition, this book has benefited in countless ways from the stimulating contacts we had with numerous biologists during the recent preparation of our larger text, *Biology*, Sixth Edition. We are fortunate to be part of a truly global village dedicated to excellence in biology education.

A major goal for this new edition was to enhance the book's connections to students' lives outside the biology classroom. To help us with this goal, several people contributed drafts for chapter introductions and/or Connection modules. We are particularly indebted to Maura Flannery of St. John's University for suggesting, researching, and writing drafts for 13 of the new chapter introductions. Eric Simon of New England College wrote lively drafts for three others, as well as for a number of the new and revised Connection modules. Also, science journalist April Lynch and developmental editor Kim Johnson Krummel made major contributions to several chapter introductions and Connection modules. Others contributing to the Connection modules were science journalist Lisa Krieger and our publishing colleague and friend Deborah Gale. The overall plan for the Connection modules benefited from the thoughtful suggestions of Jill Raymond of Rock Valley College. We are grateful to all these individuals for helping enliven the book with fresh material.

In addition, we want to acknowledge the important contributions of our coauthor Larry Mitchell. Larry did not participate directly in the preparation of this edition, but much of his work on previous editions remains integral to the book.

The superb publishing team for this edition was headed up by executive editor Beth Wilbur. We cannot thank her enough for her unstinting efforts on behalf of the book and for her commitment to excellence in biology education. Directing the project on a daily basis was our unflappable senior project editor Ginnie Simione Jutson. Multitalented developmental manager Pat Burner was, as usual, indispensable. Pat helped revise several chapters and deserves much credit for the high quality of the book as a whole and of the enclosed CD-ROM, as well. We are similarly grateful to freelance developmental editor Kim Johnson Krummel; we much appreciate her thoroughness, creativity, and good humor, and the book is far better than it would have been without her efforts. Yet another invaluable member of the editorial team was developmental editor Evelyn Dahlgren, who contributed to myriad aspects of the project; among other tasks, Evelyn checked copyedit and art proofs, oversaw the supplements program, and helped develop the sample-chapter booklet. Thanks also to publishing assistant Krystina Sibley, who also helped coordinate the supplements. We wish to express our appreciation to executive producer Lauren Fogel, development director Kay Ueno, editorial director Frank Ruggirello, and president Linda Davis for their ongoing support.

This book and all the other components of the teaching package are both attractive and pedagogically effective in large part because of the hard work and creativity of the production professionals on our team. We wish to thank Jamie Sue Brooks, who initiated the production planning, and Yonie Overton, who supervised the final design of the book and the production of the sample chapter. Actually producing the book itself were Jon Peck and Joan Keyes of Dovetail Publishing Services. They were a pleasure to work with, as was our main copyeditor, Janet Greenblatt. We are also grateful to copyeditors John Burner and Pete Shanks, indexer Charlotte Shane, and proofreader Linda Smith. The book itself would not have come into existence without the efforts of production and manufacturing manager Diane Southworth and manufacturing buyer Vivian McDougal.

For users of this book, the illustrations and photos are as important as the prose. We have been fortunate to work again with senior art supervisor Donna Kalal and freelance developmental artist Carla Simmons, our colleague on this book since the first edition. Carla is are largely responsible for the beauty and coherence of the illustration program. Both the book and the Campbell Image Presentation Library have benefited greatly from the unceasing efforts of expert photo researcher Travis Amos. And we love the interior design by Frances Baca and the cover design by Yvo Riezebos, which together bring an inviting new look to the book.

For creating the supplementary materials that support this book, thanks go to David Reid, Ed Zalisko, and Gene Fenster, who prepared the new *Instructor's Guide to Text and Media*; further thanks to Ed and Gene for their work on the *Test Bank*. Steven Anderson coordinated the production of these materials, as well as the excellent *Student Study Guide* by Richard Liebaert and the second edition of *Laboratory Investigations for Biology*, by Jean Dickey. Chris Romero and Steve Norton prepared the *PowerPoint Lectures*. Playing key roles in the development and production of the electronic supplements were developmental editor John Burner, associate editor Aaron Gass, senior producer for art and media Russell Chun, artist Karl Miyajima, and web developers Andrew Corbett, Steve Wright, and Jim Hufford. Thank you, one and all!

The members of the Addison Wesley/Benjamin Cummings sales group and the Benjamin Cummings marketing department—in particular, Josh Frost, Chalon Bridges, Jason Newhauser, and Alexandra Fellowes—have continued to help us connect with biology instructors and their teaching needs. We thank them for all their hard work and enthusiastic support.

Finally, we are deeply grateful to our families and friends for their support, encouragement, and patience.

*Neil Campbell, Jane Reece, and Martha Taylor*

## Fourth Edition Reviewers

Dennis Anderson, *Oklahoma City Community College*
Gail Baker, *LaGuardia Community College*
Mark Barnby, *Ohlone College*
Stephen Barnhart, *Santa Rosa Junior College*
Kirk A. Bartholomew, *Central Connecticut State University*
Tania Beliz, *College of San Mateo*
Mehdi Borhan, *Johnson County Community College*
Kathleen Bossy, *Bryant College*
Robert Boyd, *Auburn University*
Bradford Boyer, *State University of New York, Suffolk County Community College*
Agnello Braganza, *Chabot College*
Charles Brown, *Santa Rosa Junior College*
Joseph C. Bundy, Jr., *University of North Carolina at Greensboro*
Warren Buss, *University of Northern Colorado*
Russell Centanni, *Boise State University*
Ruth Chesnut, *Eastern Illinois University*
Bob Cowling, *Ouachita Technical College*
Jean DeSaix, *University of North Carolina at Chapel Hill*
Veronique Delesalle, *Gettysburg College*
Mary Dettman, *Seminole Community College*
Kathleen Diamond, *College of San Mateo*
Robert P. Donaldson, *George Washington University*
Cory Etchberger, *Longview Community College*
Dennis Forsythe, *The Citadel Military College of South Carolina*
Bernard Frye, *University of Texas at Arlington*
Anne Galbraith, *University of Wisconsin-LaCrosse*
Rosa Gambier, *State University of New York, Suffolk County Community College*
Gail Gasparich, *Towson University*
Patricia Glas, *The Citadel Military College of South Carolina*
Peggy Green, *Broward Community College*
Miriam L. Greenberg, *Wayne State University*
Peggy Guthrie, *University of Central Oklahoma*
Blanche Haning, *North Carolina State University*
Richard Hanke, *Rose State College*
Phyllis Hirsch, *East Los Angeles College*
William Hixon, *St. Ambrose University*
Kim Hodgson, *Longwood College*
Lauren Howard, *Norwich University*
Georgia Ineichen, *Hinds Community College*
R. Jensen, *Saint Mary's College*
Marlene Kayne, *The College of New Jersey*
Judy Kaufman, *Monroe Community College*
Kenneth Kerrick, *University of Pittsburgh at Johnstown*
Joyce Kille-Marino, *College of Charleston*
Joanne Kilpatrick, *Auburn University Montgomery*
Stephen Kilpatrick, *University of Pittsburgh at Johnstown*
Eliot Krause, *Seton Hall University*
Geneen Lannom, *University of Central Oklahoma*
Brenda Latham, *Merced College*
Karen Lee, *University of Pittsburgh at Johnstown*
Harvey Liftin, *Broward Community College*
Kirsten Lindstrom, *Santa Rosa Junior College*
Dave Loring, *Johnson County Community College*
James Mack, *Monmouth University*
Joan Maloof, *Salisbury State University*
Timothy Metz, *Campbell University*
Robert Miller, *University of Dubuque*
Brad Mogen, *University of Wisconsin-River Falls*
David Pearson, *Bucknell University*
Andrew Penniman, *Georgia Perimeter College*
Russell L. Peterson, *Indiana University of Pennsylvania*
Jill Raymond, *Rock Valley College*
Stephen Reinbold, *Longview Community College*
Michael Renfroe, *James Madison University*
Bruce Robart, *University of Pittsburgh at Johnstown*
Jeanette Rollinger, *College of the Sequoias*
Steven Roof, *Fairmont State College*
Lynette Rushton, *South Puget Sound Community College*
Linda Sabatino, *State University of New York, Suffolk County Community College*
Douglas Schelhaas, *University of Mary*
Julie Schroer, *Bismarck State College*
Judy Shea, *Kutztown University of Pennsylvania*
Brian Shmaefsky, *Kingwood College*
Mark Shotwell, *Slippery Rock University*
Gary Sojka, *Bucknell University*
Ralph Sorensen, *Gettysburg College*
David Stanton, *Saginaw Valley State University*
Bruce Tomlinson, *State University of New York Fredonia*
Nancy Tress, *University of Pittsburgh at Titusville*
Kimberly Turk, *Mitchell Community College*
John Vaughan, *Georgetown College*
Mary Beth Voltura, *State University of New York Cortland*
Jerry Waldvogel, *Clemson University*
Neil Woffinden, *University of Pittsburgh at Johnstown*
Mark Wygoda, *McNeese State University*
William Yurkiewicz, *Millersville University of Pennsylvania*
Ray S. Williams, *Appalachian State University*

## Third Edition Reviewers

Jane Aloi-Horlings, *Saddleback College*
Loren Ammerman, *University of Texas at Arlington*
Jane Beiswenger, *University of Wyoming*
William Bradshaw, *Brigham Young University*
Becky Brown-Watson, *Santa Rosa Junior College*
Paul Boyer, *University of Wisconsin-Parkside*
Michael Bucher, *College of San Mateo*
George Cain, *University of Iowa*
M. Carabelli, *Broward Community College*
Mary Colavito-Shepanski, *Santa Monica College*
Lewis Deaton, *University of Louisiana-Lafayette*
Susan Dunford, *University of Cincinnati*

Thomas Emmel, *University of Florida*
Bernard Frye, *University of Texas at Arlington*
Gail Gasparich, *Towson University*
Grant Gerrish, *University of Hawaii*
Sylvia Greer, *City University of New York*
Maggie Haag, *University of Alberta*
Jean Hegelsen, *Colin County Community College*
Carl Hoagstrom, *Ohio Northern University*
Mark Ikeda, *San Bernardino Valley College*
Charles Jacobs, *Henry Ford Community College*
Fred James, *Presbyterian College*
Tom Kantz, *California State University, Sacramento*
Peter Kish, *Southwestern Oklahoma State University*
Richard Mortensen, *Albion College*
Bette Nybakken, *Hartnell College*
Debra Pearce, *Northern Kentucky University*
James Pru, *Belleville Area College*
Charles Pumpuni, *Northern Virginia Community College*
Bruce Reid, *Kean College*
Laurel Roberts, *University of Pittsburgh*
Duane Rohlfing, *University of South Carolina*
Robert Schoch, *Boston University*
Brian Scholtens, *College of Charleston*
Ross Strayer, *Washtenaw Community College*
Marshall Sundberg, *Emporia State University*
Hilda Taylor, *Acadia University*
Donald Trisel, *Fairmont State College*
Ann Vernon, *St. Charles County Community College*
Sandra Winicur, *Indiana University South Bend*
Tony Yates, *Seminole State College*
Uko Zylstra, *Calvin College*

## Second Edition Reviewers

Michael Abbott, *Westminster College*
Tania Beliz, *College of San Mateo*
Rudi Berkelhamer, *University of California, Irvine*
Linda Butler, *University of Texas at Austin*
Carolee Caffrey, *University of California, Los Angeles*
Van Christman, *Ricks College*
Don Cox, *Miami University*
Norma Criley, *Illinois Wesleyan University*
Jean DeSaix, *University of North Carolina at Chapel Hill*
Alfred Diboll, *Macon College*
Susan Dunford, *University of Cincinnati*
Norman Ellstrand, *University of California, Riverside*
David Essar, *Winona State University*
Laurie Faber, *Grand Rapids Community College*
Eugene Fenster, *Longview Community College*
Robert Galbraith, *Crafton Hills College*
George Garcia, *University of Texas at Austin*
Shelley Gaudia, *Lane Community College*
Douglas Gayou, *University of Missouri-Columbia*
Rebecca German, *University of Cincinnati*
Frank Gilliam, *Marshall University*
David Glenn-Lewin, *Wichita State University*
Robert Grammer, *Belmont University*
Leah Haimo, *University of California, Riverside*
James Hampton, *Salt Lake Community College*
Ira Herskowitz, *University of California, San Francisco*
Jean Higgins-Fonda, *Prince George's Community College*
John Holt, *Michigan State University*
Michael Hudecki, *State University of New York Buffalo*
Russell Johnson, *Ricks College*
Tracy Kahn, *University of California, Riverside*
Mahlon Kelly, *University of Virginia*
Robert Koch, *California State University, Fullerton*
Deborah Langsam, *University of North Carolina at Charlotte*
Kevin Lien, *Portland Community College*
David Magrane, *Morehead State University*
Presley Martin, *Drexel University*
Mitchell McGinnis, *North Seattle Community College*
Iain Miller, *University of Cincinnati*
Christopher Murphy, *James Madison University*
Peter Nordloh, *Southeastern Community College*
Stephen Novak, *Boise State University*
Michael O'Donnell, *Trinity College*
Karen Olmstead, *University of South Dakota*
Steven O'Neal, *Southwestern Oklahoma State University*
Margaret Peterson, *Concordia Lutheran College*
Rebecca Pyles, *East Tennessee State University*
Douglas Reynolds, *Central Washington University*
Jim Rosowski, *University of Nebraska*
Lisa Shimeld, *Crafton Hills College*
Linda Simpson, *University of North Carolina at Charlotte*
John Stolz, *Duquesne University*
Donald Streuble, *Idaho State University*
Leslie Vander Molen, *Humboldt State University*
Patrick Woolley, *East Central College*

## First Edition Reviewers

Daryl Adams, *Mankato State University*
Dawn Adrian Adams, *Baylor University*
Olushola Adeyeye, *Duquesne University*
Dan Alex, *Chabot College*
Sylvester Allred, *Northern Arizona University*
Jane Aloi, *Saddleback College*
Marjay Anderson, *Howard University*
Chris Barnhart, *University of San Diego*
William Barstow, *University of Georgia*
Ernest Benfield, *Virginia Polytechnic Institute*
Harry Bernheim, *Tufts University*
Richard Bliss, *Yuba College*
Lawrence Blumer, *Morehouse College*