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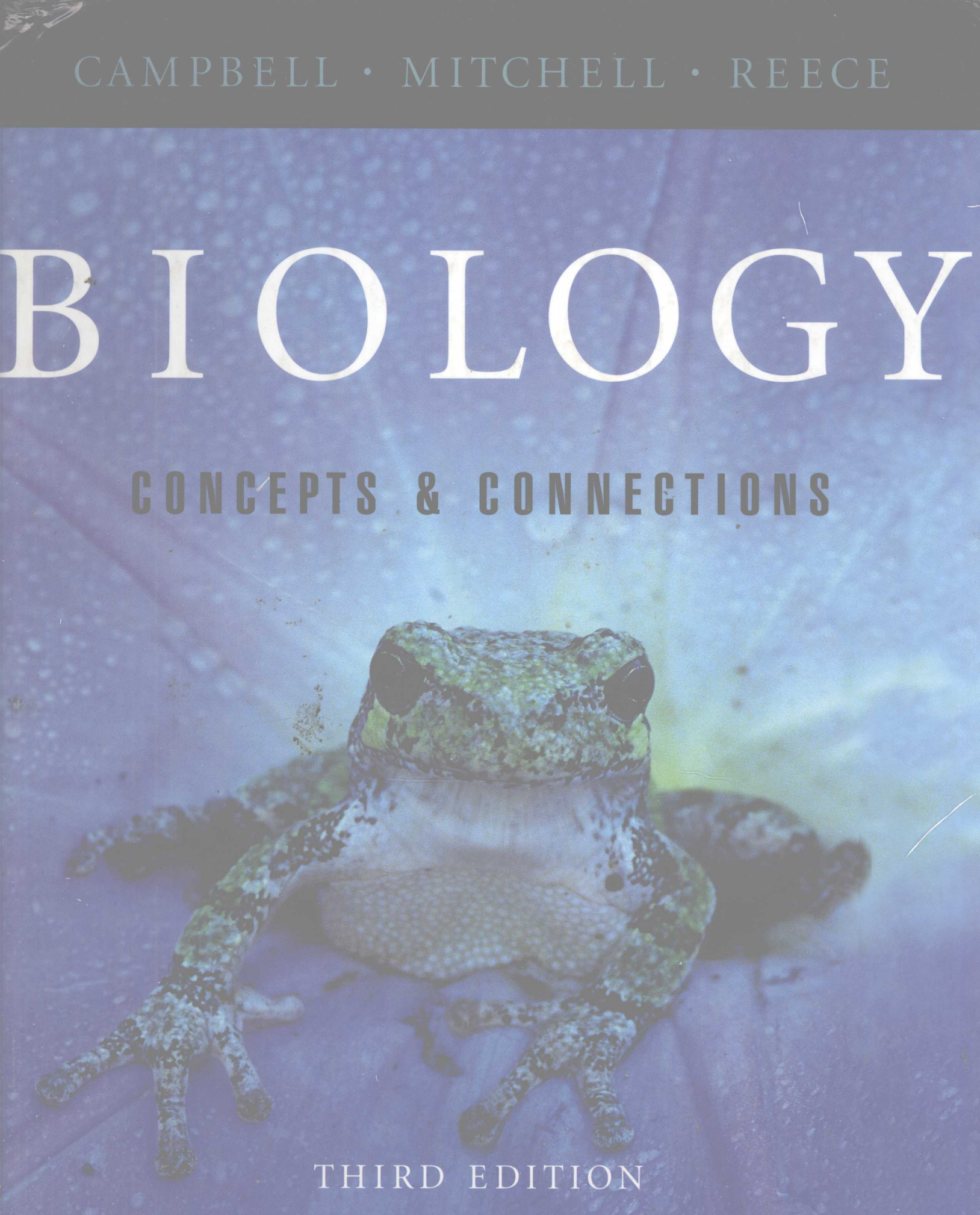
BIOLOGY

CONCEPTS & CONNECTIONS



THIRD EDITION

BIOLOGY

CONCEPTS & CONNECTIONS

THIRD EDITION

Neil A. Campbell
Lawrence G. Mitchell
Jane B. Reece

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To Rochelle and Allison, with love

N.A.C.

To Mary, with love

L.G.M.

In memory of my parents

J.B.R.

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About the Authors

Left to right, authors Campbell, Reece, and Mitchell

Neil A. Campbell

has taught general biology for 30 years and, with Drs. Reece and Mitchell, has coauthored *Biology,* Fifth Edition, the most widely used text for biology majors. His enthusiasm for sharing the fun of science with his 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 research articles on how certain desert plants survive in salty soil and how the sensitive plant (*Mimosa*) and other legumes move their leaves. His diverse teaching experiences include courses for nonbiology majors at Cornell University, Pomona College, and San Bernardino Valley College, where he received the college's first Outstanding Professor Award in 1986. Dr. Campbell is currently a visiting scholar in the Department of Botany and Plant Sciences at UC Riverside.

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 textbooks *Zoology* and *Biology,* Fifth Edition. 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 currently an affiliate professor in the Division of Biological Sciences at the University of Montana. He devotes most of his time to writing and conservation issues.

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. from Harvard University, an M.S. 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. She has taught biology at Middlesex County College (New Jersey) and Queensborough Community College (New York). During her 12 years as an editor at Benjamin/Cummings, Dr. Reece played major roles in a number of successful textbooks, including *Microbiology: An Introduction,* by G. J. Tortora, B. R. Funke, and C. L. Case; and *Molecular Biology of the Gene,* Fourth Edition, by J. D. Watson et al. She was a coauthor of *The World of the Cell,* Third Edition, with W. M. Becker and M. F. Poenie, and of *Biology,* Fifth Edition.

Preface

As we head into the new millennium, 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 go beyond the practical applications of biology. 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, and a focus on engaging students from a wide variety of majors.

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 third 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 new book would integrate smoothly with an exciting new program of supporting materials in electronic media.

TEACHING STRATEGIES OF *BIOLOGY: CONCEPTS & CONNECTIONS,* 3RD EDITION

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 five main teaching strategies as they are embodied in the third edition of *Biology: Concepts & Connections.*

This book brings the main concepts of biology into sharp focus—and now makes their organizing framework more explicit

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 can 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.

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 but a carefully crafted statement of a biological concept. Printed in large type, each concept 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.

In this new edition, we make the framework that connects a chapter's concepts more explicit by grouping the concept modules under prominent general headings. For example, the concept modules in Chapter 4 that describe the structures and functions of the nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, and vacuoles are grouped under the general heading "Organelles of the Endomembrane System." Students first see the framework of general headings and subordinated concepts in the outline that now opens each chapter, and the general headings are displayed on maroon bars where they fall within the chapter. They are also used to organize the Chapter Summary at the end of the chapter.

Reinforcing the message of every module in this edition is a checkpoint question. Located at the end of each module, these questions encourage students to test themselves repeatedly as they proceed through a chapter. The questions vary in approach. Some questions directly test the student's understanding of the main concept or part of it; 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 confidence; opportunities for more comprehensive self-testing are provided at the end of the chapter and in the materials that accompany the book.

Application modules relate biological concepts to students' lives

Students are more motivated to study biological concepts that they can connect to their own lives and interests—concepts associated with health issues, economic problems, environmental quality, ethical controversies, and social responsibility. In this edition, heading statements in green type with a red shading in the background distinguish the numerous application modules that go beyond the core biological concepts. We have also reorganized Unit II, Cellular Reproduction and Genetics, placing more modules dealing with human biology and medicine closer to related core concepts. At the end of each chapter in the book, "Science, Technology, and Society" questions encourage students to apply the concepts they have learned to various social and environmental issues.

Organisms and biological diversity remain center stage throughout the book

Students are more familiar with animals, plants, and other organisms than they are with molecules, cells, or even ecosystems. *Biology: Concepts & Connections* builds on that interest by keeping the spotlight on organisms in every chapter. The illustrated essay that begins each chapter usually portrays a natural scene featuring a biological species and how it is adapted to its environment. The biology of that organism and others is woven through the chapter, even when the chapter takes students inside organisms for a look at cells or stands back for a view of populations, communities, or ecosystems. Our hope is that the chapter-opening essays will help nurture students', and thus society's, appreciation for biological diversity.

This edition ends with a new, capstone chapter on conservation biology, Chapter 38, which further highlights the importance of biological diversity and scientific efforts to sustain it.

The many connections to whole organisms also contribute to the book's versatility in serving a variety of syllabi. Whether a course begins with biological chemistry, with ecology, or somewhere in between, instructors can customize the chapter sequence without having students lose their orientation; whatever the topic, students can connect the concepts to whole organisms.

The theme of evolution unifies the book

Organisms are this book's stars, and evolution provides its story line. 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 bewildering collection of facts to a coherent study of changing life on a changing planet. In *Biology: Concepts & Connections,* students will study the structure, function, and behavior of organisms in an evolutionary context. And throughout the book, students will view the unity and diversity of life—the similarities and differences among organisms—as the dual consequences of descent with modification. Our updated and enhanced coverage of evolution in Chapter 1 and Unit III, including the new Chapter 19 on human evolution, strengthen the unifying theme of the book.

The process of science continues to be prominent in this new edition

A biology course should make students familiar with the scientific process of posing and testing 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. Other ways of connecting to the process of science are provided to users of this book via electronic media. Activities on the Student Interactive Study Partner CD-ROM that comes with each new book, as well as activities available at the book's web site, provide further exposure to the scientific process. In fact, this book will work best for students who participate actively in learning about biological concepts and their applications.

NEW CONCEPTS AND CONNECTIONS IN THIS EDITION

Chapter 1, "Introduction: The Scientific Study of Life," includes a modern introduction to the diversity of organisms and their classification, focusing on the three domains—Bacteria, Archaea, and Eukarya. The chapter now

features ongoing studies of rainforest epiphytes as an extended example of how the process of science works. Module 1.5 presents life's fundamental features more explicitly than in previous editions.

In **Unit I, The Life of the Cell,** our introduction to the basic chemistry, structure, and energetics of cells, we have fine-tuned a number of modules to help clarify topics that students find difficult. Topics that have been updated include the functions of the cytoskeleton (Module 4.17) and the extracellular matrix (Module 4.19). Among the improved figures is Figure 7.6B, showing the interaction of light with chloroplasts; the same module has new information about the functions of carotenoids in plant cells. A new Talking-About-Science module (7.14) features Nobel laureate Mario Molina, who discusses his research on the Earth's ozone layer.

In reorganizing **Unit II, Cellular Reproduction and Genetics,** we have integrated topics in human genetics that were formerly in the last chapter of the unit into earlier chapters to support the core genetic concepts where they are first presented. The result is a unit that will be more accessible and appealing to students. Other highlights of the revision of Unit II include clearer diagrams of mitosis and meiosis (Modules 8.6 and 8.14), a new emphasis on human pedigrees in Module 9.8, updated coverage of animal cloning (Module 11.3), and a more focused account of the regulation of gene expression in eukaryotes (see especially Module 11.6). To our already strong coverage of the genetic basis of cancer (Modules 11.13–11.15), we have added an interview with leading breast-cancer researcher Mary-Claire King. The final chapter in the unit, Chapter 12, is now titled "DNA Technology and the Human Genome," highlighting the book's updated description of human DNA and the progress of the Human Genome Project (Modules 12.13–12.15). The verbal and graphic explanations of the major methods of DNA technology and their applications to law, industry, medicine, and agriculture have been improved. Two modules on the risks and ethical questions arising from the use of the technology conclude the chapter and the unit.

Major new features in this edition's **Unit III, Concepts of Evolution,** include a discussion of alternative species concepts (Module 14.2) and a new interview with popular author and educator Richard Dawkins (Module 14.9). Also, in Chapter 15, we have added new material on evolutionary trends in horses (Module 15.8) and have extensively revised our coverage of DNA and RNA sequence analysis in evolutionary research (Module 15.12). The new Module 15.14 provides a step-by-step illustration of cladistic analysis.

Unit IV, The Evolution of Biological Diversity, includes a modern treatment of archaea (Modules 16.8 and 16.12) and recent hypotheses about the origins of metabolism (Module 16.11). In Module 16.15, on pathogenic bacteria, we explain how certain strains of *E. coli* can cause life-threatening illness. Module 17.9 now includes a discussion of the loss of biological diversity in harvested forests and includes some thoughts on forest management by Michael Dombeck, Chief of the U.S. Forest Service. Several new photos enhance our coverage of animal diversity in Chapter 18. We also have added a section on incomplete and complete metamorphosis (Module 18.13), and updated our discussion of the evolutionary relationships between annelids and arthropods (Module 18.12), lungfishes and amphibians (Module 18.19), and dinosaurs and birds (Module 18.21). Module 18.23 includes a discussion of the current controversy about the origins of segmentation. Opening with an illustrated essay on the Tyrolean Ice Man, Chapter 19, Human Evolution, now completes this unit.

Our revision of **Unit V, Animals: Form and Function,** includes new information on the hormonal control of fat metabolism (Module 21.15), more attention to the health hazards of tobacco and smoking (Module 22.7), updated applications of monoclonal antibodies (Module 24.12), and a clearer account of the roles of T cells in immunity (Module 24.13). The introduction to Chapter 26 has an updated discussion of the hormone melatonin. Reflecting the rapid pace of research in neurobiology, our revision of Chapter 28, Nervous Systems, was the most extensive in this unit. New art and added text enhance our survey of nervous-system structure in Modules 28.10 and 28.11. In Modules 28.14 and 28.15, a new figure and a table illustrate human brain development and adult structure. The chapter ends with a new module on cellular changes in long-term potentiation and long-term depression.

Reflecting exciting new discoveries in plant biology, the most extensively revised chapter of **Unit VI, Plants: Form and Function,** is Chapter 33, Control Systems in Plants. New to this chapter are an updated discussion of biological clocks in plants (33.10), an interview with leading *Arabidopsis* researcher Gloria Coruzzi (33.13), and an up-to-date account of the defenses against herbivores and pathogens that have evolved in plants (33.14).

A significant new feature of **Unit VII, Ecology,** is a greater emphasis on disturbance and environmental change, both natural and human-caused. We make the connection between habitat alteration and the current high rate of species loss early in the unit (Module 34.9). Module 36.6 elaborates on the pivotal roles of disturbance in communities, providing the necessary background for a detailed look at ecosystem alteration and its effects in our new conservation biology chapter (Chapter 38). New topics in this capstone chapter include the value of biodiversity, human impacts on habitats in developed and developing nations, biodiversity hotspots and endemic species, population fragmentation, source and sink habitats, population viability analysis, landscape ecology, gap analysis, movement corridors, and restoration ecology. Other highlights

of the revision of our ecology unit include the addition of temperate rainforests in our biome survey (34.10), an updated section on cognition and cognitive maps (37.11), a heavily revised and updated module on age structures of human populations in developed and developing nations (35.9), and a timely interview with climate-change researcher Camille Parmesan of the University of Texas at Austin.

* * *

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 any member of the author team.

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Acknowledgments

Biology: Concepts & Connections, Third Edition, results from the combined efforts of many people, and the authors wish to extend heartfelt thanks to all those who contributed to this and previous editions. Our work on this edition began with input from the biologists acknowledged in the Third Edition reviewer list on p. xi, who shared with us their experiences teaching introductory biology and provided specific suggestions for improving both the text and art of this book. Camille Parmesan of the University of Texas at Austin helped us update information on global warming and provided the interview in Chapter 35. Frank Gilliam of Marshall University and Michael Dombeck and Ariel Lugo of the U.S. Forest Service graciously provided comments and photographs that appear in our ecology unit. 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,* Fifth Edition. We are fortunate to be part of a global community dedicated to excellence in biology education.

For creating the ancillary materials that support this book, special thanks go to Richard Liebaert, who is the author of the outstanding *Student Study Guide* and the Interactive Study Partner CD-ROM. (He also originated many of the chapter review materials in the text itself.) We also much appreciate all the contributions of Eugene Fenster, who revised the *Instructor's Guide* and the *Test Bank;* the other authors of the *Test Bank* (Deborah Langsam, Linda Simpson, Lisa Shimeld, Marshall Sundberg, and David Tauck); and Iain Miller, the author of the helpful new *Instructor's Guide to Media.*

The superlative publishing team for this edition was headed up by executive editor Erin Mulligan and senior editor Adam Ray. We appreciate their hard work, creativity, and commitment to excellence in biology education and to our biology group. Senior developmental editors Shelley Parlante and Pat Burner were indispensable; they deserve much credit for the high quality of this book and the enclosed CD-ROM, respectively. We are also grateful to project editor Kirsten Watrud, who handled the printed supplements for the book, and publishing assistant Maureen Kennedy, who was in charge of the electronic supplements; we expect great things of these two talented individuals.

Production professionals were involved in this edition from its inception. The components of the teaching package are both attractive and pedagogically effective in large part because of their hard work and creativity. We wish to express our gratitude to senior production editor Angela Mann, production managing editor Laura Kenney, senior art supervisor Donna Kalal, senior production editor Larry Olsen (who handled the supplements), and art and design manager Don Kesner (who personally created some outstanding new pieces of art). Senior multimedia artist Russell Chun made important contributions to the electronic components of our learning package. Freelancers played a number of key roles in book production, and we'd like to give special thanks to Kelly Murphy (who helped organize the art program), copyeditor Chad Colburn, layout artist Pat Coleman, proofreader Carol Lombardi, permissions expert Ariane DePree-Kajfez, and indexer Charlotte Shane. It was a pleasure to work with photoresearcher Stephen Forsling, and we love the cover designed by Yvo Riezebos.

We are indebted to a number of artists for the book's beautiful and instructive illustrations. These include the artists for previous editions of this book and several artists who contributed to our larger text for life science majors, *Biology.* We'd especially like to acknowledge the major influence of artist Carla Simmons on the entire art program. The revised art for this edition of the book was mainly the work of the artists of Precision Graphics and freelancer Karl Miyajima. The book itself would not have come into existence without the efforts of prepress manager Lillian Hom and prepress supervisor Vivian McDougal.

The members of the Addison Wesley Longman sales group and the Benjamin/Cummings marketing department 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 again deeply grateful to our families and friends for their support, encouragement, and patience.

Neil Campbell, Larry Mitchell, and Jane Reece

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FOR THE STUDENT

Interactive Study Partner CD-ROM

Richard Liebaert, Linn-Benton Community College

Packaged free with the text, the Study Partner contains 126 interactive exercises, animations, and lab simulations, and 20 test questions per chapter with feedback and text references. Icons appear throughout the text to guide students to applicable activities on the CD-ROM.

Special Edition of *The Biology Place*™ for *Biology: Concepts and Connections,* Third Edition

This web-based learning environment is specifically keyed to the text chapters and includes interactive tutorials, investigative learning activities, lab simulations, more than 3,000 quiz questions, and relevant news articles that help students apply concepts of biology to everyday life. A 12-month subscription is now available at no extra cost to all college students who purchase a text. See www.biology.com/cmr for more details.

Study Guide

Richard Liebaert, Linn-Benton Community College

Written by the author of many *Biology: Concepts and Connections* Chapter Review questions, this popular study guide offers a variety of interactive exercises. Icons throughout the study guide refer students to applicable activities on the Interactive Study Partner CD-ROM.

Laboratory Investigations for Biology

Jean L. Dickey, Clemson University

The order of topics in this lab manual parallels the organization of *Biology: Concepts and Connections.* Each of the 20 labs is designed with options to allow instructors to customize both the topics covered and the extent of student-guided inquiry.

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The Chemistry of Life CD-ROM by Robert M. Thornton

A Short Guide to Writing about Biology, Third Edition by Jan A. Pechenik

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Contains virtually all the art from *Biology: Concepts and Connections* with clear, easy-to-read labels. (Available to qualified college adopters.)

Instructor's Presentation CD-ROM

Animations, tables from the text, and all transparency art from *Biology: Concepts and Connections,* Third Edition are included. A presentation program enables instructors to design a customized slide show of images, import illustrations and photos from other sources, export figures into other presentation software programs, and edit them.

Instructor's Guide to Media

Iain Miller, University of Cincinnati

Provides guidance on how to use the electronic tools available with the text and how to integrate them into your course.

Instructor's Guide

Eugene J. Fenster, Longview Community College, and Fred Rhoades, Western Washington University

The *Instructor's Guide* contains lecture outlines and instructional activities. It also includes course outlines for instructors who use alternative syllabi and references to resources on the World Wide Web. Available in printed form, on disk, and on-line.

Test Bank

Contributions from Eugene J. Fenster, Longview Community College, Deborah Langsam and Linda Simpson, University of North Carolina–Charlotte, Lisa Shimeld, Crafton Hills College, David Tauck, Santa Clara University, and Marshall Sundberg, Emporia State University

The test bank includes questions at three levels: factual, conceptual, and applications-based. Available in print form and on Macintosh, DOS, and Windows test-generating programs. (Available to qualified college adopters.)

How to Use This Book

To the Student

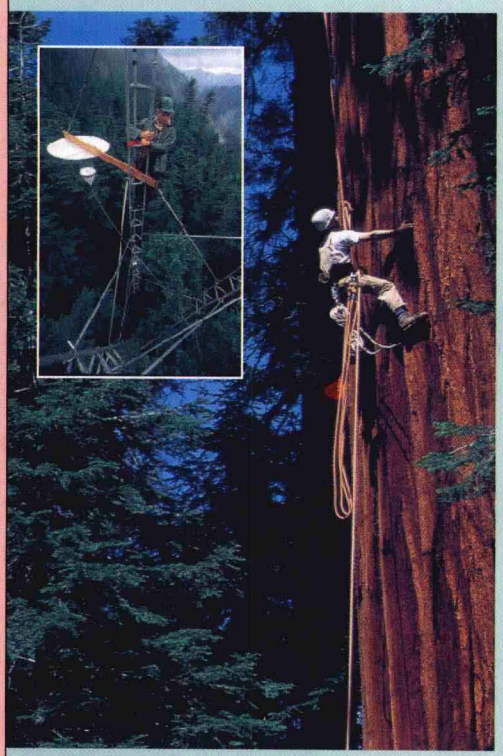
Like the world it describes, *Biology: Concepts and Connections* is a system of connected and complementary elements. This section shows you how to use the text and its media partners to make studying easier.

After reviewing this guide, read Chapter One, "Introduction: The Scientific Study of Life." Chapter One gives you a framework for the process of science and the scope of biology as a science. Attention to the concepts and connections in this chapter will pay dividends throughout your course.

CHAPTER OPENERS HOLD A KEY TO THE CHAPTER

- Most chapters begin with a story about an organism—its way of life, its unique characteristics, its interactions with its environment, and how biologists study it. This story highlights the chapter's main subject and often relates the process of science to the topics at hand.
- An outline, showing the chapter's main topics and their underlying concepts, offers a preview to the chapter.

1 Introduction: The Scientific Study of Life



Outline

The Scope of Biology

1.1 Life's levels of organization define the scope of biology

The Process of Science

1.2 Scientists pose and test hypotheses to answer questions about nature

1.3 The process of science: A case study in a tropical rain forest

Evolution, Unity, and Diversity

1.4 The diversity of life can be arranged into three domains

1.5 Unity in diversity: All forms of life have common features

1.6 Evolution explains the unity and diversity of life

1.7 Living organisms and their environments form interconnecting webs

Connections to Everyday Life

1.8 Biology is connected to our lives in many ways

The canopies, or treetops, of forests are one of nature's great showplaces of different kinds of living organisms. Biologists estimate that fully half of the 5 million to 50 million species on Earth spend all or much of their time here, yet canopies were virtually unexplored until about 15 years ago. The canopies of tropical rain forests, areas near the equator where yearly rainfall often exceeds 200 centimeters (80 inches), harbor the greatest number of species. Equally wet forests in the coastal regions of western Canada and the northwestern United States also are home to remarkable numbers. The dominant trees in many northern rain forests are centuries-old firs, hemlocks, and spruces. Extending into northern California are remnants of truly ancient rain forests dominated by redwoods and giant sequoia trees that are thousands of years old.

Research on forest canopies blossomed in the 1970s when scientists began using mountain climbers' roping techniques to reach the treetops. In the large photograph at the left, Humboldt State University researcher Steve Sillett is roping his way into the 90-meter-high canopy of a 2000-year-old giant sequoia tree in northern California.

Roping techniques allow researchers to move from one area of forest to another, but they are not the only way to get into a canopy. For projects that can be done in a limited area, some researchers prefer large construction cranes with horizontal booms that rotate over the canopy. More permanent are platforms, walkways, and towers built into the treetops. In the small photograph on the facing page, a researcher from the University of Washington stands on a tower set up to collect samples of mist, part of a long-term study of how water circulates between the forest and the atmosphere.

Canopy research is not for everyone. Researchers often spend a week or more in treetops, sleeping in hammocks strung between branches higher than a 20-story skyscraper. Their rewards include sights, sounds, and smells found nowhere else. Pioneer forest researcher Dr. Jerry Franklin expresses his enthusiasm for canopy research this way: "Trees are one of Earth's main points of contact with the air. This is our chance to learn about the dialogue between trees and the atmosphere."

A summer evening is a good time to experience a canopy's rich array of life. In a rain forest in the northwestern U.S., brown and greenish fungi, lichens, and earthy mats of moss cling to the high branches. Your eye might catch the split-second shadow of a flying squirrel across a bright moon. Rarely seen because they are active only at night, these foot-long rodents speed-glide between the big trees. Insects are especially abundant in the canopy twilight, and bats flit about, often eating close to their own body weight in insects in a single night. Owls, another group of nocturnal hunters, are silent on the wing, but each species has its own distinctive hoot.

A flying squirrel

The enormous variety of living organisms in forest canopies and the science of canopy research set the stage for this chapter's introduction to biology, the scientific study of life.

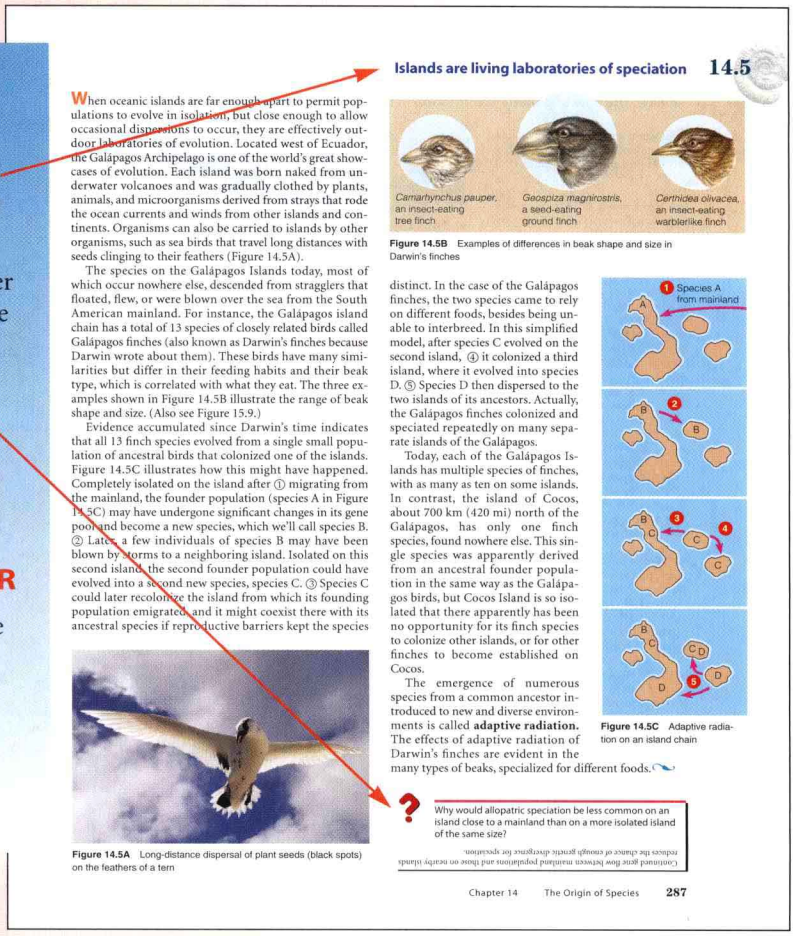
1

CHAPTERS HELP YOU UNDERSTAND CONCEPTS

- Each module features a central concept, which is announced in the heading. You can grasp each concept fully before going on to the next.
- Modules are numbered for easy reference and are never longer than two facing pages—you never have to turn the page to see the figures.
- Each module ends with a self-test question. Feedback is provided on the spot.
- A few main headings organize each chapter into groups of concept modules. The main headings appear in maroon bars across the page.

ILLUSTRATIONS AND TEXT WORK TOGETHER

- Use both as you study. The illustrations reinforce the message of the text and vice versa. They are both integral to understanding the concepts.
- Some figures take you through a sequence of steps labeled with red-circled numbers. These numbers also appear in the text, keyed to the explanation of the steps in the process.



Islands are living laboratories of speciation 14.5

When oceanic islands are far enough apart to permit populations to evolve in isolation, but close enough to allow occasional dispersions to occur, they are effectively outdoor laboratories of evolution. Located west of Ecuador, the Galápagos Archipelago is one of the world's great showcases of evolution. Each island was born naked from underwater volcanoes and was gradually clothed by plants, animals, and microorganisms derived from strays that rode the ocean currents and winds from other islands and continents. Organisms can also be carried to islands by other organisms, such as sea birds that travel long distances with seeds clinging to their feathers (Figure 14.5A).

The species on the Galápagos Islands today, most of which occur nowhere else, descended from stragglers that floated, flew, or were blown over the sea from the South American mainland. For instance, the Galápagos island chain has a total of 13 species of closely related birds called Galápagos finches (also known as Darwin's finches because Darwin wrote about them). These birds have many similarities but differ in their feeding habits and their beak type, which is correlated with what they eat. The three examples shown in Figure 14.5B illustrate the range of beak shape and size. (Also see Figure 15.9.)

Evidence accumulated since Darwin's time indicates that all 13 finch species evolved from a single small population of ancestral birds that colonized one of the islands. Figure 14.5C illustrates how this might have happened. Completely isolated on the island after ① migrating from the mainland, the founder population (species A in Figure 14.5C) may have undergone significant changes in its gene pool and become a new species, which we'll call species B. ② Later, a few individuals of species B may have been blown by storms to a neighboring island. Isolated on this second island, the second founder population could have evolved into a second new species, species C. ③ Species C could later recolonize the island from which its founding population emigrated, and it might coexist there with its ancestral species if reproductive barriers kept the species distinct. In the case of the Galápagos finches, the two species came to rely on different foods, besides being unable to interbreed. In this simplified model, after species C evolved on the second island, ④ it colonized a third island, where it evolved into species D. ⑤ Species D then dispersed to the two islands of its ancestors. Actually, the Galápagos finches colonized and speciated repeatedly on many separate islands of the Galápagos.

Today, each of the Galápagos Islands has multiple species of finches, with as many as ten on some islands. In contrast, the island of Cocos, about 700 km (420 mi) north of the Galápagos, has only one finch species, found nowhere else. This single species was apparently derived from an ancestral founder population in the same way as the Galápagos birds, but Cocos Island is so isolated that there apparently has been no opportunity for its finch species to colonize other islands, or for other finches to become established on Cocos.

The emergence of numerous species from a common ancestor introduced to new and diverse environments is called **adaptive radiation.** The effects of adaptive radiation of Darwin's finches are evident in the many types of beaks, specialized for different foods.

Figure 14.5A Long-distance dispersal of plant seeds (black spots) on the feathers of a tern

Figure 14.5B Examples of differences in beak shape and size in Darwin's finches

Figure 14.5C Adaptive radiation on an island chain

? Why would allopatric speciation be less common on an island close to a mainland than on a more isolated island of the same size?

Continued gene flow between mainland populations and those on nearby islands reduces the chance of enough genetic divergence for speciation.

Chapter 14 The Origin of Species 287

Photosynthesis, Solar Radiation, and Earth's Atmosphere

Photosynthesis moderates the greenhouse effect; deforestation intensifies it 7.13

The trees in the photograph (Figure 7.13A) form part of an **old-growth forest** in the Pacific Northwest. Such a forest is an ancient one that has never been seriously disturbed by humans. Many of the trees—mainly Douglas fir here—are thousands of years old. The forest they dominate is one of a few remaining undisturbed areas that contain harvestable timber in the United States.

Old-growth forests are the focus of a long-standing controversy between the timber industry and conservationists. Trees like these contain a lot of marketable lumber, and economic arguments can be made for harvesting them. On the other side of the controversy, conservationists argue that old-growth forests are home to many species that can survive nowhere else, and that we should save these remnants of our ancient forests for future generations.

The photosynthesis carried out by old-growth forests has direct bearing on the controversy. At center stage is CO_2, the gas that plants use to make sugars in photosynthesis and that all organisms give off as waste from cellular respiration.

Carbon dioxide normally makes up about 0.03% of the air we breathe. This amount of CO_2 in the atmosphere provides plants with plenty of carbon. It also helps moderate world climates, because CO_2 retains heat from the sun that would otherwise radiate from Earth back into space. Warming induced by CO_2 is called the **greenhouse effect** because atmospheric CO_2 traps heat and warms the air just as clear glass does in a greenhouse (Figure 7.13B). The greenhouse effect keeps the average temperature on Earth some 10°C warmer than it would be otherwise.

Ironically, planet Earth may now be overheating from the greenhouse effect. The amount of atmospheric CO_2 has been on the rise in the past century, mainly because of worldwide industrialization and the increased use of gas, coal, and wood as fuels. When these substances are burned, the carbon in them is released as CO_2. The increase in atmospheric CO_2 seems to be contributing to rise in global temperatures. Photosynthesis consumes CO_2, tending to counteract the greenhouse effect, but the global rate of photosynthesis may decline as we clear large tracts of forest for farming and urban expansion. Even if deforestation continues, especially in the tropics, the western and southeastern United States, Canada, and Siberia.

Figure 7.13A An old-growth forest in the Pacific Northwest

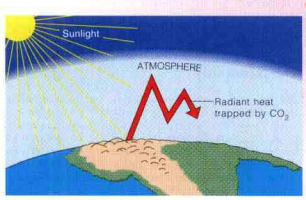


Figure 7.13B The greenhouse effect of CO_2 in the atmosphere

The greenhouse effect has come up on both sides of the old-growth forest controversy. Those who favor saving old-growth trees argue that these large photosynthesizers remove a lot of potentially harmful CO_2 from the atmosphere. Those favoring harvesting argue that replacing old trees with seedlings would actually increase photosynthesis and reduce atmospheric CO_2.

Relative to their size and weight, young, rapidly growing trees do, in fact, take up CO_2 at a faster rate than older trees. However, when old trees are harvested, much less than their bulk becomes lumber. All the roots and most branches are left behind to decompose. Most of the wood itself is turned into paper, sawdust, or fuel—products that usually decompose or are burned within a few years. Their decomposition and burning turn the carbon compounds that were in the tree into CO_2, and this puts much more CO_2 in the atmosphere than young trees can take up.

In the next module, we'll hear more about harmful effects of human activities on Earth's atmosphere.

? Explain the greenhouse effect.

Chapter 7 Photosynthesis: Using Light to Make Food

TALKING ABOUT SCIENCE

7.14 Mario Molina talks about Earth's protective ozone layer

As photosynthesis reduces the CO_2 in Earth's atmosphere, it also produces the O_2 on which plants, animals, and most other organisms depend for cellular respiration. This O_2 benefits organisms in another way: High in the atmosphere it is converted to ozone, a form of oxygen that plays an important protective role for life on Earth. Among the scientists who study the ozone layer is Mario Molina of MIT, who in 1995 shared a Nobel Prize for his research on how certain pollutants are damaging that layer. In a recent interview, Dr. Molina explained why the ozone layer is important.

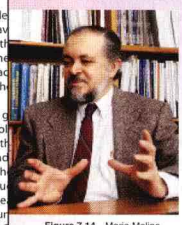


Figure 7.14 Mario Molina

The ozone layer shields the Earth's surface from powerful ultraviolet radiation that comes from the sun. This UV radiation is harmful to organisms, including humans. For example, UV radiation causes sunburn, and skin cancer can be a cumulative result of exposure. There is also evidence that UV can damage crops. Certain developing animals, such as the larvae of fish, seem to be particularly sensitive.

He described how the ozone forms and how it is destroyed.

The ozone forms when high-energy solar radiation breaks apart O_2 molecules and frees oxygen atoms. These then react with unbroken O_2 molecules. The result is ozone, which has *three* oxygen atoms (O_3). So ozone is continuously forming by the action of sunlight on the atmosphere. This is balanced by continuous destruction of the ozone molecules when they react with other chemical compounds that are naturally present in the atmosphere. Humans have disrupted that balance by releasing certain industrial chemicals that hasten this destruction.

The research that won Dr. Molina the Nobel Prize dealt with the destruction of ozone by one particular class of chemicals, called chlorofluorocarbons, or CFCs. In 1974, when Dr. Molina and his colleagues first published their CFC-ozone depletion theory, CFCs were used in large amounts as refrigerants, as propellants in spray cans, as solvents, and in the process for making plastic foams.

We predicted that the continuous release of CFCs would damage the protective ozone layer. CFCs are very stable compounds, and this stability allows them to make it up to the ozone layer, which is about 15 miles above the surface of the Earth. There solar radiation converts them to very reactive chemicals called free radicals, which then destroy the ozone.

How did scientists and the general public react to the alarming possibility that the ozone layer was thinning?

At first, there was very little reaction because not many more people, including politicians, became concerned about ozone depletion. There was also growing awareness about the role of UV radiation in skin cancer and other biological damage. Then, in 1985, scientists documented a

dard of living?

That's an issue, but there is another important element that I've observed from my own experience. When I was going to the university in Mexico, no one cared about pollution. Dealing with pollution seemed like a luxury. Today, everybody in Mexico City cares about pollution, so solving this problem no longer seems like something that industrialized countries want to impose upon them. The costs of pollution are enormous in Mexico City, where I was born. If only there had been insight about what would happen to the city, pollution could have been reduced at a much lower cost. It's much more difficult to repair the environment now, but I think there is a strong incentive to do that in developing countries. It's not easy because of the complications of social and economic issues. Science and technology are very important components, but not the only ones, so scientists will have to be humble and realize their limits.

The connections between science, technology, and society, so clearly exemplified by the work of Mario Molina, are a major theme of this book. This theme will come up again in the next unit, on cellular reproduction and genetics.

RED SHADING IDENTIFIES MODULES THAT CONNECT BIOLOGY TO HUMAN ISSUES

- "Talking About Science" modules profile men and women working in the world of science. Most of these modules feature interviews.
- Other modules relate biological concepts to health, social, or environmental issues.