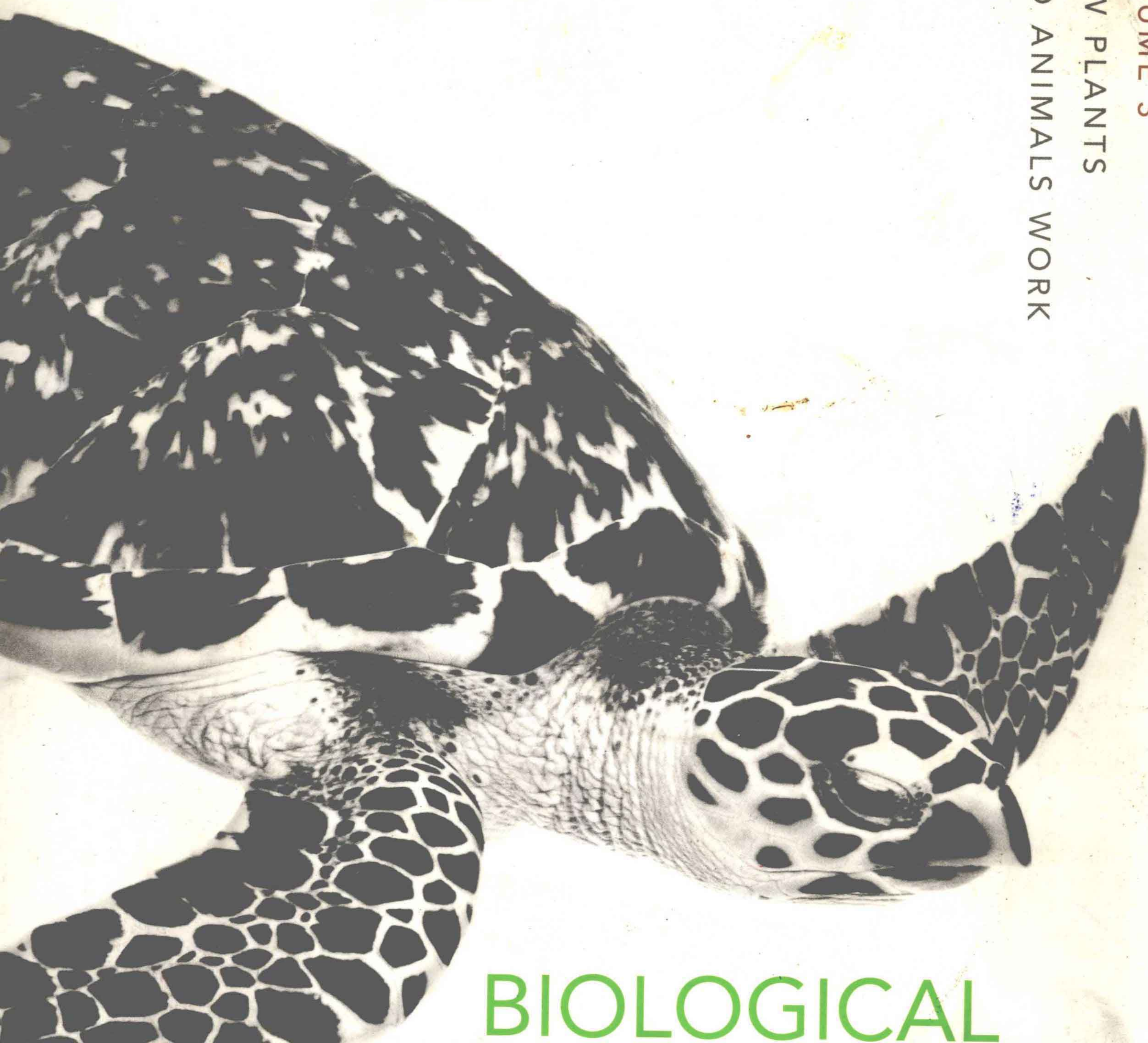
VOLUME 3

HOW PLANTS AND ANIMALS WORK



BIOLOGICAL SCIENCE

SCOTT FREEMAN

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UNIVERSITY OF WASHINGTON

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For Students

It's difficult to imagine a more exciting time to launch a career related to biology. The advent of whole-genome sequencing and a rising interest in conservation biology are giving new momentum to a knowledge explosion that began several decades ago. From biochemistry, cell biology, and genetics to physiology, ecology, and evolution, the pace of discovery in the biological sciences is nothing short of astonishing. Your instructors are introducing you to what may currently be the most dynamic of all human endeavors.

Delving into biology through this introductory course should help you further two important goals. The first involves personal growth. The topics you'll be learning about pervade your life. Biology is about the food you eat and the air you breathe. It's about the history of life on Earth and the organisms that share the planet with us now. You'll be learning why we get sick, how we reproduce, how plants make food from sunlight. Biology is so basic that understanding it is a fundamental part of becoming an educated person. Taking this course can open your eyes, help you see and think about life in a new way, and fuel a lifelong curiosity about the natural world.

The second goal of a course like this involves a potential career path. By preparing you for more advanced classes and a major in the biological sciences, this introductory course will be a crucial first step in acquiring the background you'll need to enter a biology-related profession and help solve pressing problems in health, conservation, or agriculture. Many of the great challenges facing us today—from climate change and species extinctions to antibiotic resistance and emerging viruses—demand expertise in biology.

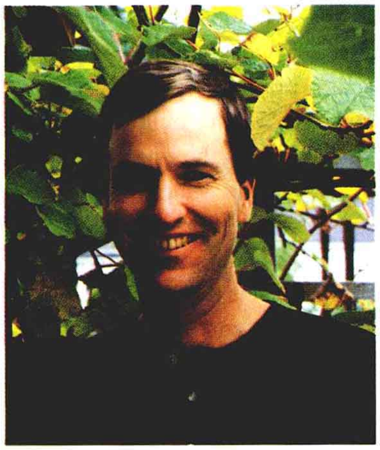
The purpose of this text is to help you make that important first step toward majoring in the biological sciences and pursuing a career related to biology. Its goal is not only to be a valuable reference for the fundamentals but also to introduce you to the excitement that drives this science. The presentation focuses on the questions that biologists ask about the natural world and how they go about answering them. Its objective is to introduce the core ideas that biologists use to make sense of the massive amount of information emerging from laboratories around the world.

The overall theme in this text is to help you learn how to think like a biologist. No matter what path your career takes, it is virtually certain that you will need to evaluate new hypotheses, analyze new types of data, and draw conclusions that change the direction of your work almost daily. Many of the facts you learn as an introductory student will change, but the analytical skills you learn in this course will serve you for life. Learning to think like a biologist will prepare you for upper-level courses and make you a better professional—whether you end up as a physician, pharmacist, educator, conservationist, or researcher.

If you approach this book with an open and inquiring mind, ready to challenge knowledge even as you absorb it, then you will have done your job. If this book communicates a sense of excitement about biological science and inspires you to keep learning more, it will have done its job. Thank you for joining a great adventure.

Scott Freeman

Preface



Scott Freeman received his Ph.D. in Zoology from the University of Washington and was nominated for an Excellence in Teaching Award in 1989. He was subsequently awarded an Albert Sloan Postdoctoral Fellowship in Molecular Evolution at Princeton University to investigate how generation time affects the rate of molecular evolution. Dr. Freeman's research publications explore a range of topics from the behavioral ecology of nest parasitism to the molecular systematics of the blackbird family. As an affiliate faculty member at the University of Washington, he has taught courses in evolution and has played an active role in the redesign of the general biology course. He is currently teaching the majors general biology course using an inquiry-based approach that emphasizes the logic of experimental design and the mastery of core concepts required for success in upper-level courses. Dr. Freeman is the co-author of *Evolutionary Analysis*, which presents evolutionary principles in the same spirit of inquiry that drives research.

Faculty who teach introductory biology may have the most exciting and difficult job on campus. The excitement springs from the breathtaking pace of advances in the biological sciences and the wide array of training and career options that are now open to prospective majors; the difficulty lies in introducing students to an already imposing and rapidly increasing number of facts and concepts.

When I took introductory biology as an undergraduate in 1975, faculty members were coping with the information explosion by extending the length of their introductory courses and using ever-larger textbooks. Today we don't have those options. Course length is capped at one year and most texts already run in excess of 1100 pages. Over the past decade in particular, presenting a fact-based, synoptic overview of what we know about biology has become increasingly untenable.

In short, the information explosion has changed our jobs. Instead of asking students to focus primarily on memorizing facts, more and more instructors are focusing their course on teaching students how to think like a biologist.

Why a New Introductory Textbook?

I wrote *Biological Science* to support professors who want their students to experience a more inquiry-driven approach in introductory biology. My goal was to write a book infused with the questions and the enthusiasm for learning that drive biological research. To help students understand how biologists think, each chapter is built around a series of questions that are fundamental to the topic being addressed. While exploring each question, the presentation incorporates data for students to interpret, offers evidence for competing hypotheses, introduces contemporary researchers, refers to work in progress, and highlights what researchers don't yet know. My aim was to help you teach biology the way you do biology—by asking questions and analyzing data to find answers.

At the same time, I made a strong commitment to covering the basics. We teach students who want to become doctors, researchers, science journalists, teachers, and conservationists. We have an obligation to prepare them for success in upper division courses, MCATs, and GREs, and to introduce the canon of facts and concepts that they must master to major in biology. Instead of listing these facts and concepts in an encyclopedic manner, however, *Biological Science* introduces them in the context of answering a question. In this textbook, facts become tools for understanding—not ends in themselves.

In addition to finding an appropriate balance between covering facts and exploring the scientific process, the level of the presentation is crafted to be appropriate for introductory students. Sections and sub-sections in the text begin with an overview of what question is being asked and end with commentary that helps students pull the material together. Instead of getting lost in the details of how an experiment was done, the text emphasizes why it was done and what the data mean.

Because beginning students are concerned about themselves and their world, most chapters explore how the topic relates to human welfare and all chapters end with an essay inspired by medical, commercial, or environmental concerns.

The Forest and the Trees: Helping Students to Synthesize and Unify

In addition to coping with an enormous amount of content in this course, instructors have to manage its diversity. In *Biological Science*, the emphasis on inquiry and experimentation provides a unifying theme from biochemistry through ecosystem ecology. In addition, the text highlights the fundamental how and why questions of biology. How does this event or process occur at the molecular level? In an evolutionary context, why does it exist?

The majority of chapters include at least one case history of an analysis done at the molecular level. Natural selection is introduced by exploring the evolution of antibiotic resistance via point mutations in the RNA polymerase gene of *Mycobacterium tuberculosis*. In the diversity unit, students learn about extracellular digestion in fungi by exploring experiments on the regulation of cellulase genes. A section of the behavior chapter features research on a gene involved in fruit fly foraging behavior. These are just three of many examples.

Similarly, evolutionary analyses do not begin and end with the evolution unit. Concepts like adaptation, homology, natural selection, and tree thinking are found in virtually every chapter. Unit 1, for example, presents traditional content in biochemistry—ranging from covalent bonding to the structure and function of macromolecules—in the context of chemical evolution and the origin of life. Meiosis is analyzed in terms of its consequences for generating genetic variation and making natural selection possible. Shared mechanisms of DNA repair and pattern formation are explained in the context of gene homologies. The overriding idea is that molecular and evolutionary analyses can help unify introductory biology courses, just as molecular tools and evolutionary questions are helping to unify many formerly disparate research fields within biology.

Supporting Visual Learners

Clear, attractive, and extensive graphics are critical to our success in the classroom. To emphasize the importance of analyzing figures in biology and to support students who learn particularly well visually, the book's art program is both extensive and closely interwoven with the manuscript. Each figure originated with rough sketches that I made while working on the first draft manuscript, which Dr. Kim Quillin then revised to increase clarity and improve appearance.

Throughout this process, our intent was to build an art program that is easy to read and that supports the book's focus on thinking like a biologist. A quick glance through the book should convince you that the art is as distinctive as the text. Color is used judiciously to highlight the main teaching points. Layouts flow from top to bottom and left to right, and extensive labeling lets students work through each figure in a step-by-step manner. Questions and exercises in the captions challenge students to actively interpret the graphics. The overall look and feel of the art is clean, clear, and inviting.

Serving a Community of Teachers

By de-emphasizing the encyclopedic approach to learning biology and focusing more on the questions and experimental tools that make biology come alive, our hope was to offer a book that is more readable and attractive to students and teachers alike. Embarking on an introductory course that launches a career in biology should be exciting, not anxiety-ridden. Learning concepts well enough to apply them to new examples and datasets may be more challenging for some students than memorizing facts, but it is also more compelling. By motivating the presentation with questions, and then using facts as tools to find answers, students of biology may come to think and feel more like the people who actually do biology.

I've always viewed working on this project as a gift, because it was a chance to serve the community of bright, enthusiastic, and dedicated people who teach this course. Thank you for your devotion to biology, for your commitment to your students, and for considering *Biological Science*. Teachers change lives.

Scott Freeman
University of Washington

Acknowledgments

This is the first new introductory biology textbook for majors to appear in over 15 years. The book and associated media were over five years in the making and reflect contributions from hundreds of teachers and researchers around the world. First and foremost among these individuals are the colleagues who contributed first-draft chapters in their areas of expertise. A commitment to scholarship and a passion for teaching resonated throughout these drafts and made an enormous impact on the published versions. The biologists who contributed draft chapters are:

Warren Burggren	University of North Texas
Kathleen Hunt	University of Washington
Kevin Kelley	University of California, Long Beach
Mary Rose Lamb	University of Puget Sound
Andrea Lloyd	Middlebury College
James Manser	Harvey Mudd College
Carol Reiss	Brown University
Thomas Sharkey	University of Wisconsin
DianeTaylor	Georgetown University
Carol Trent	Western Washington University
Susan Whittemore	Keene State College

Focus Group Participants and Reviewers

The contributors and I were guided and advised by introductory biology instructors who attended workshops held in Sundance, Utah while chapters for *Biological Science* were being drafted and revised. Many of the individuals who made up these focus groups were actively involved in efforts to reform introductory biology courses for majors; all helped to hone the look, feel, and content of the book. Workshop participants were:

Peter Berget	Carnegie Mellon University
Jack Burk	California State University, Fullerton
Mark Decker	University of Minnesota
Judith Heady	University of Michigan, Dearborn
Jean Heitz	University of Wisconsin
Carole Kelley	Cabrillo College
Judith Kjelstrom	University of California, Davis
Karen Koster	University of South Dakota
Dan Krane	Wright State University
Harry Nickla	Creighton University
Julie Palmer	University of Texas, Austin
Fred Singer	Radford University
Barbara Wakimoto	University of Washington
Charles Walcott	Cornell University
John Whitmarsh	University of Illinois, Urbana-Champaign
Dan Wivagg	Baylor University

The chapters themselves were thoroughly reviewed as they moved through the production process. Reviewers included experienced teachers who checked for scientific accuracy as well as issues such as level, pacing, and student comprehension. Other reviewers were experts in particular subfields who focused almost exclusively on making sure that chapters were accurate and current. In addition to multiple rounds of review in draft, all 52 chapters underwent a final review for accuracy just prior to publication.

To a person, our reviewers supplied exemplary attention to detail, expertise, and empathy for students. I am deeply indebted to all of the colleagues who reviewed chapters for *Biological Science*; it is simply impossible to overstate how crucial these individuals were to the success of this book. Their effort reflects a deep commitment to excellence in teaching and a profound belief in the importance of introductory courses for training the next generation of professionals. The individuals who reviewed chapters for *Biological Science* are listed at the end of this section.

Media and Supplements Authors

The media and supplements that accompany *Biological Science* were authored by a team of talented and dedicated introductory biology instructors led by Harry Nickla of Creighton University, Andrea Lloyd of Middlebury College, Julie Palmer of the University of Texas at Austin, and Warren Burggren of the University of North Texas. Our media and supplements authors brought an extraordinarily high level of creativity, experience, and ability to this project.

Jay Brewster	Pepperdine University
Brian Bagatto	University of Akron
Judith Heady	University of Michigan, Dearborn
Laurel Hester	South Carolina Governor's School for Science and Math
Carole Kelley	Cabrillo College
Heidi Picken-Bahrey	University of Washington
David Pindel	Corning Community College
Susan Rouse	Emory University

Our intent was to provide a media and supplements package that would be both original and tightly focused on solving key problems confronted by instructors and students in introductory biology. To meet this goal, our authors' efforts were guided by a group of innovative instructors who met as a focus group in New York City and again in Austin, Texas. The focus group participants followed up on these meetings by reviewing the media components and supplements as they were being produced.

John Bell	Brigham Young University
Peter Berget	Carnegie Mellon University
Ruth Buskirk	University of Texas, Austin
Judith Heady	University of Michigan, Dearborn
Kathleen Hunt	University of Washington
Mark Johnston	Dalhousie University
Carole Kelley	Cabrillo College
Julie Palmer	University of Texas, Austin
Robert Winning	Eastern Michigan University

The media and supplements authors were also assisted by biologists who contributed draft versions of the content. The media contributors for *Biological Science* are particularly experienced and creative instructors who use media extensively in their classrooms.

John Bell	Brigham Young University
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Bill Russin	Northwestern University
Christina Trivett	Weber State University
Stuart Wagenius	Chicago Botanic Garden
Tracy Washburn	Sumanas, Inc.
Susan Whittemore	Keene State College

The Book Team

Textbook writing is a team effort. The look and feel of the art program is due to Dr. Kim Quillin, whose combination of creativity and content knowledge enabled her to invent a fresh and effective approach to the design of figures. Her fingerprints are on every single graphic in this book. The Prentice Hall team was equally resourceful, talented, and fun. Project Manager Karen Horton coordinated the contributor's efforts, the reviewer program, and the production of media and supplements with grace and aplomb. Photo researcher Yvonne Gerin was tireless in researching photographs to complement the text and Production Editor Donna Young expertly managed the thousands of details required to complete a project of this scope. Susan Middleton and David Liittschwager graciously provided the photographs for the cover, the title page, and the unit openers. Media Editor Andy Stull was responsible for assembling the media program accompanying this text and Jennifer Welchans, Executive Marketing Manager, is enthusiastically promoting *Biological Science* to ensure that professors have an opportunity to consider this textbook for their course. Development Editor Carol Trueheart acted as my conscience and taskmaster during the writing process; her insights, guidance, and ear have made me a much better author. More than any other individual, though, this book is a testament to the vision, courage, and talent of Sheri Snavely, Editor-in-Chief of Biology and Geosciences at Prentice Hall. *Biological Science* exists because of her devotion to excellence in biology publishing and her determination to offer teachers an innovative new option in introductory biology. She is a completely remarkable editor and person.

Finally, I thank Alex Davenport for help with library research and Susan, Ben, and Peter Freeman for their love and support. This book is dedicated to the memory of my mother and father, Elizabeth and William Freeman.

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Lecture Presentation Tools

Instructor Resource CD-ROM (IRCD)

The Instructor Resource CD-ROM for *Biological Science* simplifies your life by placing powerful, customizable tools at your fingertips. This comprehensive, easy-to-use electronic resource provides everything you need to both prepare for and present a lecture. It features all of the illustrations and and photographs from the book—both as exportable images and as prepared PowerPoint slides. The PowerPoint slides are fully editable, allowing you complete customization capabilities. The Instructor Resource CD-ROM also features hundreds of animations and activities that can be incorporated into your lecture presentation. These same animations and activities are part of a series of more comprehensive, chapter-specific animations and activities located on the Student CD-ROM. Each animation and activity can be presented either with or without text, audio narration, and self-grading quizzes. Imagine being able to put together a presentation using art from the textbook, video clips, and animations from the Student CD. Students are motivated to explore and use the media provided with their text when they see it presented to them in the classroom. This tool gives you the power to visually present and highlight a key concept from the text and then assign it as homework. All of the answers to the activities, end-of-chapter material, and website quizzes are included on the Instructor Resource CD-ROM.

Transparency Package and Instructor Resource Kit

Transparencies are an effective way to visually reinforce your lecture presentation. Every illustration from the text—including art, photographs, and tables—is available on four-color transparency acetates. We've put a lot of thought into how to deliver such a large number of acetates to you in a way that is easy for you to use and organize for lecture. The transparency set is three-hole-punched and organized by chapter in manila folders, which are stored in an Instructor Resource Kit file box along with the printed lecture tools from the Instructor Resource Guide. Some labels and all of the hand pointers in the test illustrations have been deleted from these transparencies to enhance projection. Labels and images have been enlarged and modifed to ensure optimal readability in a large lecture hall.

Instructor Guide

Edited by Julie Palmer, University of Texas at Austin

Contributors: Carole Kelley, Cabrillo College; Judith Heady, University of Michigan at Dearborn; David Pindel, Corning Community College; Susan Rouse, Emory University

The Instructor Guide for *Biological Science* includes not only the traditional instructor support tools—lecture outlines and student objectives—but it also provides additional, more contemporary resources for today's teaching challenges—motivating students, reinforcing their understanding of the material, and helping them to develop critical thinking skills. These resources include chapter-by-chapter suggestions for inquiry-based classroom activities, simple demonstrations, and problems involving the data presented in a given chapter. Answers to all of the activities and problems—including answers to the figure caption questions and exercises and the end-of-chapter questions—are included in this Instructor Guide, making it easier to assign them to students. All content in the Instructor Guide is available in a printed volume or included electronically on the Instructor Resource CD-ROM.

Assessment Tools

Test Questions (over 2600 questions) and TestGen EQ

The Test Questions for *Biological Science* have been written and edited by the author, Scott Freeman, and a team of talented instructors, to ensure the quality and accuracy of this important resource as well as its tight integration with the text. It contains a variety of questions compiled from our reviewers, top educators, and the author's own teaching experience. The Test Questions contain multiple choice questions in the following formats: factual recall, conceptual, and application/data interpretation questions that are in keeping with the most recent MCAT and GRE standards. The Test Questions are available as a printed volume and as part of the TestGen EQ Computerized Testing Software, a text-specific testing program that is networkable for administering tests. It allows instructors to view and edit electronic questions, export the questions as tests, and print them in a variety of formats.

Laboratory Support

Symbiosis: The Prentice Hall Custom Laboratory Program for Biology

With *Symbiosis*, you can custom-build a lab manual that exactly matches your teaching style, your content needs, and your course organization. You choose the labs you want from our extensive list of Prentice Hall publications or Pearson Custom

Publishing's own library of biology labs. You choose the sequence. Using the template tools provided in our unique **Lab Ordering and Authoring Kit**, you can create your own custom-written labs and then incorporate graphics from our biology graphics library. You can even add your course notes, syllabi, or other favorite materials. The result is a cleanly designed, well-integrated lab manual to share with your students.

Course Management Tools

Blackboard is a comprehensive and flexible eLearning software platform that delivers a course management system, customizable institution-wide portals, online communities, and an advanced architecture that allows for web-based integration of multiple administrative systems.

WebCT provides you with high-quality, class-tested material pre-programmed and fully functional in the WebCT environment. Whether used as an online supplement to either a campus-based or a distance-learning course, our pre-assembled course content gives you a tremendous headstart in developing your own online courses.

Course Compass is a dynamic, interactive eLearning program. Its flexible, easy-to-use course management tools allow you to combine Pearson Higher Education content with your own.

Instructors 1st For qualified adopters, Prentice Hall is proud to introduce Instructors 1st—the first integrated service committed to meeting your customization, support, and training needs for your course.

For the Student

Student CD-ROM

The Student CD-ROM for *Biological Science* provides resources to help students visualize difficult concepts, explore complex biological processes, and review their understanding of the most challenging material presented in this course. This comprehensive, easy-to-use electronic resource is integrated with the textbook, providing students either with rapid access to extended learning opportunities while reading the chapter or with detailed textbook references while working through an activity on the CD. These activities include animations to visualize elaborate biological concepts or processes and animated tutorials that allow students to explore more complex topics. The Student CD has an intuitive interface, a familiar chapter-based organization, and a powerful search engine, all designed to help students expertly navigate this resource. Each activity includes full audio narration, an integrated glossary, and an audio pronunciation guide. In addition, the CD also serves as a portal to the review and research tools provided on the Student Website, bringing together all of the resources to help students succeed in their course.

Student Website (www.prenhall.com/freeman/biology)

The Student Website for *Biological Science* provides students with the self-assessment, current research, and communication tools needed to help them succeed in their introductory biology course. Within each chapter on the Website, self-grading quizzes allow students to assess their understanding of the chapter material as well as providing an explanation should a student choose an incorrect answer to a question. Further, the Website includes a broad collection of science and research links for the subject areas described in each chapter. These links are outstanding tools for students wishing to explore a chapter's concepts or to extend their knowledge beyond the scope of the text. In combination with the Student CD, the Student Website provides a valuable set of resources to help students develop the skills that will help them in both their introductory biology course as well as in upper-division courses.

Student Study Guide

Edited by Warren Burggren, University of North Texas

Contributors: Jay Brewster, Pepperdine University; Laurel Hester, South Carolina Governor's School for Science and Mathematics; Brian Bagatto, University of Akron

The Student Study Guide helps students focus on the fundamentals chapter-by-chapter and contains additional resources to help students prepare for a career in the biological sciences. Each chapter presents a breakdown of chapter themes, key biological concepts, exercises, self-assessment activities, and quizzes. Additionally, the Study Guide features four introductory, stand-alone chapters: Introduction to Experimentation and Research in the Biological Sciences, Presenting Biological Data, Understanding Patterns in Biology and Improving Study Techniques, and Reading and Writing to Understand Biology.

Science on the Internet

Andrew Stull, Prentice Hall and Harry Nickla, Creighton University

This free, practical resource provides straightforward step-by-step directions for accessing regularly updated biology resource areas online as well as an overview of general online navigation strategies. This booklet is a helpful companion to the Student Website for *Biological Science*.

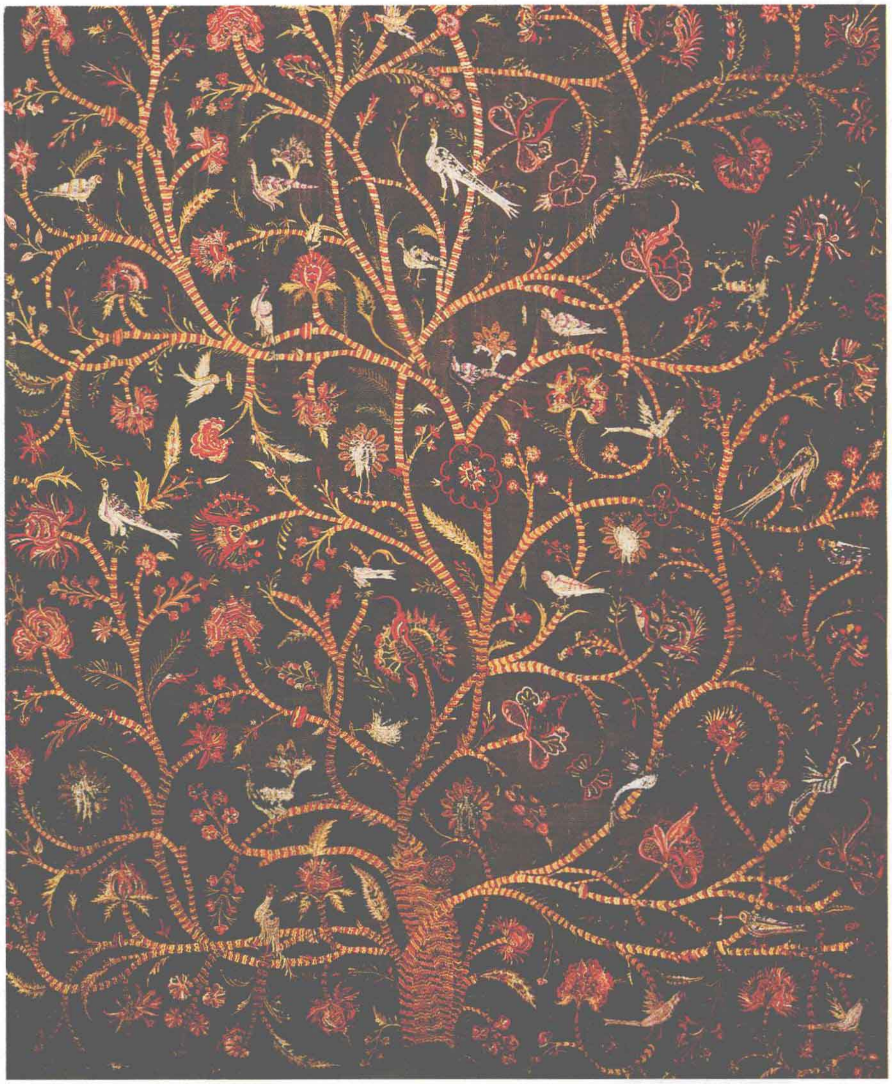
BIOLOGICAL SCIENCE

Biology and the Tree of Life

1

At its core, biological science is a search for the features and processes that unify the remarkable diversity of living organisms. Chapter 1 is an introduction to this search. Its goals are to convince you that the diversity of life is indeed remarkable, and that biologists have identified fundamental mechanisms and traits that unify all organisms. Appreciating the diversity of life—and understanding its underlying unity—is the first step in learning how to think like a biologist.

Chapter 1 begins with two of the greatest unifying ideas in all of science: the cell theory and the theory of evolution by natural selection. When these concepts emerged in the mid-1800s, they revolutionized how biologists understand the world. A major part of this revolution was the realization that all organisms are related to one another through common ancestry. Bacteria, mushrooms, roses, and robins are all part of a family tree, similar to the genealogies that connect individual people. How do biologists study this "tree of life"? What does it look like? The chapter concludes by exploring these questions.



In ancient and modern cultures, the tree of life, shown on this antique tapestry, has symbolized fertility, everlasting life, and peace among nations. This chapter explains that in modern biology, the tree of life is a literal representation of the relationships among species.

1.1 The Cell Theory

1.2 The Theory of Evolution by Natural Selection

1.3 The Tree of Life

1.4 Biological Science

1.1 The Cell Theory

The initial conceptual breakthrough in biology—the cell theory—emerged only after some 200 years of work. In 1665 the Englishman Robert Hooke used a crude microscope to examine the structure of cork (a bark tissue) from an oak tree. The instrument magnified objects to just 30 times (30×) their normal size, but it allowed Hooke to see something extraordinary. In the cork he observed small, pore-like compartments that were invisible to the naked eye (**Figure 1.1a**, page 2). These structures came to be called cells.

Soon after Hooke published his results, a Dutch scientist named Anton van Leeuwenhoek succeeded in developing much more powerful microscopes—some capable of magnifications up to 300×. Leeuwenhoek inspected samples of pond water with these instruments and made the first observations of single-celled organisms (**Figure 1.1b**). He also observed and described the structure of blood cells and sperm cells from humans.

In the 1670s, Marcello Malphigi concluded that plant tissues like leaves and stems were composed of cells. Lorenzo Oken extended this observation in 1805 by claiming that all organisms consist of cells. In the late 1830s Oken's hypothesis was backed by Matthias Schleiden and Theodor Schwann, who independently reached the same conclusion after examining hundreds of plant and animal tissues under magnification. The conclusion was a classic example of inductive reasoning: Scientists made a broad generalization only after making hundreds of supporting observations.

Since the 1830s, however, microscopes have advanced dramatically. Biologists have discovered hundreds of thousands of new organisms. Has Schleiden and Schwann's conclusion held up? Is it true that all organisms are made of cells?

Are *All* Organisms Made of Cells?

The smallest organisms known today are bacteria that are barely 200 nanometers wide (**Table 1.1**). Lined up end to end, it would take 5000 of these organisms to span the distance between the smallest hash marks on a ruler (a millimeter). The tallest organisms known are sequoia trees from the Pacific Coast of the United States. Sequoias can be over 100 meters tall—the equivalent of a 20-story building. Bacteria and sequoias are composed of the same fundamental building block, however: the cell. Bacteria are unicellular (one-celled) organisms; sequoia trees are multicellular (many-celled) organisms.

Biologists are increasingly dazzled by the diversity and complexity of cells as advances in microscopy enable them to examine cells at higher magnifications. Oken, Schleiden, and Schwann's basic conclusion is intact, however. As far as is known, all organisms are made of cells. Today, a **cell** is defined as a water-based compartment filled with concentrated chemicals and bounded by a thin, flexible structure called a membrane.

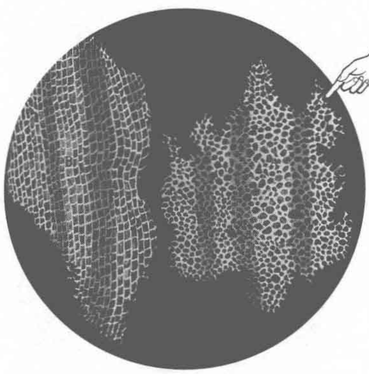
However, as important as the claim made by Oken, Schleiden, and Schwann was, it formed only the first part of the cell theory. In addition to understanding what organisms are made of, scientists wanted to know the origin of that fundamental material—where does it come from?

Where Do Cells Come From?

Most scientific theories have two components. One component describes a pattern in the natural world, and the other component identifies a mechanism or process that is responsible for creating that pattern. Malpighi, Oken, Schleiden, and Schwann all articulated the pattern component of the cell theory. In 1858 Rudolph Virchow forcefully backed Oken's statement of the process component by stating that all cells arise from preexisting cells. The complete **cell theory**, then, can be stated as follows: All organisms are made of cells, and all cells come from preexisting cells.

The Oken-Virchow claim was a direct challenge to an alternative hypothesis called **spontaneous generation**. This is the proposition that organisms can arise spontaneously under certain conditions. For example, the bacteria and fungi that spoil foods like milk and wine were thought to simply appear in

(a) The first view of cells: Robert Hooke's drawing from 1665



(b) Anton van Leeuwenhoek was the first to view single-celled "animalcules" in pond water.

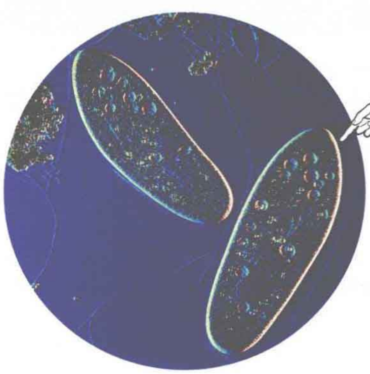


FIGURE 1.1 The Discovery of Cells

TABLE 1.1 Some Prefixes Used in the Metric System

Prefix	Abbreviation	Meaning	Example
giga-	G	10^9	1 gigameter (Gm) = 1×10^9 m
mega-	M	10^6	1 megameter (Mm) = 1×10^6 m
kilo-	k	10^3	1 kilometer (km) = 1×10^3 m
deci-	d	10^{-1}	1 decimeter (dm) = 1×10^{-1} m
centi-	c	10^{-2}	1 centimeter (cm) = 1×10^{-2} m
milli-	m	10^{-3}	1 millimeter (mm) = 1×10^{-3} m
micro-	μ*	10^{-6}	1 micrometer (μm) = 1×10^{-6} m
nano-	n	10^{-9}	1 nanometer (nm) = 1×10^{-9} m

*μ is the Greek letter mu (pronounced "mew").