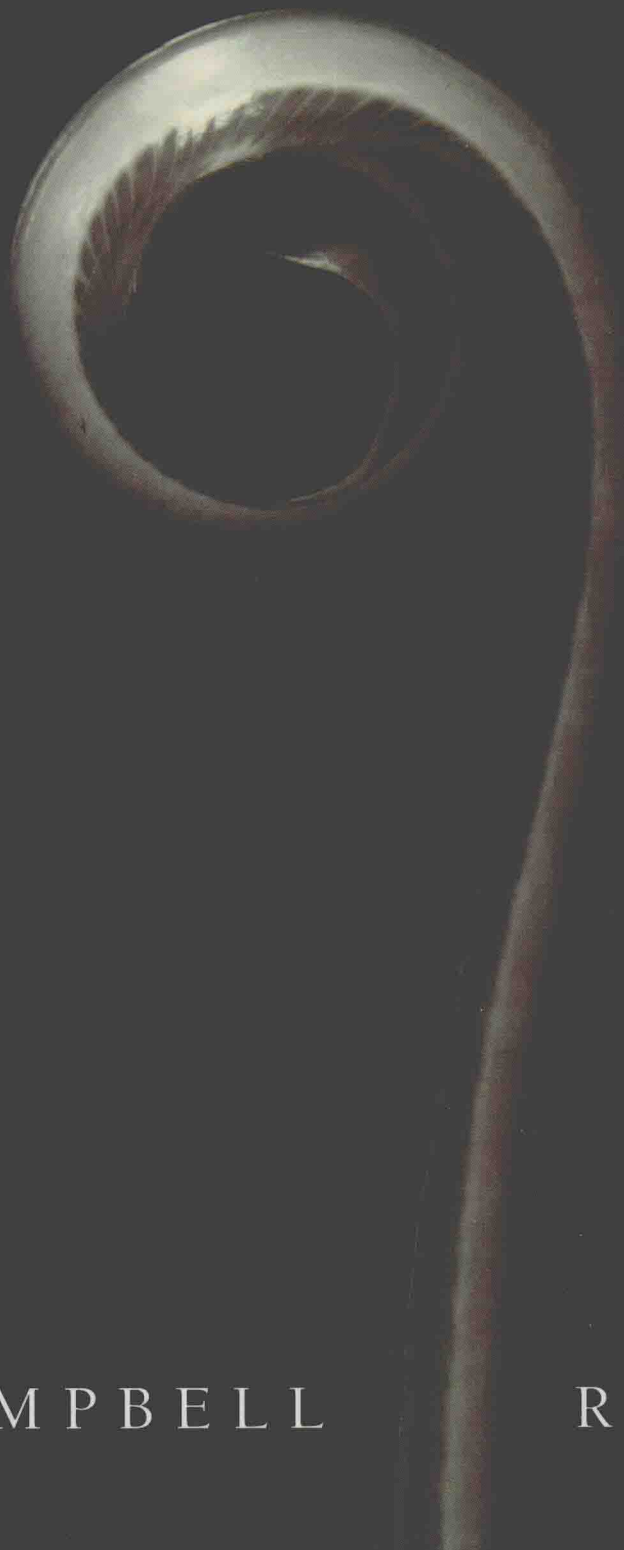
# BIOLOGY

*Seventh Edition*



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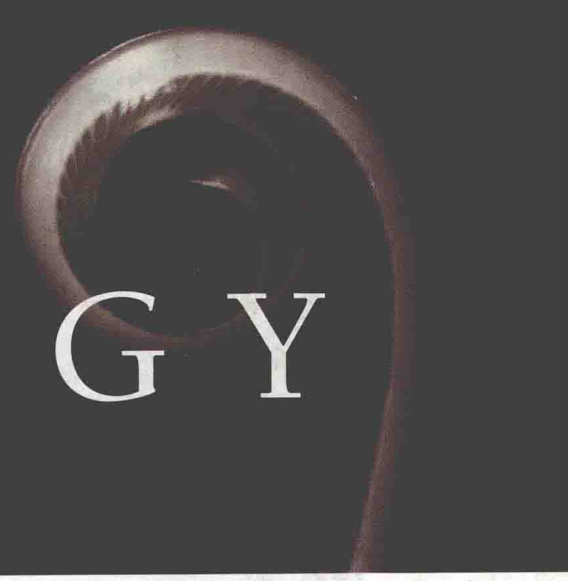

# BIOLOGY

*Seventh Edition*


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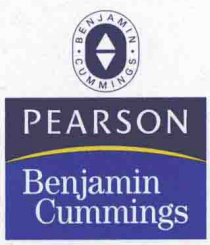


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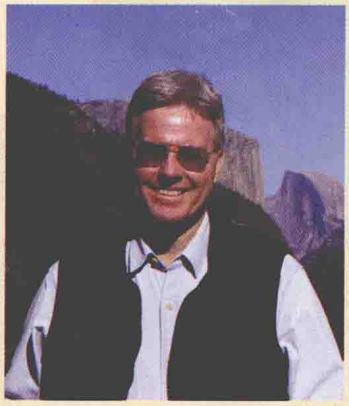


**Neil A. Campbell** combined the investigative nature of a research scientist with the soul of an experienced and caring teacher. He earned his M.A. in Zoology from UCLA and his Ph.D. in Plant Biology from the University of California, Riverside, where he received the Distinguished Alumnus Award in 2001. Dr. Campbell published numerous research articles on how certain desert and coastal plants thrive in salty soil and how the sensitive plant (*Mimosa*) and other legumes move their leaves. His 30 years of teaching in diverse environments included general biology courses at Cornell University, Pomona College, and San Bernardino Valley College, where he received the college's first Outstanding Professor Award in 1986. Most recently Dr. Campbell was a visiting scholar in the Department of Botany and Plant Sciences at the University of California, Riverside. In addition to his authorship of this book, he coauthored *Biology: Concepts and Connections* and *Essential Biology* with Jane Reece. Each year, over 600,000 students worldwide use Campbell/Reece biology textbooks.

To Rochelle and Allison, with love

—N.A.C.

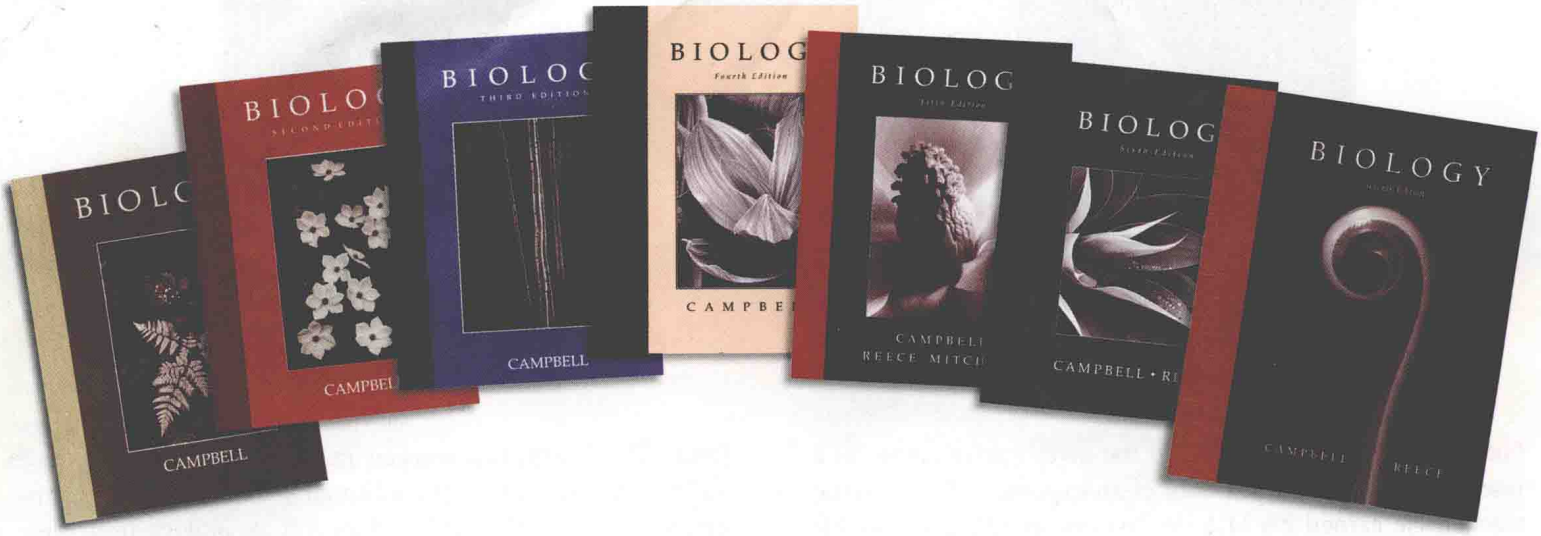
**Jane B. Reece** has worked in biology publishing since 1978, when she joined the editorial staff of Benjamin Cummings. Her education includes an A.B. in Biology from Harvard University, an M.S. in Microbiology from Rutgers University, and a Ph.D. in Bacteriology from the University of California, Berkeley.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

To Paul and Daniel, with love

—J.B.R.

NEIL A. CAMPBELL
died October 21, 2004 after finishing work on this revision.
He is deeply mourned by his many friends and colleagues
at Benjamin Cummings and
throughout the biology community.

# Preface




Charles Darwin described evolution as a process of "descent with modification." It is a phrase that also fits the continuing evolution of *BIOLOGY*. This Seventh Edition is our most ambitious revision of the book since its origin—a new textbook "species" with several evolutionary adaptations shaped by the changing environment of biology courses and by the astonishing progress of biological research. But these adaptive modifications are still true to the two complementary teaching values at the core of every edition of *BIOLOGY*. First, we are dedicated to crafting each chapter from a framework of key concepts that will help students keep the details in place. Second, we are committed to engaging students in scientific inquiry through a combination of diverse examples of biologists' research and opportunities for students to practice inquiry themselves.

These dual emphases on concept building and scientific inquiry emerged from our decades of classroom experience. It is obviously gratifying that our approach has had such broad appeal to the thousands of instructors and millions of students who have made *BIOLOGY* the most widely used college science textbook. But with this privilege of sharing biology with so many students comes the responsibility to continue improving the book to serve the biology community even better. As we planned this new edition, we visited dozens of campuses to hear what students and their instructors had to say about their biology courses and textbooks. What we learned from those conversations about new directions in biology courses and the changing needs of students informed the many improvements you'll find in this Seventh Edition of *BIOLOGY*.

## We have restructured each chapter to bring its key concepts into even sharper focus

The discovery explosion that makes modern biology so exciting also threatens to suffocate students under an avalanche of information. The past few editions of *BIOLOGY* set the details in a context of key concepts, typically ten to twenty per chapter. In this new edition, we have taken the next evolutionary step of restructuring each chapter to help students focus on fewer, even bigger ideas—typically just five or six key concepts per chapter. A new Overview section at the beginning of each chapter sets an even broader context for the key concepts that follow. And at the end of each of the concept sections, a Concept Check with two or three questions enables students to assess whether they understand that concept before going on to the next. Answers to the Concept Check questions are located in Appendix A, as are the answers to the Self-Quizzes from the Chapter Review at the end of each chapter.

In our ongoing interactions with students and instructors, they have responded enthusiastically to our new organization and pedagogy. Compared to other textbooks, including earlier editions of our own, students have found the new chapter structure and design of *BIOLOGY*, Seventh Edition, to be more inviting, more accessible, and much more efficient to use. But in achieving these goals, we have not compromised the depth and scientific accuracy the biology community has come to expect from us.

# 54 Ecosystems

▲ Figure 54.1 An aquarium, an ecosystem bounded by glass.

**Key Concepts** keep the supporting details in context.

## Key Concepts

**54.1** Ecosystem ecology emphasizes energy flow and chemical cycling

**54.2** Physical and chemical factors limit primary production in ecosystems

**54.3** Energy transfer between trophic levels is usually less than 20% efficient

**54.4** Biological and geochemical processes move nutrients between organic and inorganic parts of the ecosystem

**54.5** The human population is disrupting chemical cycles throughout the biosphere

The **Overview** sets the stage for the rest of the chapter.

## Overview

### Ecosystems, Energy, and Matter

An **ecosystem** consists of all the organisms living in a community as well as all the abiotic factors with which they interact. Ecosystems can range from a microcosm, such as the aquarium in **Figure 54.1**, to a large area such as a lake or forest. As with populations and communities, the boundaries of ecosystems are usually not discrete. Cities and farms are examples of human-dominated ecosystems. Many ecologists regard the entire biosphere as a global ecosystem, a composite of all the local ecosystems on Earth.

Regardless of an ecosystem's size, its dynamics involve two processes that cannot be fully described by population or community processes and phenomena: energy flow and chemical cycling. Energy enters most ecosystems in the form of sunlight. It is then converted to chemical energy by autotrophs and dissipated as heat. Chemical elements are recycled among abiotic and biotic components of the ecosystem. Photosynthetic organisms assimilate these elements in inorganic form from the air, soil, and water and incorporate them into organic molecules, some of which are consumed by animals. The elements are returned in inorganic form to the air, soil, and water by the metabolism of plants and animals and by other organisms, such as bacteria and fungi, that break down organic wastes and dead organisms.

Both energy and matter move through ecosystems via the transfer of substances during photosynthesis and feeding relationships. However, because energy, unlike matter, cannot be recycled, an ecosystem must be powered by a continuous influx of energy from an external source—in most cases, the sun. Energy flows through ecosystems, while matter cycles within them.

Resources critical to human survival and welfare, ranging from the food we eat to the oxygen we breathe, are products of ecosystem processes. In this chapter, we will explore the dynamics of energy flow and chemical cycling in ecosystems and consider some of the impacts of human activities on these processes.

Each numbered **Concept Head** announces the beginning of a new concept section.

## Concept 54.1

### Ecosystem ecology emphasizes energy flow and chemical cycling

Ecosystem ecologists view ecosystems as transformers of energy and processors of matter. By grouping the species in a community into trophic levels of feeding relationships (see [illegible] transformation of energy in [illegible]ments of chemical elements

▲ Figure 54.3 Fungi decomposing a dead tree.

consumers in an ecosystem. In a forest, for example, birds might feed on earthworms that have been feeding on leaf litter and its associated prokaryotes and fungi. But even more important than this channeling of resources from producers to consumers is the role that detritivores play in making vital chemical el[illegible] available to producers.

D[illegible] the organic material in an e[illegible]ents in inor[illegible]

**Concept Check Questions** at the end of each concept section encourage students to assess their mastery of the concept.

### Concept Check 54.1

1. Why is the transfer of energy in an ecosystem referred to as energy flow, not energy cycling?
2. How does the second law of thermodynamics explain why an ecosystem's energy supply must be continually replenished?
3. How are detritivores essential to sustaining ecosystems?

*For suggested answers, see Appendix A.*

## Concept 54.2

### Physical and chemical factors limit primary production in ecosystems

The amount of light energy converted to chemical energy (organic compounds) by autotrophs during a given time period is an ecosystem's **primary production.** This photosynthetic product is the starting point for studies of ecosystem metabolism and energy flow.

#### Ecosystem Energy Budgets

Most primary producers use light energy to synthesize energy-rich organic molecules, which can subsequently be broken down to generate ATP (see Chapter 10). Consumers acquire their organic fuels secondhand (or even third- or fourthhand) through food webs such as that in Figure 53.13. Therefore, the extent of photosynthetic production sets the spending limit for the energy budget of the entire ecosystem.

*Global Energy Budget*

[illegible] bombarded [illegible]

# New "Exploring Figures" provide efficient access to many complex topics

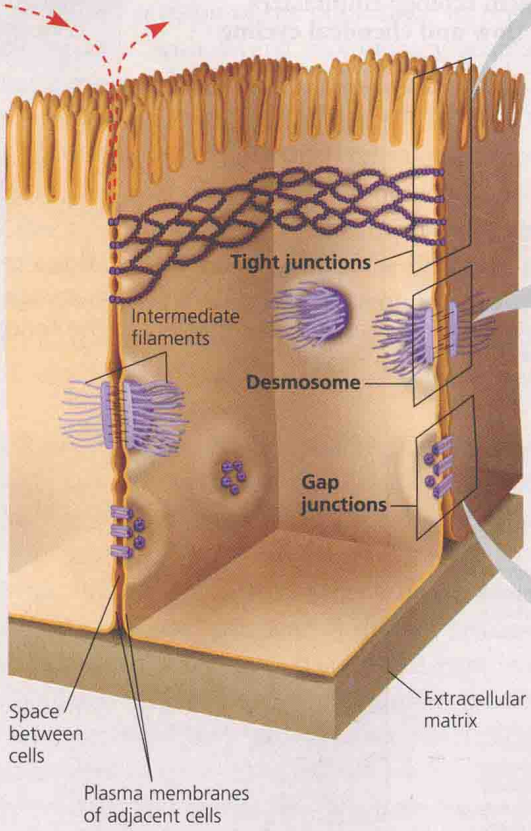
Biology is a visual science. Thus we have always authored *BIOLOGY's* graphics and narrative side by side to coordinate their message. In the Seventh Edition, this text-art integration reaches its next evolutionary level with a new feature called "Exploring Figures." Each of these large figures is a learning unit that brings together a set of related illustrations and the text that describes them. The Exploring Figures enable students to access dozens of complex topics much more efficiently, now that the textual and visual components have merged.

The Exploring Figures represent core chapter content, not to be confused with some textbooks' "boxes," which feature content that is peripheral to the flow of a chapter. Modern biology is challenging enough without diverting students' attention from a chapter's conceptual storyline. Thus, each Exploring Figure is referenced in the main text body where it fits into the development of a concept, just as the text points students to all the other supporting figures at the appropriate places in the narrative.

In **Exploring Figures**, art, photos, and text are fully integrated.

Figure 6.31

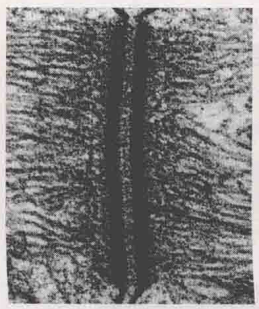
## Exploring Intercellular Junctions in Animal Tissues





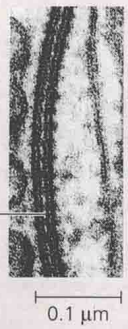
### TIGHT JUNCTIONS

At **tight junctions**, the membranes of neighboring cells are very tightly pressed against each other, bound together by specific proteins (purple). Forming continuous seals around the cells, tight junctions prevent leakage of extracellular fluid across a layer of epithelial cells.




### DESMOSOMES

**Desmosomes** (also called *anchoring junctions*) function like rivets, fastening cells together into strong sheets. Intermediate filaments made of sturdy keratin proteins anchor desmosomes in the cytoplasm.




### GAP JUNCTIONS

**Gap junctions** (also called *communicating junctions*) provide cytoplasmic channels from one cell to an adjacent cell. Gap junctions consist of special membrane proteins that surround a pore through which ions, sugars, amino acids, and other small molecules may pass. Gap junctions are necessary for communication between cells in many types of tissues, including heart muscle and animal embryos.

# Scientific inquiry is more prominent than ever in *BIOLOGY* and its supplements

One objective for many biology instructors is for students to learn to think as scientists. In both the lecture hall and laboratory, colleagues are experimenting with diverse approaches for involving students in scientific inquiry, in which questions about nature focus strategic investigation and analysis of data. New textbook features and new inquiry-based supplements make this edition of *BIOLOGY* more effective than ever as a partner to instructors who emphasize the process of science.

## Modeling Inquiry by Example

Scientific inquiry has always been one of *BIOLOGY*'s unifying themes. Each edition has traced the history of many research questions and scientific debates to help students appreciate not just "what we know," but "how we know," and "what we do not yet know." In *BIOLOGY*, Seventh Edition, we have strengthened this theme by making examples of scientific inquiry much more prominent throughout the book.

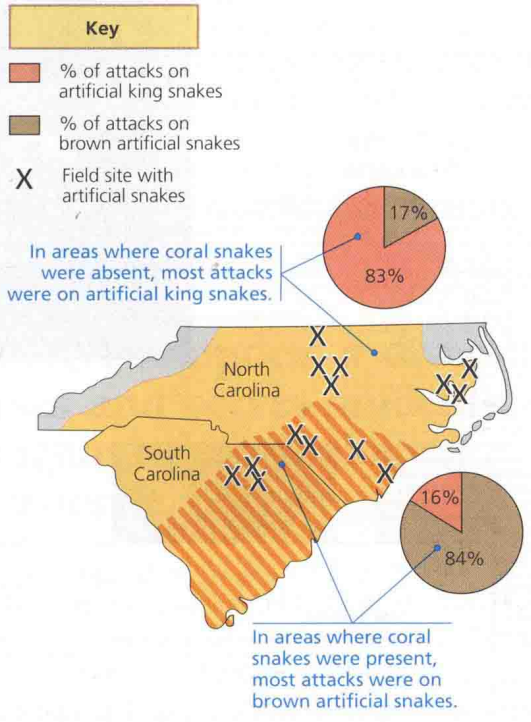
The increased emphasis on inquiry begins in Chapter 1, where we have thoroughly revised the introduction to the many ways that scientists explore biological questions. Chapter 1 also introduces a new feature called "Inquiry Figures," which showcase outstanding examples of experiments and field studies in a format that is consistent throughout the book. Complementing the Inquiry Figures are the new "Research Method Figures," which walk students through the techniques and tools of modern biology. You can find a list of the Inquiry and Research Method Figures on pages xx-xxi. These new features, like the Exploring Figures, are integral to chapter flow rather than being appended as boxed asides.

New **Inquiry Figures** and **Research Method Figures** help students learn to think like scientists.

**Figure 1.29**
**Inquiry Does the presence of poisonous coral snakes affect predation rates on their mimics, king snakes?**

**EXPERIMENT** David Pfennig and his colleagues made artificial snakes to test a prediction of the mimicry hypothesis: that king snakes benefit from mimicking the warning coloration of coral snakes *only* in regions where poisonous coral snakes are present. The Xs on the map below are field sites where the researchers placed equal numbers of artificial king snakes (experimental group) and brown artificial snakes (control group). The researchers recovered the artificial snakes after four weeks and tabulated predation data based on teeth and claw marks on the snakes (see Figure 1.28).

**RESULTS** In field sites where coral snakes were present, predators attacked far fewer artificial king snakes than brown artificial snakes. The warning coloration of the "king snakes" afforded no such protection where coral snakes were absent. In fact, at those field sites, the artificial king snakes were *more* likely to be attacked than the brown artificial snakes, perhaps because the bright pattern is particularly easy to spot against the background.

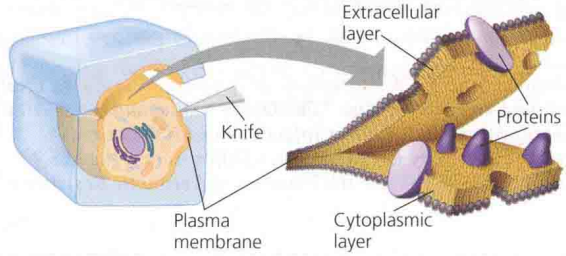



**CONCLUSION** The field experiments support the mimicry hypothesis by not falsifying the key prediction that imitation of coral snakes is only effective where coral snakes are present. The experiments also tested an alternative hypothesis that predators generally avoid all snakes with brightly colored rings, whether or not poisonous snakes with that coloration live in the environment. That alternative hypothesis was falsified by the data showing that the ringed coloration failed to repel predators where coral snakes were absent.

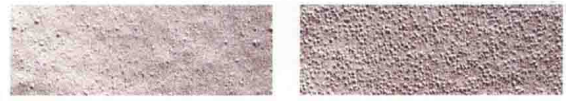
**Figure 7.4**
**Research Method Freeze-Fracture**

**APPLICATION** A cell membrane can be split into its two layers, revealing the ultrastructure of the membrane's interior.

**TECHNIQUE** A cell is frozen and fractured with a knife. The fracture plane often follows the hydrophobic interior of a membrane, splitting the phospholipid bilayer into two separated layers. The membrane proteins go wholly with one of the layers.




**RESULTS** These SEMs show membrane proteins (the "bumps") in the two layers, demonstrating that proteins are embedded in the phospholipid bilayer.



## Learning Inquiry by Practice

Modeling scientific inquiry by example has only ephemeral impact unless students have an opportunity to apply what they have learned by asking their own biological questions and conducting their own investigations. On a small scale, *BIOLOGY*, Seventh Edition, encourages students to practice thinking as scientists by responding to "Scientific Inquiry" questions in the Chapter Review at the ends of chapters.

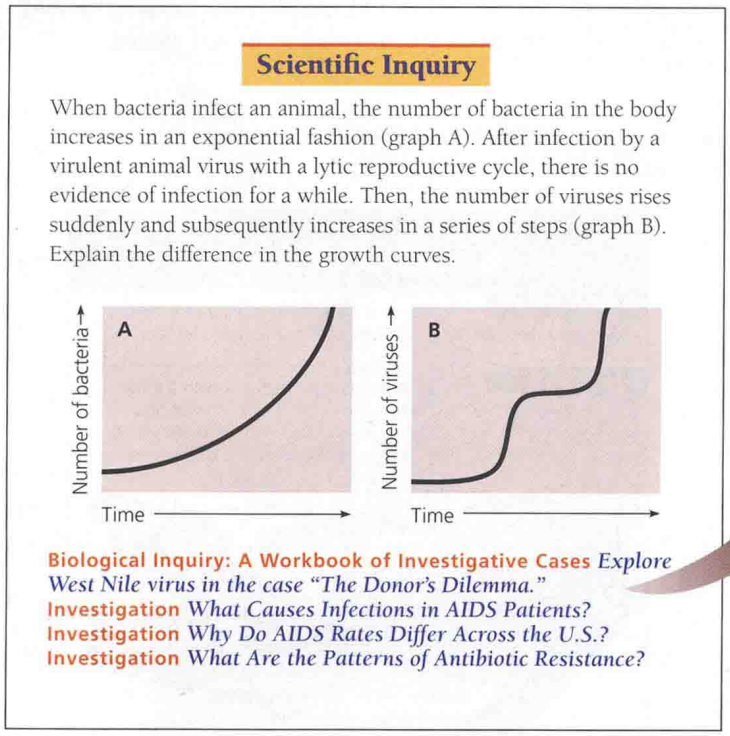
On a much bigger scale, new supplements build on the textbook to provide diverse opportunities for students to practice scientific inquiry. One example is *Biological Inquiry: A Workbook of Investigative Cases*, by Margaret Waterman of Southeast Missouri State University and Ethel Stanley of Beloit College, which is available without cost to students whose instructors request it as a supplement to the textbook. This innovative new workbook offers eight case studies, coordinated with the eight units of chapters in *BIOLOGY*. In each case, a realistic scenario sets up a series of inquiry-based activities. The cases work well either as class-discussion projects or as take-home assignments for students working alone, or better, in small groups.

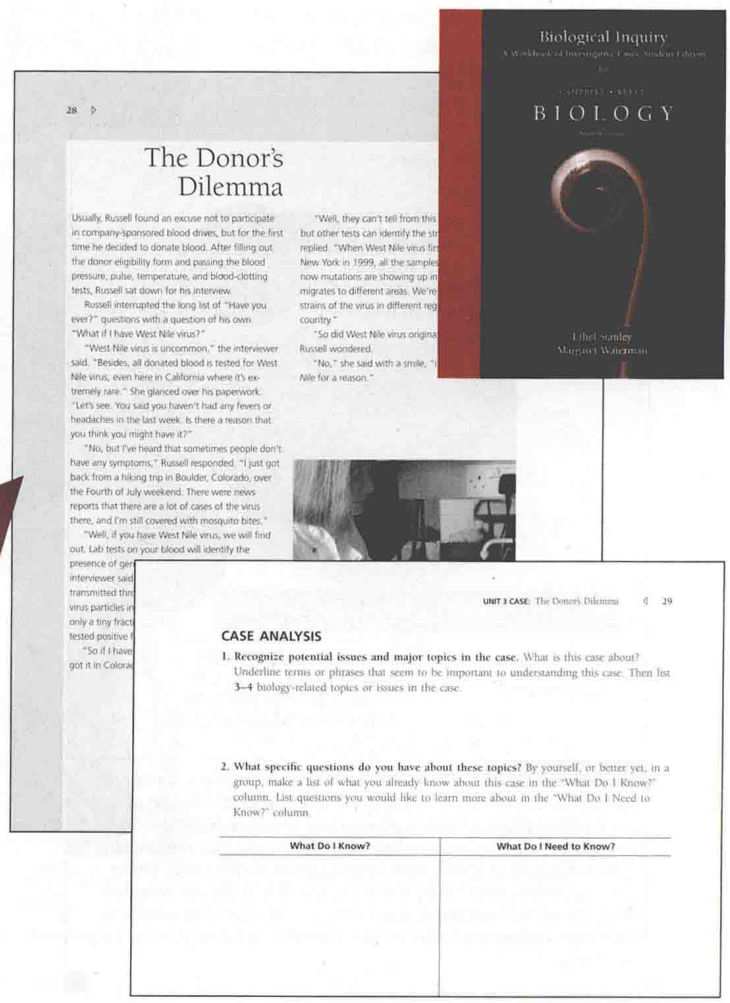
Another student-centered supplement is *Practicing Biology*, by Jean Heitz, University of Wisconsin, Madison, which is also available without additional cost upon request of instructors using *BIOLOGY*, Seventh Edition. This workbook supports various learning styles with a variety of activities—including modeling, drawing, and concept-mapping—that help students construct an understanding of biological concepts.

Students will find still more opportunities for active learning at *www.campbellbiology.com* and the CD-ROM that is included with each book. And the excellent *Student Study Guide*, by Martha Taylor of Cornell University, continues to be a proven learning tool for students.

## The Campbell/Reece Interviews: A Continuing Tradition

Scientific inquiry is a social process catalyzed by communication among people who share a curiosity about nature. One of the many joys of authoring *BIOLOGY* has been the privilege to humanize science by interviewing some of the world's most influential biologists. Eight new interviews that introduce the eight units of the textbook provide students with windows to inquisitive minds that are driving progress in biology and connecting science to society. The interviewees for this edition are listed on page xxiii.




**Inquiry Questions, Media Investigations,** and the new **Biological Inquiry Workbook** help students practice scientific inquiry.

### Balancing Inquiry with a Conceptual Foundation

Although this new edition of *BIOLOGY* showcases the process of science more prominently than ever, there are two good reasons to avoid overstating the power of inquiry-based content in any biology textbook.

First, those of us who advocate more inquiry in biology courses mainly have student-centered inquiry in mind, not textbook-centered inquiry. As a mostly passive experience, reading about inquiry in a textbook should be merely an entryway to a variety of active experiences that are promoted by inquiry-based supplements, by investigative labs, and by activities that instructors create to support student-centered inquiry.

Second, the most important way a textbook can support student inquiry is by providing context with clear, accurate explanation of the key biological concepts. Just as biologists generally study the scientific literature as background for their own inquiry, students will be much more successful in their personal inquiry if it emerges from a basic understanding of the relevant biology. Thus, *BIOLOGY*, Seventh Edition, is *not* a "reform textbook" of the genre that replaces a careful unfolding of conceptual content with a stream of relatively unconnected research examples, requiring beginning students to put it all together for themselves. We believe that such an unbalanced reaction to the call for inquiry-based reform is likely to leave most students frustrated and ill-equipped to practice active inquiry in their labs, course projects, class discussions, and Socratic lecture environments. In *BIOLOGY*, Seventh Edition, we have carefully integrated the inquiry-based content into the development of each chapter's main ideas so that the research examples reinforce rather than obscure the conceptual framework.

## *BIOLOGY* supports a diversity of courses and serves students throughout their biology education

Even by limiting our scope to a few key concepts per chapter, *BIOLOGY* spans more biological territory than most introductory courses could or should attempt to cover. But given the great diversity of course syllabi, we have opted for a survey broad enough and deep enough to support each instructor's special emphases. Students also seem to appreciate *BIOLOGY*'s breadth and depth; in this era when students sell many of their textbooks back to the bookstore, more than 75% of students who have used *BIOLOGY* have kept it after their introductory course. In fact, we are delighted to receive numerous letters and emails from upper-division students and graduate students, including medical students, expressing their appreciation for the long-term value of *BIOLOGY* as a general resource for their continuing education.

Just as we recognize that few courses will cover all 55 chapters of *BIOLOGY*, we also realize that there is no one "correct" sequence of topics for a general biology course. Though a biology textbook's table of contents must be linear, biology itself is more like a web of related concepts without a fixed starting point or a prescribed path. Diverse courses can navigate this network of concepts starting with molecules and cells, with evolution and the diversity of organisms, or with the big-picture ideas of ecology. We have built *BIOLOGY* to be versatile enough to support various syllabi. The eight units of the book are largely self-contained, and most of the chapters within each unit can be assigned in a different sequence. For example, instructors who integrate plant and animal physiology can merge chapters from Unit Six (Plant Form and Function) and Unit Seven (Animal Form and Function). Instructors who begin their course with ecology and continue with this "top-down" approach can assign Unit Eight (Ecology) right after Chapter 1, which introduces the unifying themes that provide students with a panoramic view of biology no matter what the topic order of the course syllabus.

## Evolution and *BIOLOGY*'s other themes connect the concepts and integrate the whole book

The first chapter articulates 11 themes that provide touchstones for students throughout the book and distinguish our approach in *BIOLOGY* from an encyclopedic topical approach. In this Seventh Edition, we have added the theme of "biological systems" to integrate a variety of research initiatives based on high-throughput data collection and readily available computing power. But as in all previous editions, the central theme is evolution, which unifies all of biology by accounting for both the unity and diversity of life. The evolutionary theme is woven into every chapter of *BIOLOGY*. Evolution and the other whole-book themes work with the chapter-level concepts to help students construct a coherent view of life that will serve them long after they have forgotten the details fossilized in any biology textbook.

***Neil Campbell and Jane Reece***

# Acknowledgments

One of the eminent scientists interviewed in this new edition pointed out that much of the fun of doing biology comes from working with a diversity of talented people. The same can be said for making a biology textbook. Fortunately for us, this Seventh Edition of *BIOLOGY* is the product of the talents, dedication, and enthusiasm of a large and varied group of people. The authors wish to express their deepest thanks to the numerous instructors, researchers, students, publishing professionals, and artists who have contributed to this edition.

As authors of both past and present editions of this text, we are mindful of the daunting challenge of keeping up to date in all areas of our rapidly expanding subject. We are particularly grateful to the seven Contributors and Advisers listed on the title page, whose expertise has ensured that the book is current and enlivened with fresh examples. We worked especially closely with developmental biologist Lisa Urry, who had major responsibility for updating content and implementing our new format and features for Units 1–3 and Chapter 47. Her rigorous scholarship and attention to detail in the areas of biological chemistry, cell and molecular biology, genetics, and developmental biology were a great boon. We thank her for her commitment and enthusiasm, relentless hard work, punctuality, and good cheer throughout the process. Equally helpful was ecologist Manuel Molles, who brought his scientific and teaching expertise to the revision of Unit 8, enhancing the structure of the unit and its verbal and visual presentation of ecology; he played a major role rewriting the behavioral ecology chapter, which is essentially new. He also helped provide a more ecological perspective to Chapters 40, 42, and 44, in the unit on animal form and function. Science writer Carl Zimmer contributed many improvements and new perspectives to Unit 5, the diversity unit. Evolutionary biologist Christopher Wills helped us tackle the challenge of improving and updating Unit 4, the evolution unit, and Chapter 26. Plant biologist Peter Minorsky helped bring Unit 6 up to date. And neurobiologist Antony Stretton advised us on the revision of Chapters 48 and 49. As in earlier editions, immunologist Mary Jane Niles organized and implemented the significant revision of Chapter 43.

Thanks also to the instructors who suggested revised or new Concept Check and Chapter Review questions. These include (in alphabetical order) Bruce Byers, Jean Heitz, William Hoese, Tom Owens, Mark Lyford, Randy Phillis (special thanks), Mitch Price, Fred Sack, Richard Showman, and Elspeth Walker. It's not easy to write good questions, and we appreciate the time and effort these dedicated educators contributed to enhancing the effectiveness of our book's questions.

Further helping us improve *BIOLOGY*'s scientific accuracy and pedagogy, about 240 biologists and teachers, cited on the list that follows these Acknowledgements, provided detailed reviews of one or more chapters for this edition. Special thanks to Lawrence Brewer, Richard Brusca, Anne Clark, Douglas Eernisse, Mark Kirk, Walter Judd, Mike Levine, Diane Marshall, Nick Money, Tom Owens, Kevin Padian, Daniel Papaj, Mitch Price, Bruce Reid, and Alistair Simpson for their guidance.

Thanks also to the numerous other professors and their students, from all over the world, who offered suggestions by writing directly to the authors. In addition, we appreciate the candid and specific feedback we received from the students and faculty who participated in group discussions held at Skyline College, Mills College, and Indiana University. Last but not least, we thank our coauthors on our nonmajors texts, Eric Simon and Marty Taylor, for providing rigorous feedback on a number of chapters. Of course, we alone bear the responsibility for any errors that remain in the text, but the dedication of our contributors, advisers, reviewers, and correspondents makes us especially confident in the accuracy of this edition.

Many scientists have also helped shape this Seventh Edition by discussing their research fields with us, answering specific questions in their areas of expertise, and, often, sharing their ideas about biology education. Neil Campbell thanks the many University of California, Riverside, colleagues who have influenced this book, including Ring Carde, Richard Cardullo, Mark Chappell, Darleen DeMason, Norman Ellstrand, Anthony Huang, Bradley Hyman, Tracy Kahn, Elizabeth Lord, Carol Lovatt, Eugene Nothnagel, John Oross, Timothy Paine, David Reznick, Rodolfo Ruibal, Clay Sassaman, William Thomson, John Trumble, Rick Redack, Mike Adams, and the late John Moore (whose "Science as a Way of Knowing" essays have had such an important influence on the evolution of *BIOLOGY*). Jane Reece thanks members of the Mills College Biology and Chemistry/Physics Departments, especially Elisabeth Wade, as well as Fred Wilt, John Gerhart and Kris Niyogi from the University of California, Berkeley, for their assistance to contributor Lisa Urry.

Interviews with prominent scientists have been a hallmark of *BIOLOGY* since its inception, and conducting these interviews was again one of the great pleasures of revising the text. To open the eight units of this Seventh Edition, we are proud to include interviews with Lydia Makhubu, Peter Agre, Eric Lander, Kenneth Kaneshiro, Linda Graham, Natasha Raikhel, Erich Jarvis, and Gene Likens.

The value of *BIOLOGY* as a learning tool is greatly enhanced by the supplementary materials that have been created for instructors and students. We recognize that the dedicated authors of these materials are essentially writing mini (and not so mini) books. We much appreciate the hard work and creativity of the following: Margaret Waterman and Ethel Stanley (authors of the new *Biological Inquiry: A Workbook of Investigative Cases*); Jean Heitz (*Practicing Biology*, 2nd edition); Joan Sharp (*Instructor's Guide*); Janet Lanza (*New Designs for Bio-Explorations*); Chris Romero (PowerPoint Lectures); Laura Zanello (*Spanish Glossary*); and Judith Morgan and Eloise Brown Carter (*Investigating Biology Lab Manual*, 5th Edition). We thank Bill Barstow for heading up the test bank team, and we wish to acknowledge the test bank contributors: Jean DeSaix, Michael Dini, Conrad Firling, Peter Follette, Mark Hens, Janice Moore, Tom Owens, Marshall Sundberg, Robert Yost, and Ed Zalisko. Thanks also to Bill Wischusen, who compiled our Active Learning Questions and wrote discussion points. Once again, we thank our long-time colleague Marty Taylor for her excellent and student-focused work on the *Student Study Guide;* she has now completed seven editions of this popular student aid. In addition, we are grateful to the many other people—biology instructors, editors, artists, production experts, and narrators—who are listed in the credits for the impressive electronic media that accompany the book.

*BIOLOGY*, Seventh Edition, results from an unusually strong synergy between a team of scientists and a team of publishing professionals. An all-new design, the comprehensive revision of the illustration

program as well as the text, the addition of major new pedagogical features, and a rich package of supplements, both printed and electronic, combined with a tight schedule to create unprecedented challenges for the publishing team.

The members of the core book team at Benjamin Cummings brought extraordinary talents and extraordinarily hard work to this project. Our leader, Editor-in-Chief Beth Wilbur, is a full colleague in the book's creation and a respected advocate for biology education in general and our book in particular in the academic community. Enthusiastic, creative, endlessly supportive of us and the other members of the team, Beth is a wonderful person and a pleasure to work with. Unflappable under pressure, she navigates difficult situations gracefully—a major asset in a project of this complexity.

The incomparable Deborah Gale, Director of Development, managed the entire project on a day-by-day basis. Deborah coproduced the first and second editions of the book, along with the developmental editing of the second edition, and we have been delighted with her return. Amazingly, Deborah is able to combine a totally professional, no-nonsense management style and a willingness to dig into the nitty-gritty with a sense of humor that kept the rest of us happily slaving away at her direction.

Supervising editors Pat Burner and Beth Winickoff had the awesome responsibility of overseeing in detail the work of the contributors, developmental editors, and developmental artists. Together, Pat and Beth carefully read every single chapter and checked every illustration, doing whatever was necessary to make this edition the most effective biology textbook available—and, we think, exceeding the high standards established in previous editions. We are immensely grateful to Pat, the multitalented and tireless Developmental Manager for Biology who has been our colleague for many years, for her incredible dedication, sound editorial judgment, and extraordinary attention to detail. The exceptionally talented Beth Winickoff, new to this Seventh Edition, was the originator of our new process of book development and production. Beth brought fresh perspectives on process, pedagogy, and editorial approach—in addition to her superb hands-on editing of six chapters. We look forward to working again with Pat and Beth on subsequent editions (after they recover from this one, of course!).

The responsibilities of the developmental editors for this edition were especially challenging. Almost all the chapters were heavily revised, requiring intensive editorial involvement from initial planning through production. We were fortunate to have on our team some of college publishing's top developmental editors. In alphabetical order, they were John Burner (Units 5–7), Alice Fugate (Units 4 and 7), Sarah Jensen (Units 2, 3, and 7), Matt Lee (Units 5 and 7), Suzanne Olivier (Units 1 and 2), Ruth Steyn (Units 3 and 7), and Susan Weisberg (Units 7 and 8). In addition to their other tasks, John Burner, Matt Lee, and Ruth Steyn brought their specific content expertise to bear on their chapters' revisions.

The support of our bright, efficient, and good-natured Publishing Assistants, Trinh Bui and Julia Khait, is much appreciated. What would we all have done without them?

We also want to thank someone who doesn't fit neatly into any of our publishing categories: our colleague, former editor, and friend Robin Heyden. Robin brought her imaginative energy and dedication to biology education to the Seventh Edition in several ways. These include early planning for the development of the media for this edition and the conception and developmental management of the new case study workbook by Margaret Waterman and Ethel Stanley. Robin also organized the first Benjamin Cummings Biology Leadership Conference, which brought us a fresh supply of creative teaching ideas from outstanding biology educators.

Once again the book has benefited greatly from the work of Russell Chun, our Senior Producer, Art and Media. Russell established a vibrant new art style for this edition that met the requirements of the content and exceeded our expectations for pedagogical and aesthetic excellence. Under his direction were the developmental artists, who developed all the new figures and redesigned many of the older ones to make them clearer and more appealing. These skilled and creative illustrators were Hilair Chism (Units 1–3 and 7), Blakeley Kim (Unit 8), Kenneth Probst (Units 4 and 5), and Laura Southworth (Units 3 and 7). Carla Simmons (Units 5 and 6) has contributed her artistic and pedagogical talents to every edition of this textbook. Final rendering of the hundreds of new and revised illustrations was carried out by Russell, Phil Guzy, Steve McEntee, and the artists of Precision Graphics. Meanwhile, Photo Editor Travis Amos led a team of photo researchers in finding hundreds of new photos for this edition. The photo researchers were Brian Donnelly, Donna Kalal, Ira Kleinberg, Robin Samper, and Maureen Spuhler. The efficient Donna Kalal also coordinated the ordering of photos from a multitude of sources. We are indebted to the entire art and photo team and to the book's talented text and cover designer, Mark Ong, for the most beautiful and visually effective edition ever. In addition to creating the stunning design, Mark was involved in laying out every chapter, and his artistic sensibility reinforced all of our goals for this revision.

The book production team had the crucial responsibility of converting the text manuscript and illustrations to pages ready for the printer. Many thanks to Managing Editor Erin Gregg, who was responsible for overseeing the complex design and production process, including the management of both in-house and freelance employees. At GTS Companies (the compositor), we particularly want to thank Rob Hansen, Brendan Short, Morgan Floyd, and Sherrill Redd, who provided expertise and solutions to complicated production challenges with good humor, and designer Kirsten Sims, who helped us improve the appearance and pedagogical utility of the Exploring Figures. Finally, we thank Manufacturing Manager Pam Augspurger, without whose work you would not be holding a physical copy of the book in your hands.

We are pleased to thank the topnotch publishing professionals who worked on the book's printed supplements. Amy Austin, Robin Heyden, Ginnie Simione Jutson, and Joan Keyes developed these supplements, and Vivian McDougal and Jane Brundage were responsible for their production.

In regard to the excellent package of electronic media that accompanies the book, we offer special thanks to Brienn Buchanan, who creatively pulled together all the elements of the student CD-ROM and website, and Christopher Delgado, who produced all of the instructor media resources, as well as the Art Notebook.

Linda Davis, President of Benjamin Cummings Publishing, has shared our commitment to excellence and provided strong support for three editions now, and we are happy to thank her once again. We also want to thank the Addison Wesley/Benjamin Cummings President, Jim Behnke (who was the editor of the first edition of this book), for his support of our new developmental process, and Editorial Director Frank Ruggirello for his vigorous commitment to the book's success.

Both before and after publication, we are fortunate to have experienced Benjamin Cummings marketing professionals on our book team. Senior Marketing Manager Josh Frost and Director of Marketing Stacy Treco provided consistent support and useful input throughout the entire development of this edition. Thanks, also, to Jeff Hester, who has recently joined the marketing team. We much appreciate the work of the talented Lillian Carr and her marketing communications team, who have created stunning brochures, posters, and other materials that have helped get the word out about

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The Addison Wesley/Benjamin Cummings field staff, which represents *BIOLOGY* on campus, is our living link to the students and professors who use the text. The field representatives tell us what you like and don't like about the book, and they provide prompt service to biology departments. The field reps are good allies in science education, and we thank them for their professionalism in communicating the features of our book.

Finally, we wish to thank our families and friends for their encouragement and for enduring our continuing obsession with *BIOLOGY*.

***Neil Campbell and Jane Reece***
October 2004

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# Supplements

## Supplements for the Student

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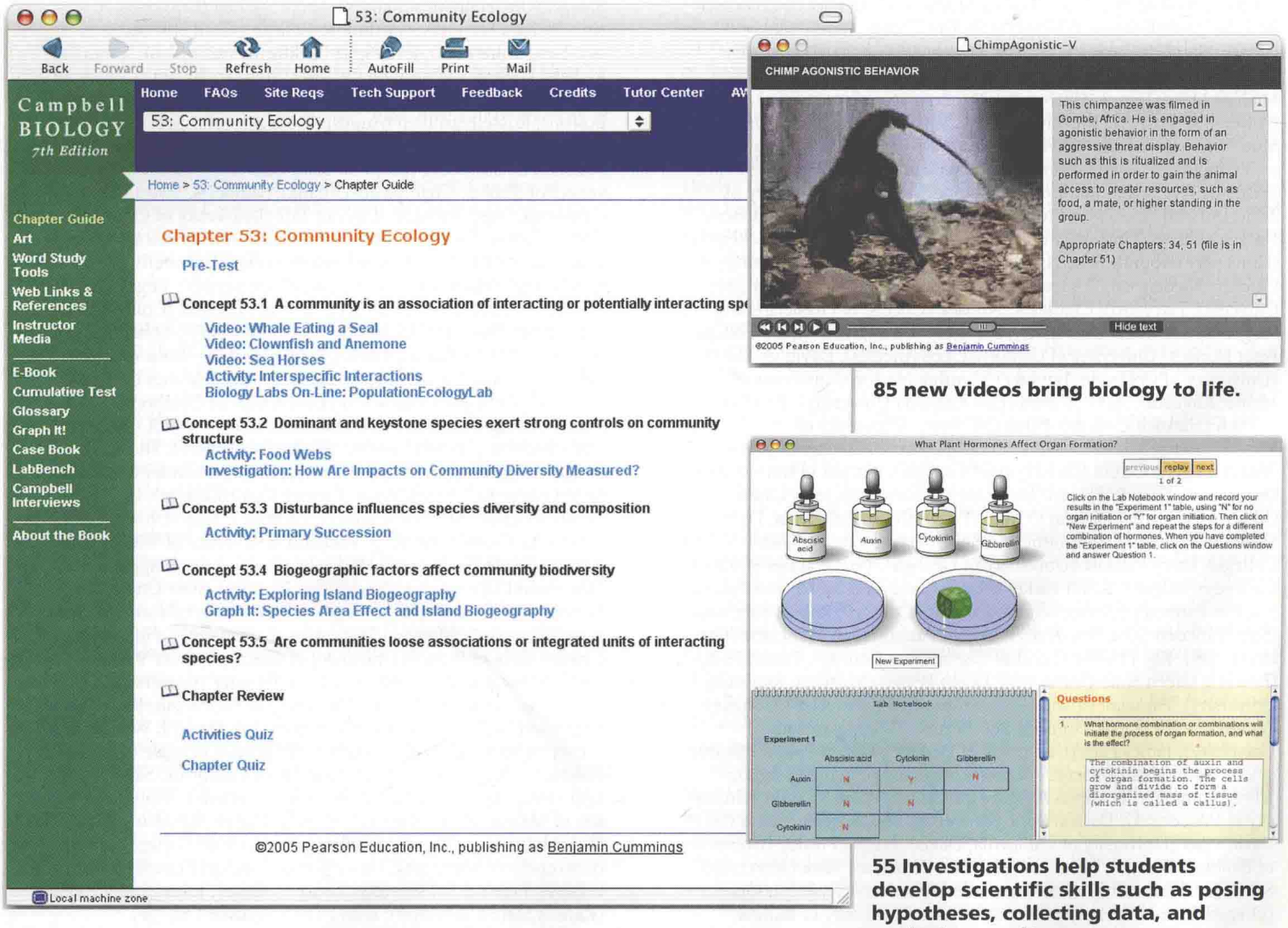


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