BIOLOGY

CAMPBELL

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NEIL A. CAMPBELL

San Bernardino Valley College

The Benjamin/Cummings Publishing Company, Inc.

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Compositor: Graphic Typesetting Service

Film Preparation: Color Response, Inc.

About the cover: "Leaves, Mount Rainier National Park, Washington c. 1942." Photograph by Ansel Adams. Courtesy of the Trustees of the Ansel Adams Publishing Rights Trust. All rights reserved.

Figure acknowledgments begin on page C-1.

Library of Congress Cataloging-in-Publication Data
Campbell, Neil A., 1946-
Biology.
(The Benjamin/Cummings series in the life science)
Includes bibliographies and index.
1. Biology. I. Title. II. Series.
QH308.2.C34 1987 574 86-28328
ISBN 0-8053-1840-2

DEFGHIJ-DO-898

The Benjamin/Cummings Publishing Company, Inc.
2727 Sand Hill Road
Menlo Park, California 94025

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To Rochelle and Allison,
with love

About the Author

BIOLOGY is the product of 18 years of teaching experience and eight years of intensive writing and revision by Dr. Neil A. Campbell. This textbook is a natural outgrowth of Dr. Campbell's broad interest in his science. He earned his M.A. in Zoology from UCLA, where he studied the control of protein synthesis during animal development, and went on to the University of California at Riverside, where he earned a Ph.D. in Biology studying salt tolerance in desert plants. Dr. Campbell's research efforts on salt transport in plants and the cellular basis of leaf movements have resulted in publications in *Science*, *The Proceedings of the National Academy of Sciences*, and *Plant Physiology*, among other journals.

In addition to his accomplishments as a research scientist, Dr. Campbell has earned a reputation as an outstanding classroom teacher with a strong commitment to improving undergraduate education. After 10 years of teaching general biology and cell biology at San Bernardino Valley College, he took an academic leave and accepted a faculty position at Cornell University, where he reorganized a two-semester general biology course. After three successful years at Cornell, Dr. Campbell returned to California to reassume his teaching position at San Bernardino Valley College and to work more intensively on his book. He returns to Cornell each summer to teach the two-semester general biology course to advanced placement high school students and Cornell undergraduates on a six-week schedule. During his many years of teaching general biology—most frequently as the sole lecturer—Dr. Campbell has instructed over 10,000 students. His teaching sensibilities have been honed in both large lecture and small classroom environments and with a diverse group of students. He is currently Professor of Biology at San Bernardino Valley College, where in 1986 he received the "Outstanding Professor Award" for excellence in classroom instruction.

PREFACE

This book is for students, and, in a way, it is a book *by* students. The most important tool I've brought to the writing bench is my teaching experience. In front of a live audience, a teacher can discern, often by simply monitoring facial expressions, if a particular presentation is working. Feedback from students helps an instructor learn when an example or analogy can clarify a point and when it can muddle the point, when details can support the development of a concept and when they can obscure the concept. Sensitive teachers also recognize the frustration of students who are stranded between two plateaus in their understanding, not having been given enough detail to completely grasp a concept. If a difficult idea is worth mentioning, it must be adequately developed. I believe that today's college students are as bright and eager as ever before and respond well to the challenge of learning difficult material as long as it is thoughtfully and logically explained. Therefore, *BIOLOGY* presents each topic on a level that is thorough enough to prepare biology students for their intermediate coursework, while exposing nonmajors to biology on a level that is meaningful without being superficial. My primary goal has been to provide students with a text that helps them do well in their general biology course and also serves as a reference in their continuing education.

Anyone who has taught introductory biology over the past decade can attest to the dramatic change in appearance of the textbooks. The trend has been toward more spectacular photographs, more colorful artwork, and more clever boxed essays. While this escalation in production standards has certainly produced many beautiful books, there is a danger of overwhelming the student with too many distractions. Learning difficult concepts requires concentration, and eye-catching motivational devices are counterproductive if they interrupt the learning process. If a text is to be a useful teaching tool, the art and photo program should *support*, not overwhelm, the author's message. My ambition has been to produce a biology book in which words and visual aids work in harmony to facilitate learning—a book that merges high production standards with coherent topic development and careful explanation.

Another major goal has been to make this book scientifically accurate and truly modern. Biology has evolved dramatically in the past decade, changing not just in its details but in some of its most basic assumptions and paradigms. A text cannot represent these exciting changes by simply sprinkling recent discoveries into a recipe of old ideas and approaches. In planning this book, it was necessary to rethink how each facet of biology should be presented. For example, the chemiosmotic model has revolutionized our view of how cells transduce energy and should be at the foundation of a text's discussion of bioenergetics. Another example is the refinement of evolutionary biology where the orthodox view of evolution as a continuous, gradual process is being challenged by the punctuational view, which sees a more jerky tempo for evolution.

Being contemporary, however, does not mean losing touch with the past. In many fields, such as genetics and evolution, the history of biological thought helps put problems of current interest into a more meaningful perspective. Students also deserve to see that many issues are not yet settled—to see that scientific

inquiry has more to do with questions than facts. This text recognizes that intellectual debate, the lifeblood of science, abounds in biology.

SPECIAL FEATURES

The Themes Beginning biology students suffocate in an avalanche of information without unifying themes to help them grasp important relationships. The first chapter of this text articulates a few key themes in the study of life, and these themes are subsequently applied throughout the text to help students see connections in an otherwise bewildering subject. The core theme is evolution. Among the supporting themes is the correlation of structure and function, so apparent at all levels of biological organization.

The Interviews Each of the book's eight units opens with a dialogue between the author and a scientist who has made important contributions to the forthcoming field of study. These interviews, conducted specifically for this text, reinforce the themes of the book and help students see science as an activity of creative men and women rather than a collection of facts. The content of the interviews ranges from the scientists' personal experiences to discussion of the cutting edges of their respective fields. Although the interviews are intended as entrees to the succeeding chapters, instructors may find it useful to have students reread the transcripts after studying that unit. A complete list of the scientists who were interviewed is found on pages xvi–xvii.

The Methods Boxes The relationship between the development of new research methods and scientific progress is, in my opinion, underemphasized in most introductory biology texts. In learning about important theories, the best students often ask: "How do we know?" To help answer that question, this text includes boxed descriptions of certain methods that are important in biological research. Some of these methods boxes will help students understand techniques they are likely to use in the laboratory, such as chromatography and spectroscopy. Other boxes describe methods that have been crucial to progress in biology, but that few students will have an opportunity to perform. For example, one box describes the freeze-fracture method in electron microscopy, a technical breakthrough that helped change our view of biological membranes. The methods boxes convey a sense of science as a process of problem solving.

The Art and Photo Program The publisher and I have been uncompromising in our insistence that each figure support the text. From the earliest stages, the artists and I worked side-by-side to coordinate the book's words and illustrations. In fact, students will find that reexamining the figures and captions is one useful method of reviewing the contents of a chapter. Another goal for the art program was consistency. This led us to incorporate a number of refinements that should be especially helpful to students. For example, the molecule ATP is symbolized in the same color-coded style throughout the book. Equal attention was given to the photo program. Each photograph was evaluated not only for its intrinsic quality but also for how well it complemented the text. Our overall objective was to achieve a new degree of integration that would help students better understand modern biology.

CONTENT AND ORGANIZATION

This text does not attempt to impose a particular organization on general biology courses. Over the years, I have rearranged my own syllabus in various ways, finding that many different sequences are workable. This book is flexible enough for instructors to adapt its content to a variety of syllabi. The eight major units are self-contained and can be rearranged, and most of the chapters within each unit can be assigned in a different order without loss of continuity. For example, instructors who integrate plant and animal physiology rather than teaching those subjects separately can assign chapters from Units Six and Seven to fit their course. Thorough cross-referencing contributes to the text's flexibility. A brief overview of the book's organization will highlight the content of each unit.

Unit One: The Chemistry of Life While the task of teaching chemistry may be the province of prerequisite or corequisite courses, I've found that many students are inadequately prepared to succeed in their introductory biology course. This unit was developed with the uninitiated student in mind and with an eye toward its utility as a self-study tool. Instructors may choose to have students work through Chapters 2–5 on their own or make selective reading assignments from these chapters. However, Chapter 6, "Introduction to Metabolism," is an important springboard into the forthcoming material on bioenergetics and is essential reading even for those students with strong chemistry backgrounds.

Unit Two: The Cell Chapters 7–11 emphasize correlation of structure and function in the study of cells. Chapter 7 features relationships between the parts of the cell, including extensive coverage of the endomembrane system and the cytoskeleton. The concept of chemiosmosis is interwoven throughout the chapters on cellular energetics. Chapter 8, "Traffic Across Membranes," is one good example of the pedagogical effectiveness of the text's art program.

Unit Three: The Gene Chapters 12–19 take a historical approach to genetics, tracing its development from Mendel to recombinant DNA technology. I am grateful to have had access to the unpublished manuscript of the fourth edition of James D. Watson's *Molecular Biology of the Gene,* which helped me characterize this fast-moving field. Although certain aspects of molecular biology apply to all organisms, this unit also recognizes the many important differences between prokaryotic and eukaryotic genetics. Instructors should note that the molecular aspects of development are covered in Chapter 18, while the descriptive and cellular aspects of plant and animal development are discussed in Chapters 34 and 43, respectively. The genetics unit culminates with a chapter on biotechnology, which introduces students to the methods and potential applications of gene splicing.

Unit Four: Evolution Evolution is the most important fact of life, and it is the one theme that surfaces in every part of this text. Chapters 20–23 focus on how evolution is studied and how it occurs. It is unfortunate that the creationist furor (mentioned nowhere in the book except here) has diverted attention from the many legitimate debates among evolutionary biologists. This robust field is alive with controversy about the timetable and mechanisms of evolution. Evolutionary biologists having diverse viewpoints reviewed this unit, and they have agreed that the chapters are accurate and objective in representing the important issues in evolution.

Unit Five: The History of Life Chapters 24–30 trace the history of biological diversity, emphasizing important evolutionary junctures such as the origin of prokaryotes, evolution of the eukaryotic cell, the genesis of multicellular organisms, and the adaptive radiations of prevalent groups of plants and animals. The interrelationship between biological and geological history is featured throughout the unit. Instructors who do not cover the diversity of life extensively in their lectures may still want to require reading from this unit, which includes coverage of the anatomy and life cycles of various groups of organisms. I have classified life according to an updated version of the Whittaker-Margulis five-kingdom system. Instructors should be aware that viruses are not covered in this unit, but in the genetics unit (Chapter 17). The distinct evolutionary flavor of these chapters contrasts with a "parade of kingdoms" approach to biological diversity.

Unit Six: Plants: Form and Function Plant physiology is the field most commonly short-changed in introductory biology texts. In describing how plants work, Chapters 31–35 rely heavily on the relationship between structure and function in the broader context of evolution. Flowering plants are emphasized because they have been the subjects of most of the basic research in plant science. The anatomy and life cycles of other plant groups are covered in Chapter 27.

Unit Seven: Animals: Form and Function Here again, the dual themes of structure-function correlation and evolution are applied. Taking a comparative approach in Chapters 36–45, I have included many examples of anatomical and physiological adaptations in invertebrates and the various classes of vertebrates. Humans fit into this context as the primary mammalian example. One showcase of this comparative approach can be found in Chapter 40, "Controlling the Internal Environment." To prepare students for the central role of hormones in reproduction and development, as well as their integration with nervous control, I have included a complete chapter on endocrinology (Chapter 41, "Chemical Coordination"). And no modern introduction to biology would be complete without thorough coverage of immunology (Chapter 39), a field at the crossroads of molecular and organismal biology.

Unit Eight: Ecology In Chapters 46–50, I have emphasized the interplay between observational natural history, which has played such an important and enduring role in the development of ecology, and the experimental approach pioneered by Connell, Paine, and others. As in the evolution chapters, I have presented current debates where they exist, and they *do* in many arenas of ecological research. Chapter 46, "Communities," contains several examples of how I have handled controversies. The unit and the book end with a chapter on animal behavior, a subject whose roots extend to physiology and psychology but for which so much recent work has been done by behavioral ecologists.

IN-TEXT LEARNING AIDS

In an effort to make the book more useful for students, a number of learning aids have been incorporated in each chapter.

Study Outline This special form of chapter summary is intended to help students review and cull out the key points from each chapter. Specific page references are included so students can easily refer back to pertinent text discussion for further information.

Self-Quiz This multiple-choice quiz is another important tool for student review. Answers to the self-quizzes and the genetics problems (only in Chapters 13 and 14) can be found in Appendix One at the end of the book.

Challenge Questions These discussion questions are intended to stimulate further investigation by pointing to some of the intriguing questions on which scientists are working. To this end, some of the challenge questions direct students to specific references found in the Further Reading list.

Further Reading These annotated reading lists include both periodicals and more general book references to direct students who would like to learn more about a particular topic.

* * *

At the end of the book, students will find a **Glossary** including definitions and phonetic pronunciations for approximately 1000 of the key terms introduced in the text.

SUPPLEMENTS

Student Study Guide This helpful supplement, written by Dr. Marty Taylor of Cornell University, parallels the book's contents chapter by chapter and is intended to help students master the material in the text. Each chapter in the study guide includes the following elements: Chapter Summary in an alternative format to those found in the book, Test Yourself section (answers are found in the guide), and a special section to help students organize their knowledge through a process known as *concept mapping*.

Lab Collection Rather than produce just another laboratory manual to collect dust on the shelf, the publisher has come up with an innovative alternative. All adopters of this textbook will be provided with a complimentary set of laboratory experiments in a form ready for photocopying. Individual laboratory exercises have been contributed by instructors from all over the country and were edited into a consistent format by Dr. Judy Goodenough of the University of Massachusetts at Amherst. These exercises, all of which have been extensively class tested, provide a valuable resource to be used in whole or in part to augment or replace an existing laboratory manual.

Instructor's Guide This guide, prepared by Dr. Frank Heppner of the University of Rhode Island, contains a wealth of suggestions for lecture preparation, running a lab, testing, grading, and course organization and administration that would be useful to both experienced and inexperienced instructors.

Test Bank Frank Heppner has organized and compiled a set of over 1200 test questions that are keyed to the text. This thoroughly class-tested test bank is also available on TESTGEN II, a microcomputer test generation program for the IBM PC, AT and XT, and the Apple II series microcomputers.

Overhead Transparencies Also available to adopters is a set of 100 full-color acetate transparencies of many of the most important illustrations in the text, as well as 100 additional figures in the form of transparency masters.

* * *

The real test of any textbook is how well it helps instructors teach and students learn. I welcome feedback from instructors and students who have used this book. Please address your comments, criticisms, and suggestions for the next edition directly to me.

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ACKNOWLEDGMENTS

The development of this text spanned nearly eight years and involved a multitude of creative, dedicated people. *BIOLOGY* is the product of their contributions and efforts.

From the inception of the project, the publisher drew upon the expertise of biology instructors and research specialists to assure the book's scientific accuracy and pedagogic usefulness. During the initial planning of the book, we learned a great deal from the many instructors who provided syllabi of their general biology courses and responded to questionnaires about what they would like to see in a biology textbook. At a later stage of the book's development, focus groups were held: instructors who had read parts of the manuscript met with us to share their ideas about the direction of the project and in particular the art program. The publisher also commissioned 120 manuscript reviews throughout the book's development. The focus group participants and manuscript reviewers are listed on p. xiii. I am grateful to all of them for their expert advice.

Several scientists either submitted original material in first-draft form or assisted with the revision of chapters. I am particularly indebted to Julie Ann Miller, who edited about 20 chapters; Jeff Fox, who supplied early drafts of Chapters 19 ("Recombinant DNA Technology") and 39 ("The Immune System"); Stanley Faeth of Arizona State University and Gregory Capelli of The College of William and Mary, who contributed their expertise to Unit Eight, "Ecology"; Wayne Carley of Lamar University, who assisted in revising several chapters in Unit Seven, "Animals: Form and Function"; Jim Valentine of the University of California at Santa Barbara, who helped me formulate a plan for Unit Four, "Evolution"; and Debra Kirchhof-Glazier of Juniata College, who created the end-of-chapter study aids and the glossary. A complete list of contributors appears on p. xii.

Although the final responsibility for errors or inconsistencies rests with me, they are all the fewer because of the expertise of the reviewers and contributors. They worked hard to help me make this book accurate, up to date, and clear, and I thank them for their efforts.

One of the great pleasures of writing this book, indeed one of the things that kept my morale up during the many years of work, was the opportunity of conducting the interviews that open the text's eight units. The interviewees were Albert F. Bennett, Jane Lubchenco, Lynn Margulis, Linus Pauling, Peter and Birgit Satir, Steven M. Stanley, Kenneth Thimann, and James D. Watson. The commitment of these important scientists to improving undergraduate science education was encouraging and inspiring to one who shares that goal. Although the interviews in no way represent an endorsement of this text by the scientists involved, the conversations did provide me with perspective that influenced my writing.

The illustration program is such an integral part of this text that the artists could almost be considered co-authors. In the early stages of this project, two artists, Fran Milner and Georg Klatt, helped lay the conceptual and stylistic foundation for the thirteen artists who created the final illustrations. These artists are Chris Carothers, Barbara Cousins, Cecile Duray-Bito, Janet Hayes, Darwen Hennings, Vally Hennings, Georg Klatt, Linda McVay, Elizabeth Morales, Carla Simmons, Carol Verbeeck, John Waller, and Judy Waller. I am grateful to these creative people for helping set

a new standard in the quality and usefulness of biological illustrations. They should be proud of their work.

BIOLOGY is replete with beautiful as well as functional photographs. Jo Andrews managed the photoresearch program. With her team of photoresearchers, Carl May of Biological Photo Service, Kevin Schafer, and Roberta Spieckerman, and assisted by Darcy Lanham, Jo searched tirelessly for just the right photo to support a particular concept. I thank Jo and her team for helping produce a book where pictures and words work so well together.

The illustration program is showcased by a pleasing and efficient design created by Gary Head. Functional beauty was our objective, and Gary delivered. He also designed the striking and inviting cover of the book.

Pat Waldo and Deborah Gale of Partners in Publishing managed the production of *BIOLOGY*. They pulled it all together—both the text and art—under intense pressure with uncompromising standards, and I thank them both.

Jane Gillen guided the development of the text in all its stages. I respect and admire Jane for her editorial wisdom and her scientific expertise, which is particularly evident in her contributions to Unit Three, "The Gene."

Susan Weisberg and Amy Satran were the developmental editors for this project, and their commitment to excellence shows on every page. Susan was the principal developmental editor during the preparation of the final draft. She brought a refreshing point of view akin to a student's and helped immeasurably to improve the clarity of the text. Amy Satran was the developmental editor of the project during its early stages and, in its final stage, guided the development of Unit Seven, "Animals: Form and Function." Mary Koto helped develop the art program for that unit.

Pius Horner, my teaching colleague, read all parts of the book in its various stages of development and improved the text with his many suggestions.

Holly Grahlman, Rochelle Campbell, and Ann Behnke helped prepare the typescript and also flagged sections of the text that were not yet clear enough.

Robin Williams joined the project during its last year of development and was instrumental in pulling together the supplement package. Robin, along with Rick Mixter and the Benjamin/Cummings field representatives, also kept the project in touch with the needs of biology instructors nationwide.

There would be no book without Laura Argento, Production Manager of Benjamin/Cummings, who worked miracles to put *BIOLOGY* between hard covers.

I chose Benjamin/Cummings as my publisher because I believed it was the only publishing company with the vision, commitment, and imaginative personnel required to produce a new kind of introductory biology textbook. Jim Behnke nurtured this project from the time it was conceived during a meeting eight years ago in my office at Cornell. He brought all the right people together and kept the entire group focused on the common goal of producing a valuable learning aid for biology students. I thank Jim, as my publisher and friend, for his steadfast faith in this book. I am also grateful to Wayne Oler, who initiated this project with Jim and me, for his loyal support.

Most of all, I thank my family and friends, who have endured my obsession with this project for so long.

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