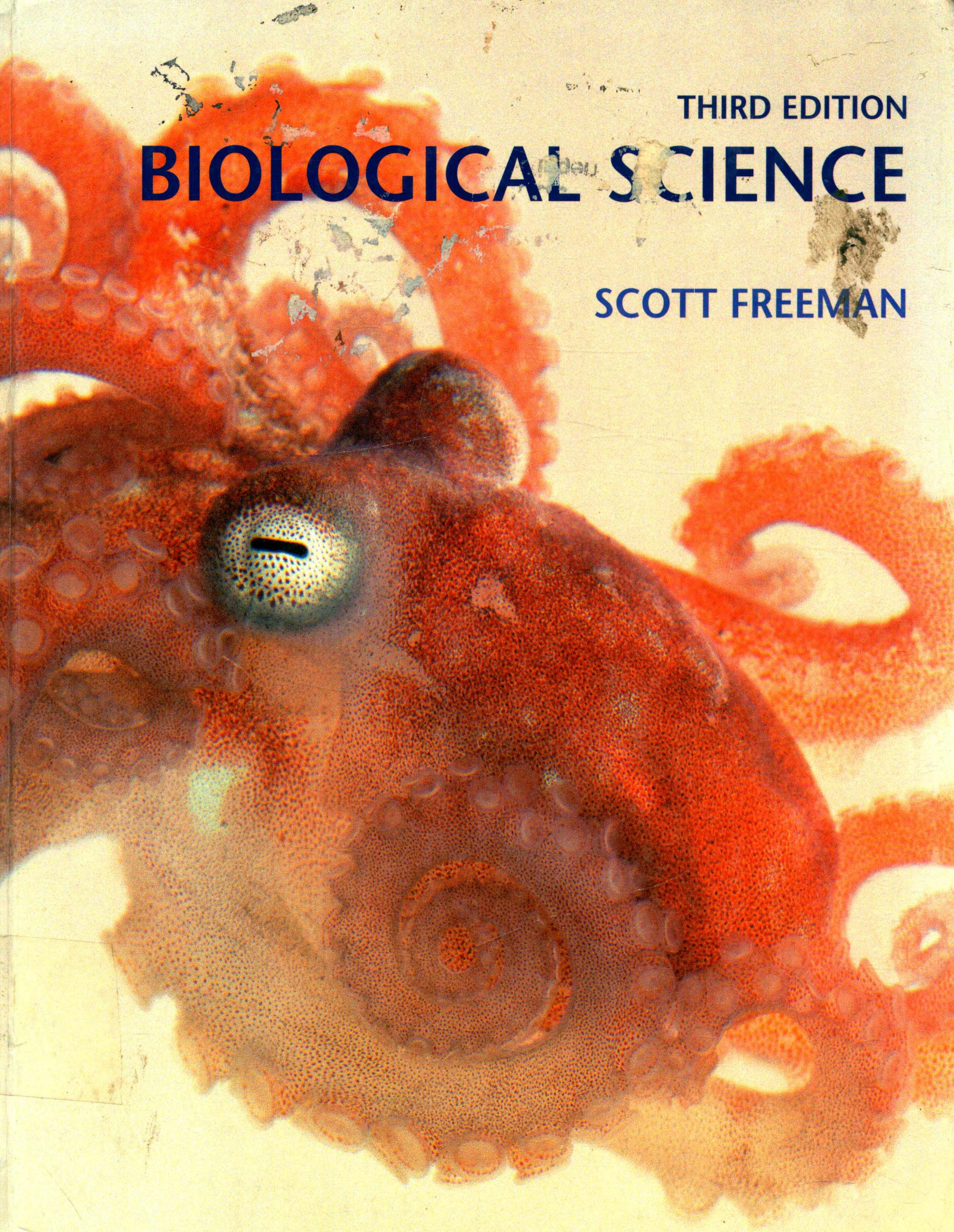


THIRD EDITION

BIOLOGICAL SCIENCE

SCOTT FREEMAN



BIOLOGICAL SCIENCE

THIRD EDITION

SCOTT FREEMAN

University of Washington



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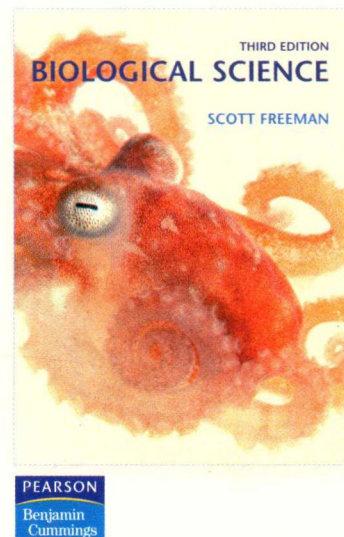
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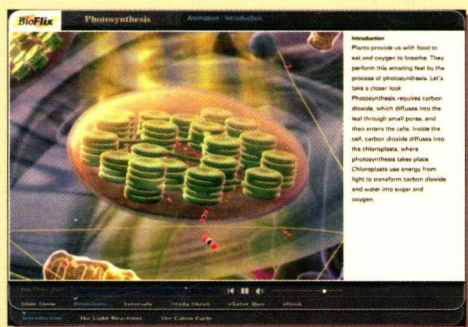
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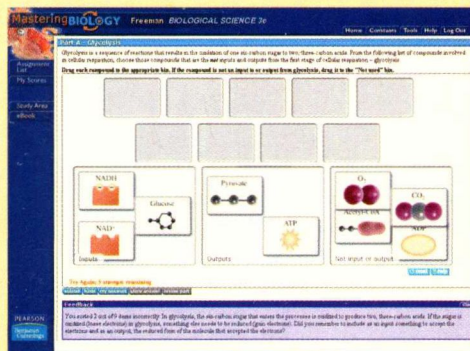
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BIOFLIX™ 3-D ANIMATIONS



BioFlix™ are 3-D movie-quality animations with carefully constructed student tutorials, labeled slide shows, study sheets, and quizzes which help bring biology to life. Topics include tour of an animal cell, tour of a plant cell, cellular respiration, photosynthesis, mitosis, meiosis, protein synthesis, water transport in plants, how neurons work, and muscle contraction.

VIDEOS



Watch brief Discovery Channel™ video clips on 29 different topics including antibiotic resistance, fighting cancer, and introduced species.

WEB ANIMATIONS

Web Animation Learn about biological concepts in a visual format with online web animations. Animations include pre-quizzes and post-quizzes to test students' understanding of dynamic concepts and processes. Additional Cell Biology Animations provide vivid images of the functions and processes of the cell.

GRAPHIT!

Graphing tutorials show students how to plot, interpret, and critically evaluate real data.

CHAPTER QUIZZES

Students can assess their comprehension of material with 20 multiple-choice quiz questions for each chapter.

ANSWER KEY

Find answers to the book's figure and table caption questions and exercises, "you should be able to..." activities, and end-of-chapter questions.

ART

View and print artwork from the textbook to follow along in class or use as a study tool in review sessions.

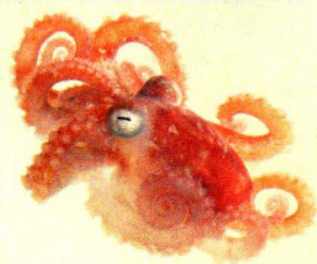
AUDIO GLOSSARY

Build your biology vocabulary with our audio glossary. Hear the correct pronunciation and learn the meaning of all key terms.

E-BOOK

Refer to a convenient online version of the book while you study.

BIOLOGICAL SCIENCE

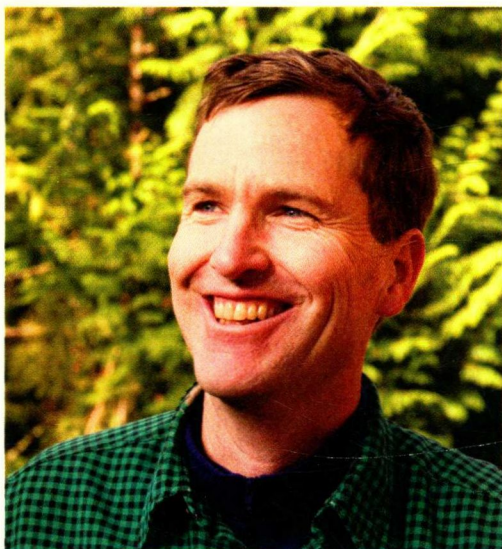


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ABOUT THE PHOTO:

He'e, *Octopus* sp. (juvenile), photographed at Midway Atoll National Wildlife Refuge, located in the Northwestern Hawaiian Islands, 29 March 2003, by David Liittschwager and Susan Middleton, authors of *Archipelago: Portraits of Life in the World's Most Remote Island Sanctuary* (National Geographic Society, 2005).

About the Author



Scott Freeman received his PhD. in Zoology from the University of Washington and was subsequently awarded an Alfred P. Sloan Postdoctoral Fellowship in Molecular Evolution at Princeton University. His current research focuses on the scholarship of teaching and learning—specifically, (1) how active learning and peer teaching techniques increase student learning and improve performance in introductory biology, and (2) how the levels of exam questions vary among introductory biology courses, standardized post-graduate entrance exams, and professional school courses. He has also done research in evolutionary biology on topics ranging from nest parasitism to the molecular systematics of the blackbird family. Scott teaches introductory biology for majors at the University of Washington and is co-author, with Jon Herron, of the standard-setting undergraduate text *Evolutionary Analysis*.

UNIT ADVISORS

An elite group of eleven content experts and star teachers worked with Scott and Kim on every aspect of the third edition. These advisors came to be treasured as they read and interpreted reviews, provided recommendations on outstanding recent papers to check, answered questions, and provided advice on an array of specific issues. The quality and accuracy of this book are a tribute to their efforts and skills.

Ross Feldberg, *Tufts University* (Unit 1)

David Wilson, *Parkland College* (Unit 1)

Paula Lemons, *Duke University* (Unit 2)

Greg Podgorski, *Utah State University* (Units 3 and 4)

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Diane Marshall, *University of New Mexico* (Unit 7)

James M. Ryan, *Hobart and William Smith Colleges* (Unit 8)

Alan Molumby, *University of Illinois, Chicago* (Unit 9)


ILLUSTRATOR



Kim Quillin combines expertise in biology and information design to create pedagogically effective and scientifically accurate visual representations of biological principles. She received her B.A. in Biology at Oberlin College and her Ph.D. in Integrative Biology (as a National Science Foundation Graduate Fellow) from the University of

California, Berkeley, and has taught undergraduate biology at both schools. Students and instructors alike have praised Kim's illustration programs for *Biological Science*, as well as *Biology: A Guide to the Natural World*, by David Krogh, and *Biology: Science for Life*, by Colleen Belk and Virginia Borden, for their success at applying core principles of information design to convey complex biological ideas in a visually appealing manner.

Preface to Instructors

 **STUDENTS**, There is also a preface for you, located right before Chapter 1. It's called "Using this Book as a Tool for Learning." Please read it—it should help you get organized and be successful in this course. *Scott Freeman*

This book is for instructors who want to help their students learn how to think like a biologist. The content knowledge, problem-solving ability, and analytical skills that this requires can help students become better human beings, in addition to preparing them for success in clinical medicine, scientific research, conservation, law, teaching, journalism, and other careers.

A course goal that focuses on thinking and learning, rather than simply memorizing, is important because today's biology students are going to be tomorrow's problem solvers. This is biology's century, not only because of the breathtaking pace of research but also because many of the most profound challenges we face today—resource shortages, overpopulation, species extinctions, drug resistance, global warming—are biological in nature. The world needs our students.

A Student-Centered Textbook

The first edition of *Biological Science* focused on offering a new approach to teaching biology—one that emphasized higher-order thinking skills over an encyclopedic grasp of what is known about biology. The second edition stayed true to this vision, but added topics and features that made the book easier for professors to use. The third edition also went through several rounds of revision driven by expert reviewers and advisors. Based on input from hundreds of professors around the world, I made thousands of changes to make the book even more accurate, current, and easy to use. But fundamentally, this edition is all about students. For the past three years, the book team and I have used insights from research on student learning—as well as direct feedback from students—as a way to create a better teaching tool.

I plunged into the literature on student learning, and members of the book team and I conducted two dozen focus groups with over 130 students. We asked students the same questions, over and over: What topics are most difficult in this chapter? What helped you "get it"? What tripped you up? How can this figure, or table, or passage of text teach better? Our goal was to create a text that is innovative, engaging, filled with the excitement that drives research, and inspired by data on how students learn.

Fairly quickly, our reading and research identified two fundamental problems:

1. *Novice learners have trouble picking out important information.* This is one of the most striking findings emerging from research on how people learn. It's also an issue that we hear about all the time as instructors. "Do we have to know X?" "Will Y be on the test?" We also see it when students come to office hours and open up their text—they've highlighted everything. Students need help figuring out which material is really important and which offers supporting details. This is crucial to their success, because if we're doing our job right, we're going to test them on the important stuff—not details that they'll forget five minutes after the exam.
2. *Novice learners have a terrible time with self-assessment.* How many times have students told you, "I understood the concepts *so well*, but just did badly on the exam"? Novice learners struggle to understand when they don't understand something. They'll sit in class or read the text and tell themselves, "Yeah, I get this, I get this," but then they crash on the exam. Experts are much more skeptical—they make themselves *use* information and ideas before they're confident they understand what's going on.

Fundamentally, our task is simple: We need to help our students become better students. Textbooks should help learners acquire the skills they need to make the novice-to-expert transition.

Supporting Novice Learners

The Gold Thread—"Learn It"

Our response to the "can't pick out the important points" problem is a battery of tools, highlighted in gold throughout the text.

- **Key Concepts** are listed at the start of the chapter. When material related to these key concepts is presented in the chapter itself, it is flagged with a gold bullet.
- **Chapter Summaries** revisit each of the key concepts. In this way, the big ideas in each chapter are laid out at the start, developed in detail, and then summarized.
- **Check Your Understanding** boxes appear at the ends of key sections within each chapter. Each box briefly summarizes

one or two fundamental points—the key ideas that students ought to have mastered before they move on.

- **Highlighted Passages** help students focus on particularly important information throughout the text.
- **Summary Tables** pull information together into a compact format that is easy to review.

In effect, the gold thread offers students expert guidance on picking out and focusing on the important, unifying points in an information-laden discipline. In addition, and in the same spirit,

- **“Pointing Hands”** in illustrations act like your hand at the whiteboard, guiding students’ attention to a figure’s central teaching points.

The Blue Thread—“Practice It”

Our response to the self-assessment problem is an array of questions and exercises, highlighted in blue throughout the text.

- **In-text “You should be able to’s”** offer exercises on topics that professors and students have identified as the most difficult concepts in each chapter.
- **Caption Questions and Exercises** challenge students to critically examine the information in a figure or table—not just absorb it.
- **Check Your Understanding** boxes present two to three tasks that students should be able to complete in order to demonstrate a mastery of specified key ideas.
- **Chapter Summaries** include “You should be able to” problems or exercises related to each of the key concepts declared in the gold, “Learn It” thread.
- **End-of-Chapter Questions** are organized around Bloom’s taxonomy of learning, so students can test their understanding at the knowledge, comprehension, and application levels.

The fundamental idea is that if students really understand a piece of information or a concept, they should be able to do something with it.

Supporting Visual Learners

Kim Quillin—this book’s illustrator—is a 1-in-6.6-billion talent. She combines superb academic training in biology (a Ph.D. from the University of California, Berkeley), insights from Edward Tufte’s research on information architecture, impressive artistic talent, and a teacher’s sensitivity to students.

Kim’s goals in the first edition were to build a visual narrative that was (1) a direct extension of the text narrative and (2)

guided by rigorous attention to the latest advances in information design. For example, figures that illustrate stepwise processes in biology were presented in a standardized, linear, and intuitive format, to spare students the “speed bumps” of convoluted compositions. In all of the figures, the drawings, colors, and labels were placed with surgical precision to maximize cleanliness and present a clear hierarchy of information. And to help bring a narrative voice to the figures, Kim integrated the “pointing hand” feature—inspired by National Academy of Sciences member M.A.R. Koehl—as a quiet and friendly way of highlighting important or challenging information such as data trends in graphs, or implications of phylogenetic trees.

The second edition stayed faithful to the original art philosophy, adding details requested by professors, formalizing experiments into boxes that made the experimental process consistent and explicit, and increasing the vibrancy and color of the drawings. Refinements in the third edition have focused on bringing the content of many individual figures up-to-date and honing the clarity, impact, and student-friendliness of every figure.

Supporting Skill Building

When instructors write learning objectives for introductory biology courses, they are paying close attention to skill building, in addition to the traditional emphasis on mastering content and concepts and the newer focus on developing higher-order thinking skills.

To aid skill building in introductory biology, I’ve added a set of nine new appendixes, called BioSkills, to the end matter of the book—just before the glossary. The BioSkills are meant to provide background on skills and techniques that are used throughout biological science. In addition, some of the BioSkills should help shore up problems with student preparation in mathematics and chemistry. They are called out at relevant points in the text. Please point them out to students who are having trouble with specific skills.

1. Reading Graphs
2. Reading a Phylogenetic Tree
3. Using Statistical Tests and Interpreting Standard Error Bars
4. Reading Chemical Structures
5. Using Logarithms
6. Making Concept Maps
7. Using Electrophoresis to Separate Molecules
8. Observing Microscopic Structures and Processes
9. Combining Probabilities

Serving a Community of Teachers

There is nothing that inspires me more than watching a passionate teacher work with motivated students. Teaching and learning is the essence of humanity, of who we are.

I write *Biological Science* because it's my way of being part of that work. As a textbook author, my greatest reward comes from interacting with inspired instructors and students from around the world—through e-mails, phone calls, focus groups, reviews, seminars, and teaching workshops.

Introductory biology courses are undergoing a slow and steady, yet remarkable, change: from a memorization-driven, largely passive exercise to a dynamic, active interchange that emphasizes higher-order thinking skills. The change is good. Instructors are stimulated and having more fun. They're approaching teaching problems in a hypothesis-testing framework, collecting data, and changing course designs based on

empirical evidence. Students are performing at a higher level and should be better prepared for graduate school, professional school, and careers related to biology. My hope is that *Biological Science* can support this change.

Thank you for considering this text, for your passion about biology, and for your work on behalf of your students. What you do is *important*.

Scott Freeman
University of Washington

This book is dedicated to the world's greatest profession: teaching. Teachers are like Johnny Appleseed—they sow seeds, but seldom get to see the trees or fruit. This edition reflects in particular four teachers who had an exceptional impact on me: Vern Bailey, Owen Jenkins, Sievert Rohwer, and Barbara Wakimoto. Thank you.

Acknowledgments

Expert Feedback

Work on this edition was organized around two pillars: feedback from our advisory board and peer reviewers, and feedback from students.

Advisory Board

A cadre of highly select advisors analyzed reviews, provided citations for particularly important recent papers, and worked with me and Kim Quillin to brainstorm ideas for improving each chapter and unit. It was a joy to work with them, and their expertise and perspective were vital to this edition.

- Unit 1 Ross Feldberg, *Tufts University*
David Wilson, *Parkland College*
- Unit 2 Paula Lemons, *Duke University*
- Unit 3 Greg Podgorski, *Utah State University*
- Unit 4 Greg Podgorski, *Utah State University*
- Unit 5 George Gilchrist, *William & Mary College*
- Unit 6 Brianna Timmerman, *University of South Carolina*
Marc Perkins, *Orange Coast College*
Michael Black, *California Polytechnic State University, San Luis Obispo*
- Unit 7 Diane Marshall, *University of New Mexico*
- Unit 8 Jim Ryan, *Hobart and William Smith Colleges*
Michael Black, *California Polytechnic State University, San Luis Obispo*
- Unit 9 Alan Molumby, *University of Illinois, Chicago*

Reviewers

Peer review is the backbone of scientific publication. Acting as a reviewer is a fundamental component of our service as professional biologists, and reviewing chapters from an introductory text is one of the most important things we can do to improve the training of the next generation of biologists. I am deeply grateful for the insights offered by the following reviewers, who drew on their extensive content expertise, teaching experience, and research practice.

- Marc Albrecht, *University of Nebraska, Kearney*
- David Asch, *Youngstown State University*
- Mariette Baxendale, *University of Missouri, St. Louis*
- Greg Beaulieu, *University of Victoria*
- Christopher Beck, *Emory University*
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 Susan Whittemore, *Keene State College*
 Ted Zerucha, *Appalachian State University*

Accuracy Reviewers

Once several rounds of peer review are completed and revised chapters and figures are produced, we rely on accuracy reviewers to check every page for errors. This work is demanding intellectually and has to be done under time pressure. The accuracy reviewers for this edition were exceptionally talented and timely.

- | | |
|-----------|---|
| Unit 1 | Wayne Becker, <i>University of Wisconsin, Madison</i> |
| Unit 2 | James Manser, <i>Harvey Mudd College (formerly)</i> |
| Unit 3 | Peter Berget, <i>Carnegie Mellon University</i>
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Correspondents

I am grateful to colleagues who take the initiative to contact me directly or through my publisher to make suggestions on how to improve the text and figures. Please never hesitate to do this—I take your comments to heart, in the spirit of a shared commitment to improved student learning. This list also includes friends and colleagues who were kind enough to respond

to emails or calls from me, asking for ideas on how to clarify specific topics.

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 Hans Landel, *Edmonds Community College*
 Frederick Lanni, *Carnegie Mellon University*
 Andi Lloyd, *Middlebury College*
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 Andrew McCubbin, *Washington State University*
 Tim Nelson, *Seattle Pacific University*
 Shawn Nordell and students, *University of St. Louis*
 Carol Pollock, *University of British Columbia*
 Joelle Presson, *University of Maryland*
 William Saunders, *LaGuardia Community College*
 David Senseman, *University of Texas, San Antonio*
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 Judy Stone, *Colby College*
 Dean Wendt, *California Polytechnic State University, San Luis Obispo*

Student Feedback

The second pillar of this edition—in addition to the role played by advisors and reviewers—was an extensive series of focus groups with students who were currently taking introductory biology or who had just completed the course.

Student Focus Group Coordinators

Planning and implementing the student focus groups would have been impossible without the support of key faculty members, who went out of their way to provide opportunities for their students to be heard.

Julie Aires, *Florida Community College, Jacksonville*
 Frank Cantelmo, *St. Johns University, New York*
 Matt Gilg, *University of Northern Florida*
 Bill Hoes, *California State University, Fullerton*
 John Nagey, *Scottsdale Community College*
 Debra Pires, *University of California, Los Angeles*
 Emily Taylor, *California Polytechnic State University, San Luis Obispo*
 John Weser, *Scottsdale Community College*

Student Focus Group Participants

The students who attended focus groups were asked three questions about chapters they were assigned to read: (1) what were the most difficult concepts, (2) why were they hard, and (3) what helped you finally get it? We usually had them work in groups, and when they reported back to us, we never failed to be deeply impressed by the quality of their ideas and their ability to articulate them. It is not possible to overstate how important student feedback was to this edition. Combined with the superb advice I was getting from advisors, reviewers, and other colleagues, I had a wealth of ideas on how to make each chapter work better for both instructors and learners. These students were *inspiring*.

California Polytechnic State University, San Luis Obispo

Jenna Arruda, Katie Camfield, Benjamin Capper, Mandsa Chandra, Rebekah Clarke, Annalisa Conn, Marisa Crawford, Katie Duffield, T.J. Eames, Megan Fay, Margaret Hackney, Steffani Hall, Gemma Hill, John Kong, Taylor Lindblom, Adam Marre, Vik Mediratta, Serena Moen, Sunil Patel, Corinne Ross, Teresa Sais, Jessie Singer, Stephanie Szeto, Kelsey Tallon, Gregory Thurston, Greg Vidovic, Melody Wilkinson, Taiga Young

California State University, Fullerton

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Florida Community College, Jacksonville

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LaGuardia Community College

Kristine Azzoli, Felicita Gonzalez, Pedro Granados, Mike Levine, Kris Ragoonath, Maria Reyes

Scottsdale Community College

Tatum Arthur, Shadi Asayesh, Angela Bikl, Abrey Britt, Drew Bryck, Jason Butler, Cindy Clifton, Dean Doty, Tannaz Farahani, Bethany Garcia, Jeff Godfrey, Troy Graziadei, Dina Habbab, Loreley Hall, Crista Jackson, Paul Krueger, David Levine, Chad Massena, Jessica Massena, Brian Martinez, Sam Mohmand, Esther Morantz, Jill Patel, Staci Puckett, Rebecca Rees, David Rosenbaum, Samantha Schrepel, Chris Schroeder, Kelsey Thomsen, Chris Volpe, Jamie Wagner, Lianne Wharton

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University of Maryland

Megan Berg, Lauren Fitzgerald, Megan Janssen, Avita Jones, Deidre Robinson

University of Northern Florida

Elysia Brennan, Christopher Ferrara, Lindsay Googe, Samantha Grogan, Marie Haagensen, Crystal Harris, Madeline Parhalo, Sherline Pierre, Stacy Pohlman, Nichole Polito, Sarah Lynn Redding, Megan Richardson, Megan Smart, Frank Snyder

Supplements Contributors

Our goal for the supplements package to accompany the Third Edition was to create learning tools that incorporate principles of active learning. Research shows that students do better in class when they are asked to use the material they are learning about. From a new workbook that encourages students to practice biology, to interactive web animations that test their knowledge, our supplements ask students to work with information, not just memorize it. My sincere thanks to the following people for their important contribution to the book's core teaching values.

Media Supplements

Marc Albrecht, *University of Nebraska, Kearney*
 John Bell, *Brigham Young University*
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Book Team

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Prentice Hall

This edition was launched by Prentice Hall and then transferred—along with all other Prentice Hall biology titles—to their sister company, Benjamin Cummings. The editorial team at Prentice Hall was responsible for establishing the vision that directed this edition. In addition, they recruited the first advisors and media and supplement contributors, and implemented the initial set of student focus groups, prior to turning the project over to their Benjamin Cummings colleagues. I am grateful for their talent, energy, and friendship, and for the extraordinary efforts they made to make the management transition as smooth as possible. These people are Andrew Gilfillan (Sponsoring Editor), Ann Heath (Executive Project Manager), Erin Mulligan (Development Editor), Lisa Tarabokjia (Editorial Assistant), and Carol Trueheart (VP, Executive Director of Development).

Benjamin Cummings

The Benjamin Cummings editorial and production team welcomed *Biological Science* into their publishing house and moved the project forward through the final critical stages of development and into production. The team was initially led by Sponsoring Editor Susan Winslow, who brought a fresh perspective to the project. Then, Market Development Manager Becky Ruden took over the Sponsoring Editor reins with focused energy and verve. She is a bright, young star. Special thanks go to Project Manager Sonia DiVittorio, who has proven herself one of the sharpest talents in textbook publishing. Sonia's tireless pursuit of quality is evident on every page. In tribute, I have given her a new title at the company: Goddess of Bookmaking.

Thanks also go to Senior Production Supervisor Shannon Tozier, who led the production team with enormous skill and perseverance, and to Design Manager Marilyn Perry, who helped create the striking interior and cover designs. Others on the book team deserving acknowledgement include: Mary Catherine Hager and Susan Weisberg (Development Editors), Anna Amato (Assistant Editor), Mercedes Grandin (Associate Editor), Ericka O'Benar (Media Producer), Yvonne Gerin, Elaine Soares, and Debbie Latronica (photo research team), Christy

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Supplements

The Freeman *Biological Science* supplements package offers a robust suite of print and electronic tools designed to help instructors make the most of their limited time and to help students study efficiently.

INSTRUCTOR RESOURCES

- The entire textbook illustration program is available in JPEG format. All tables, photos, and line drawings with (and without) labels are individually enhanced for optimal in-class projection and are pre-loaded into chapter-correlated PowerPoint presentations.
- A second set of PowerPoint presentations consists of lecture outlines for each chapter, augmented by key text illustrations and hyperlinks to Web Animations.
- A third set of PowerPoint presentations allows select key figures to be presented in a step-by-step manner. In-text figure caption exercises with illustrated answers are included in this step-edited set.
- In-class active lecture questions correlated by chapter can be used with any classroom response system and are available in PowerPoint format.
- The Instructor Guide includes lecture outlines, active learning lecture activities, answers to end-of-chapter questions, and innovative material to help motivate and engage students.
- The Printed Test Bank and Computerized Test Bank have been peer reviewed and student tested. Test questions are ranked according to Bloom's taxonomy and the improved TestGen® software makes assembling tests much easier. The Test Bank is also available in Course Management systems and in Word® format on the Instructor Resources DVD.
- Four-color Transparency Acetates with every illustration from the text are available. Labels and images have been enlarged and modified to ensure optimal projection in a large lecture hall.

STUDENT RESOURCES

- **NEW!** *Practicing Biology: A Student Workbook* offers a variety of activities such as modeling, mapping, and graphing to help students with different learning styles visualize and understand biological processes.
- **NEW!** The eBook addresses the changing needs of students and instructors in the majors biology course by offering an electronic version of the text that links directly to animations, quizzes, and videos.
- **NEW!** Complimentary access to Pearson Tutor Services provides highly interactive one-on-one biology tutoring by quali-

fied instructors seven nights a week during peak study hours. Students will be able to “drop in” for live online help, submit questions to an e-structor anytime, or pre-schedule a tutoring session with an e-structor to receive help at their convenience.

- The Study Guide presents a breakdown of key biological concepts, and helps students focus on the fundamentals of each chapter. It is designed in two parts to help students study more effectively. Part I is intended as a “survival guide,” and Part II explores the material in the textbook, chapter by chapter.

MULTIMEDIA RESOURCES

- **NEW! MasteringBIOLOGY** MasteringBiology™ offers in-depth online tutorials on biology's toughest topics. These tutorials provide hints and feedback specific to each student's misconceptions. MasteringBiology also includes diagnostic test questions and is useful for “just-in-time” teaching.
- **NEW! BioFlix** BioFlix cover the most difficult biology topics with 3-D, movie-quality animations, labeled slide shows, carefully constructed student tutorials, study sheets, and quizzes that support all types of learners. Topics include Tour of an Animal Cell, Tour of a Plant Cell, Membrane Transport, Cellular Respiration, Photosynthesis, Mitosis, Meiosis, DNA Replication, Protein Synthesis, Water Transport in Plants, How Neurons Work, Synapses, and Muscle Contraction.
- **Web Animation** Web Animations add depth and visual clarity to the most important topics and processes described in the text. Animations include pre-quizzes and post-quizzes to help students prepare for exams.
- **NEW!** Discovery Channel video clips on 29 different topics include antibiotic resistance, fighting cancer, and introduced species. Additional Cell Biology animations provide vivid images of the functions and processes of the cell.
- **NEW!** Access to BioForum, a new online community forum created just for biology educators. Learn from your peers about how they're teaching difficult topics or what resources they use to help them teach. Post activities, handouts, Web links, or other tools you would like to share with forum participants.
- **NEW!** Video demonstration shows biology educators using active learning techniques you can incorporate in your classroom immediately.
- Course Management content for *Biological Science*, 3rd Edition, is available for institutions using WebCT or Blackboard and is also available in our nationally hosted Course Compass course management system. If desired, WebCT and Blackboard cartridges containing only the Test Bank are available for download.