Introduction to BIOTECHNOLOGY

William J. Thieman and Michael A. Palladino

Introduction to Biotechnology

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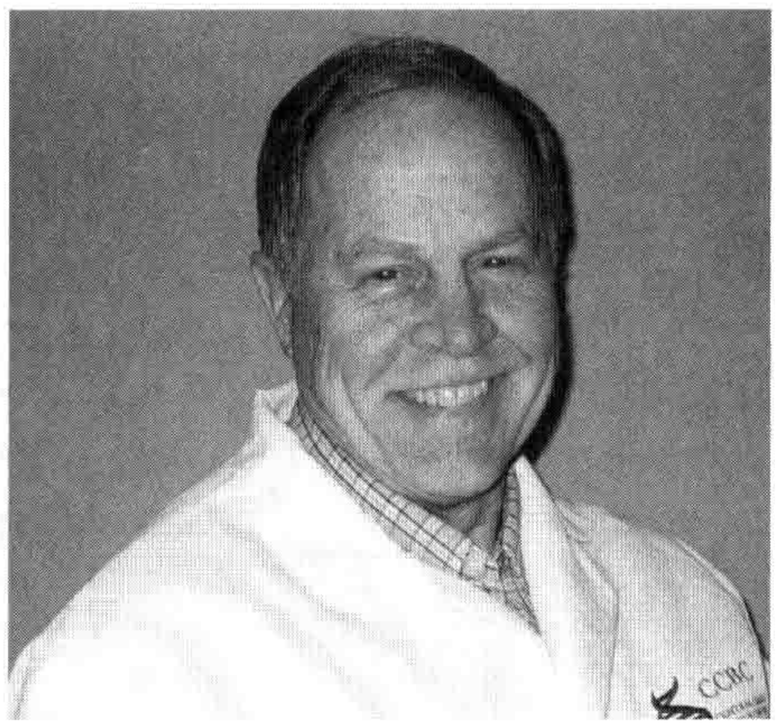
About the Authors

William J. Thieman has been teaching biology at Ventura College for 33 years and biotechnology for 9 years. He received his B.A. degree in biology at California State University at Northridge in 1966 after transferring from Pierce Junior College in 1964. He completed his M.A. degree in Zoology in 1969 at UCLA, while studying early protein synthesis regulation in sea urchin eggs. In 1993, he started a biotechnician training program at Ventura College where he has been teaching since 1970. In 1995, he added laboratory skills components to the program and articulated it as a state-approved vocational program after receiving equipment donations from biotechnology companies and funding from three separate grants.

Mr. Thieman has taught a broad range of undergraduate courses including general and human biology and cancer biology. He received the Outstanding Teaching Award from the National Biology Teachers Association in 1996 for the design of the Plant Biotechnology program and the 1997 and 2000 Student Success Award from the California Community Colleges Chancellor Office. The Economic Development Association presented the biotechnology training program at Ventura College its 1998 Program for Economic Development award for its work with local biotechnology companies.

Mr. Thieman has received numerous grants from different sources for the college biotechnology program. He received two grants one year after the other from the National Science Foundation for introducing biotechnology laboratories into biology and other science courses. He received the largest grant ever awarded to a college by a local agricultural foundation (Hansen Trust) for developing the plant biotechnology program and has received four Tech Prep grants to extend biotechnology and other science programs into local high schools through articulation. In his position with the local economic development center, he has received from biotechnology companies hundreds of thousands of dollars of used equipment that have been distributed to local colleges and high schools to teach science. He lives in Ventura, California, with his wife of 39 years and has two grown children (Dempsey and DeNai). In his spare time, he likes to hike and fish in the Sierra Nevada mountains with his wife, Billye.



Mr. Bill Thieman in the lab.

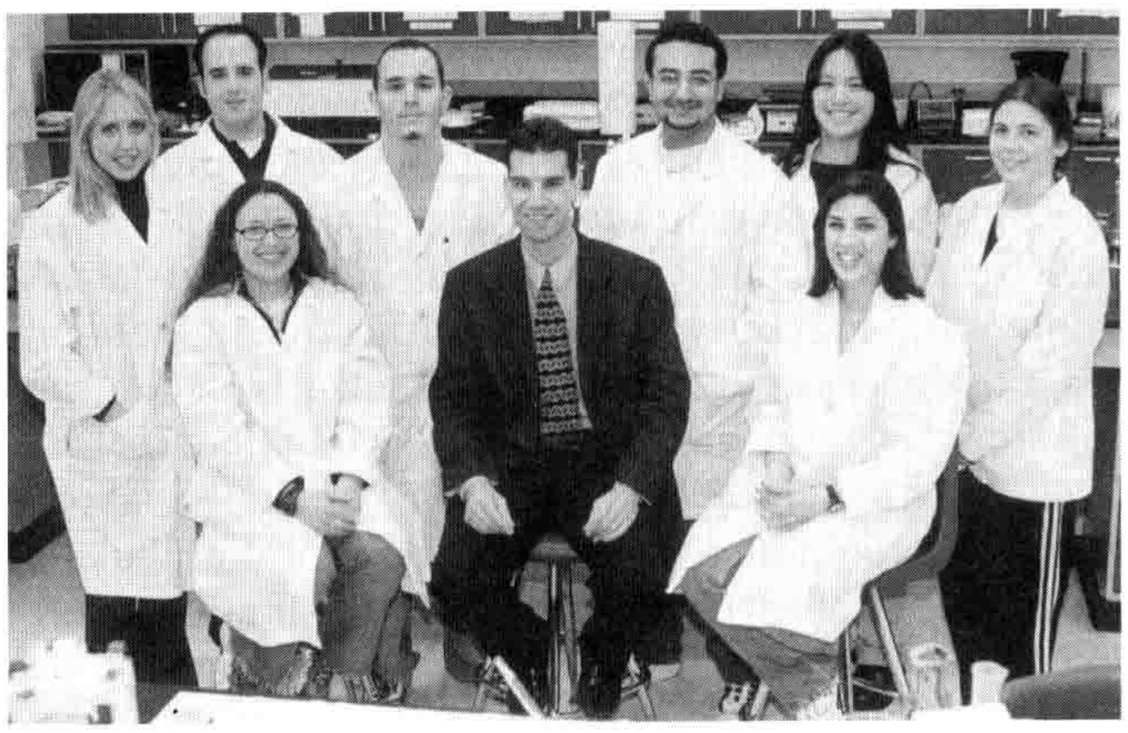
Michael A. Palladino is an Assistant Professor in the Biology Department at Monmouth University in West Long Branch, New Jersey. He received his B.S. degree in Biology from Trenton State College (now known as The College of New Jersey) in 1987, where he began doing research as an undergraduate student. From 1987 to 1988, he studied nucleic acid biochemistry in the Department of Molecular Biology at Princeton University. In 1994, he completed a Ph.D. degree in Anatomy and Cell Biology from the University of Virginia where he studied gene expression in the mammalian testis and epididymis. From 1994 to 1999, he was a faculty member at Brookdale Community College in Lincroft, New Jersey. He joined the Monmouth faculty in 1999.

Dr. Palladino has taught majors and nonmajors in a wide range of undergraduate courses. He has received several awards for research and teaching including the New Investigator Award of the American

Society of Andrology, and the 1997-98 Outstanding Colleague Award from Brookdale Community College. At Monmouth, he has an active lab of undergraduates involved in research on the cell and molecular biology of male reproductive organs. His laboratory is also using biotechnology approaches to determine sources of fecal *E. coli* pollution in New Jersey estuaries.

Dr. Palladino is involved in many scientific organizations including the American Association for the Advancement of Science (AAAS), American Society of Andrology (ASA), American Society for Microbiology (ASM), Council on Undergraduate Research (CUR), Metropolitan Association of College and University Biologists (MACUB), National Association of Biology Teachers (NABT), New Jersey Academy of Science, Sigma Xi, and the Society for the Study of Reproduction (SSR). A strong student advocate, he is an active member of student affairs committees of ASA and SSR, and he is an Executive Board Member of MACUB. He is a reviewer for several research journals, science education journals, and regional and national grant review panels.

Dr. Palladino is author of the student and instructor lab manuals for *BiologyLabs On-Line*, a series of Internet-based biology laboratories. He was a participant in the NABT/NSF project *High Quality Biotechnology on a Shoestring Budget* and has presented numerous workshops for teachers on DNA techniques and biotechnology at meetings throughout the United States. Dr. Palladino authored *Understanding the Human Genome Project* and is Series Editor for the *Benjamin Cummings Special Topics in Biology Series* of booklets designed for undergraduate students. Dr. Palladino lives in Howell, New Jersey, with his wife, Cindy; daughters Elizabeth (10 years) and Lauren (8 years); and son Michael (4 years), along with numerous pets including cats, fish, insects, reptiles, amphibians, and crustaceans many of which are collected by his daughters. In his spare time he can usually be found fishing with his children or coaching their soccer teams.



Dr. Palladino in the lab with undergraduate biology student researchers. (Photo credit: Jim Reme, Monmouth University)

Preface

It is hard to imagine a more exciting time to be studying biotechnology! Incredible advances in this discipline are occurring at a dizzying pace, and biotechnology has made an impact on many aspects of our everyday lives. *Introduction to Biotechnology* is the first biotechnology textbook written specifically for the diverse backgrounds of undergraduate students. Appropriate for students at two- and four-year schools and vocational technical schools, *Introduction to Biotechnology* will provide students who have varied backgrounds in science with the tools for practical success in the biotechnology industry through its balanced coverage of molecular biology, details on contemporary techniques and applications, integration of ethical issues, and career guidance.

This first edition of *Introduction to Biotechnology* was designed with several major goals in mind. These include:

- Providing an engaging and easy-to-understand textbook that is appropriate for a diverse student audience with varying backgrounds and science knowledge.
- Assisting instructors in teaching all major areas of biotechnology and helping students learn fundamental scientific concepts without being overwhelmed by excessive detail.
- Presenting an overview of historic applications while emphasizing modern, cutting-edge, and emerging areas of biotechnology.
- Helping students learn about how biotechnology applications can provide some of the tools to solve important scientific and societal problems for the benefit of mankind and the environment.
- Engaging and stimulating students to consider the many ethical issues associated with biotechnology.
- Incorporating Internet materials to provide students with access to up-to-date and high-quality information about biotechnology.

Introduction to Biotechnology provides a broad coverage of topics in basic sciences that apply to biotechnology including molecular biology, bioinformatics, genomics, and proteomics. As authors, we have strived to incorporate balanced coverage of basic molecular biology and practical applications, historical examples, and contemporary applications of biotechnology to provide students with the tools and basic knowledge to understand biotechnology and the related industry. *Introduction to Biotechnology* offers abundant and pedagogically sound illustrations with detailed explanations to assist students in learning about detailed processes and applications.

In our effort to introduce students to cutting-edge techniques and applications of biotechnology, we dedicated specific chapters to such emerging areas of biotechnology as agricultural biotechnology (Chapter 6), forensic biotechnology (Chapter 8), bioremediation (Chapter 9), and aquatic biotechnology (Chapter 10). Consideration of the many regulatory agencies and issues that impact the biotechnology industry are discussed in Chapter 12, Regulatory Biotechnology. In addition, although ethical issues are included in each chapter as You Decide boxes, a separate chapter (Chapter 13) is dedicated to ethics and biotechnology.

Features of *Introduction to Biotechnology*

Introduction to Biotechnology is specifically designed to provide several key elements that will help students enjoy learning about biotechnology and to prepare potential students for a career in biotechnology.

Learning Objectives

Each chapter begins with a short list of learning objectives that present key concepts that students should understand after studying each chapter.

Abundant Illustrations

Over 180 art pieces provide comprehensive coverage to support chapter content. Illustrations, instructional

diagrams, tables, and flow charts present step-by-step explanations that help students visually learn about important and complex processes used in biotechnology.

Career Profiles

A special box at the end of each chapter introduces students to different job options and career paths in the biotechnology industry and provides detailed information on job functions, salaries, and guidance for preparing to enter the workforce. Experts currently working in the biotechnology industry have contributed information to many of these **Career Profile** boxes. We strongly encourage students to refer to these profiles if they are interested in learning more about careers in the industry.

You Decide

From genetically modified foods, and genetic testing, to the prospects of using embryos for research or the possibility of human cloning, there are a seemingly endless number of topics in biotechnology that provoke ethical, legal, and social questions and dilemmas. **You Decide** boxes stimulate ethical discussion in each chapter by presenting students with a biotechnology-related situation and then asking questions and providing information relating to the social and ethical implications of biotechnology. The goal of these boxes is not to tell students what to think but to help them understand *how* to consider ethical issues and formulate their own informed decisions.

Tools of the Trade

Much like a handyman has boxes filled with tools for the right job, scientists absolutely rely on "tools" to formulate questions, solve problems, make discoveries, and advance scientific knowledge. The tools of biotechnology are laboratory techniques and procedures such as DNA cloning that drive the industry and are essential for its applications. Biotechnology is based on the application of a variety of laboratory techniques or tools in molecular biology, biochemistry, genetics, mathematics, engineering, computer science, chemistry, and other disciplines. **Tools of the Trade** boxes in each chapter present modern techniques and technologies related to the content of each chapter to help students learn about the techniques and methods that are the essence of biotechnology.

Question and Answer (Q&A)

Q & A boxes in each chapter present students with questions that encourage them to apply what they have already learned and to prompt questions that students might be wondering about as they read the book.

Questions & Activities

Six to ten questions are included in each chapter to reinforce student understanding of concepts presented in the chapter. Activities frequently include Internet assignments that ask students to explore a cutting-edge topic.

References and Further Reading

A short list of student-friendly references at the end of each chapter is provided as a starting point for students to learn more about a particular topic in biotechnology. We have carefully chosen articles that will help students and motivate them to learn more about a subject rather than select articles that are extraordinarily detailed and designed for professional scientists. Typically these references include primary research papers, review articles, and articles from the popular literature.

Keeping Current: Web Links

Because biotechnology is such a rapidly changing discipline, it is virtually impossible to keep a textbook updated on new and exciting discoveries. For instance, by the time this book was printed, new information on human genes and gene therapy applications were already being reported. To help students have access to the most current information available, a rich complement of high-quality web links to some of the best sites in biotechnology and related disciplines appears at the end of each chapter.

Realizing that one challenge of presenting web links is that sites may frequently change, we tried to select substantive sites that are well established. If you let us know when you encounter address changes, we can note these changes on the Companion Website so you will easily be able to find updated links. We encourage you to visit these sites often and to use them as resources for the most current information available.

Glossary

Like any technical discipline, biotechnology has a lexicon of terms and definitions that are routinely used when discussing biotechnology processes, concepts, and applications. The most important terms are shown in **boldface type** throughout the book and are defined as they appear in the text. Definitions of these key terms are included in a glossary at the end of the book. Be sure to pay particular attention to the key terms as you work with the textbook to help you learn the "language" of biotechnology.

Supplemental Learning Aids

Introduction to Biotechnology Companion Website (www.aw.com/biotech)

The Companion Website is designed to support instructors and students in teaching and learning biotechnology. As a student, you might use the Companion Website to review your instructor's course syllabus, deliver homework assignments, research topics in biotechnology, and participate in online discussions and lectures. Specific features for students include learning objectives, chapter reviews, flashcards of glossary terms, extensive collection of web references, and chapter search features.

For the instructor, the Companion Website is an online self-study resource that supports and augments material in the textbook. As an instructor, you might use the Companion Website to communicate with students through threaded discussion groups, assigned homework, and downloaded art from the text. You can also create your own course syllabus, complete with online assignments and links to external resources, and online quizzes.

BiologyLabs Online

BiologyLabs Online is a series of 12 interactive laboratories that enable students to learn biological principles beyond the traditional wet lab setting and perform potentially dangerous, lengthy, or expensive experiments in a safe electronic environment by designing and conducting simulated experiments online. Several labs in this online resource are appropriate for biotechnology students. Contact your local Benjamin Cummings sales representative about bundling labs in this series with *Introduction to Biotechnology*. (biologylab.awlonline.com)

Benjamin Cummings Special Topics in Biology Series

The Benjamin Cummings Special Topics in Biology Series is a series of booklets designed for undergraduate students. These booklets present the basic scientific facts and social and ethical issues around current scientific issues so that students can better understand the scientific content and weigh the issues for themselves. Contact your local Benjamin Cummings sales representative about bundling labs in this series with *Introduction to Biotechnology* or visit www.aw.com/bc for more information. Booklets in the series include:

- *Biology of Cancer*
  (ISBN 0-8053-4867-0)
  By Randall W. Phillis and Steve Goodwin, University of Massachusetts, edited by Michael A. Palladino, Monmouth University. *Biology of Cancer* presents the causes, growth patterns, and possible treatments of various types of cancers in a clear and concise format.
- *Biological Terrorism*
  (ISBN 0-8053-4868-9)
  By Steve Goodwin and Randall W. Phillis, University of Massachusetts, edited by Michael A. Palladino, Monmouth University. *Biological Terrorism* gives a brief history on the use of biological weapons, discusses the major microorganisms likely to be used in bioterrorism, and presents research that is being conducted to develop treatments against these pathogens.
- *Stem Cells and Cloning*
  (ISBN 0-8053-4864-6)
  By David A. Prentice, Indiana State University, edited by Michael A. Palladino, Monmouth University. *Stem Cells and Cloning* provides students with an introduction to two of the most controversial topics in biotechnology in the world today. Sources of stem cells and their potential applications are discussed along with scientific, political, and ethical ramifications of their use in modern medicine.
- *Understanding the Human Genome Project*
  (ISBN 0-8053-6774-8)
  By Michael A. Palladino, Monmouth University. *Understanding the Human Genome Project* explains in accessible language what students need to know about the Human Genome Project, presenting the background, recent findings, and scientific, social, and ethical implications of the project.

Acknowledgments

A textbook is the collaborative result of hard work from many dedicated individuals including students, colleagues, editors and editorial staff, graphics experts and many others. First, we thank our family and friends for their support and encouragement while we spent endless hours of our lives on this project. Without your understanding and patience, this book would not be possible.

We gratefully acknowledge the help of many talented people at Benjamin Cummings, particularly the editorial staff. Editorial duties changed several times during the preparation of this book as we managed to chase away several good people, but each editor provided creative talents and dedication to the book. We thank Michele Sordi for her interest in the book's mission and her vision to initiate this project and Peggy Williams for guiding us through reviews of first drafts of each chapter. We thank Associate Project Editor Jeanne Zalesky for keeping us on schedule and for her attention to detail, patience, enthusiasm, editorial suggestions, and great energy for the project. We inundated Jeanne with countless e-mails. She responded to every query, no matter how insignificant, with decisiveness that belies her age. Associate Editor Alexandra Fellowes joined the project at a critical stage of the production process. Her ability to identify subtle but important details was highly valued.

We thank Production Supervisor Corinne Benson for her expertise, patience, and professionalism in guiding us through the production process. She has been a great asset. Thanks go to Marketing Manager Josh Frost for his talents and creative contributions in developing promotional materials for this book. We also thank Maria McColligan, Project Manager and Lisa Travis, Illustrator, and the staff at Nesbitt Graphics, Inc. We greatly appreciate the writing talents of Chris Woolston for helping to revise several chapters.

Undergraduate students at Monmouth University read many drafts of the manuscript and critiqued art scraps for clarity and content. In particular, we thank Tanya Aubrey, Heather Golla, Jennifer Loughlin, Tricia Mallonga, Lawrence Perruzza, and John Powell for their honest reviews and suggestions from a student's perspective. We also thank Robert Sexton, a recent Monmouth University graduate and current biotechnology scientist, for contributing to the Career Profile section of Chapter 3. The 2002 Introductory Biotechnology class students at Ventura College provided many useful suggestions while they tolerated the use of the sketchy figures in PowerPoint programs, which were the result of our first draft. Our students inspire us to strive for better ways to help us teach and to help them understand the wonders of biotechnology. We applaud you for your help in creating what we hope future students will deem to be a student-friendly textbook.

We thank Dr. David A. Prentice, Indiana State University, for contributing Chapter 13 (Ethics and Biotechnology). David's knowledge of stem cells and his wealth of experience in bioethics were instrumental in developing a unique chapter that is a thought-provoking introduction to bioethics for students. We also thank Dr. Daniel Rudolph for contributing to the Career Profile in Chapter 5 (Microbial Biotechnology) and Gef Flimlin for contributing to the Career Profile in Chapter 10 (Aquatic Biotechnology).

Finally, *Introduction to Biotechnology* has greatly benefited from valued input of many colleagues and instructors who helped us with scientific accuracy, clarity, pedagogical aspects of the book, and suggestions for improving drafts of each chapter. The many instructors who have developed biotechnology courses and programs and enthusiastically teach majors and nonmajors about biotechnology provided reviews of the text and art that have been invaluable for helping shape this textbook. Your constructive criticism helped us to revise drafts of each chapter, and your words of praise helped inspire us to move ahead. All errors or omissions in the text are our responsibility. We thank

you all and look forward to your continued feedback. Reviewers of *Introduction to Biotechnology* include:

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Brooke Yool *Ohlone College*
Mike Zeller *Iowa State University*

Whether you are a student or instructor, we invite your comments and suggestions for improving the next edition of *Introduction to Biotechnology*. Please write to us at the addresses below or contact us via e-mail at bc.feedback@aw.com.

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As students ourselves, we too continue to learn about biotechnology everyday. We wish you great success in your explorations of biotechnology!

W. J. T.
M. A. P.

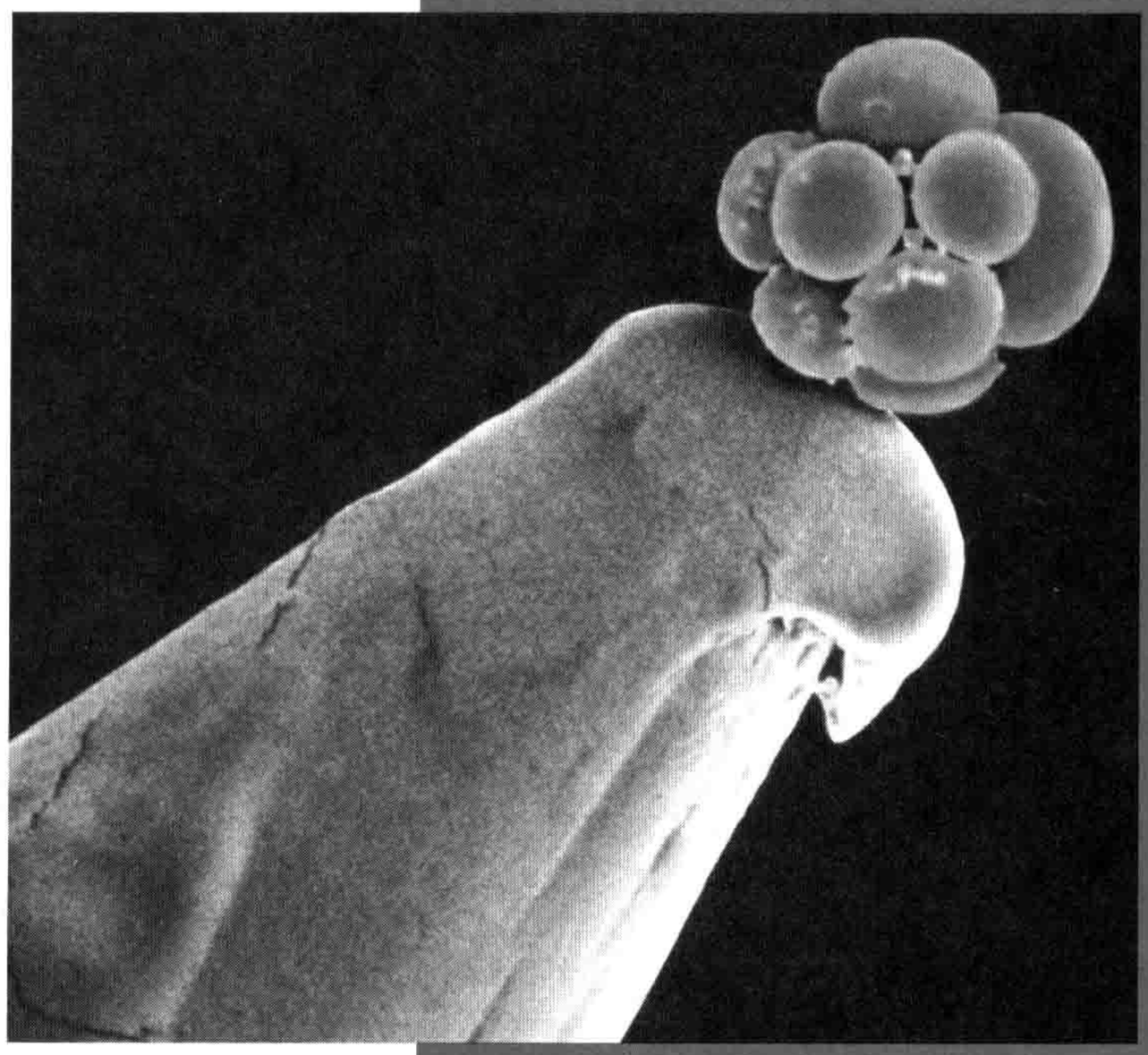
To Billye, the love of my life,
and to the hundreds of biotechnology graduates
who are now doing good science at biotechnology companies
and loving every minute of it.
W. J. T.

To Cindy, Elizabeth, Lauren, and Michael,
you are the true meaning of life and love.
M. A. P.

Contents

CHAPTER

1



Miracle cells? This tiny cluster on the tip of a pin is a human embryo approximately three days after fertilization. Some scientists believe that stem cells contained within embryos may have the potential for treating and curing a range of diseases in humans through biotechnology. Use of these cells is also one of the most controversial topics in biotechnology.

The Biotechnology Century and Its Workforce

After completing this chapter you should be able to:

- Define biotechnology and understand the many scientific disciplines that contribute to biotechnology.
- Provide examples of historic and current applications of biotechnology and its products.
- List and describe different types of biotechnology and their applications.
- Provide examples of potential advances in biotechnology.
- Discuss how medical diagnosis will change as a result of biotechnology and provide examples of how data from the Human Genome Project will be used to diagnose and treat human disease conditions.
- Understand that there are pros and cons to biotechnology and many controversial issues in this field.
- Describe career categories in biotechnology.
- Develop an understanding of some important skills and training required to be part of the biotechnology workforce.
- Discuss hiring trends in the biotechnology industry.

If you have ever eaten a corn chip, you may have been impacted by biotechnology. Don't eat chips? How about sour cream, yogurt, cheese, or milk? In this century, more and more of the foods we eat will be produced by organisms that have been genetically altered through biotechnology. Such **genetically modified (GM) foods** have become a controversial topic over the last few years as have human embryos such as the one shown in the opening photo. This chapter was designed to provide you with a basic introduction to an incredible range of biotechnology topics that you will read about in this book. As you will see, biotechnology is a multidisciplinary science with many powerful applications and great potential for future discoveries.

The purpose of this chapter is not to provide a comprehensive review of the history of biotechnology and its current applications. Instead, this chapter presents a brief introduction and overview of many topics that we will discuss in greater detail in future chapters. We begin by defining biotechnology and presenting an overview of the many scientific disciplines that contribute to this field. We will highlight both historic and modern applications and define the different types of biotechnology that you will study in this book. At the end of the chapter, we will discuss aspects of the biotechnology workforce and skills required to work in the industry. Be sure that you are familiar with the different types of biotechnology and the key terms presented in this chapter as they will form the foundation for your future studies.

1.1 What Is Biotechnology and What Does It Mean to You?

Have you ever eaten a Flavr Savr™ tomato, been treated with a monoclonal antibody, received tissue grown from embryonic stem cells, or seen a "knockout" mouse? Have you ever had a flu shot, known a diabetic who requires injections of insulin, taken a home pregnancy test, used penicillin to treat a bacterial infection, sipped a glass of wine, eaten cheese, or made bread? While you may not have experienced any of the scenarios on the first list, at least one of the items on the second list must be familiar to you. If so, you have experienced the benefits of biotechnology.

Although you may not fully understand the range of disciplines and the scientific details of biotechnology, you have experienced biotechnology firsthand. **Biotechnology** is broadly defined as using living organisms, or the products of living organisms, for human benefit (or to benefit human surroundings) to make a product or solve a problem. Remember this definition. As you learn more about biotechnology, we will expand and refine this definition with historical examples and modern applications from everyday life and look ahead to the biotechnology future.

You would be correct in thinking that biotechnology is a relatively new discipline that is only recently getting a lot of attention; however, it may surprise you to know that in many ways this science involves several ancient practices. As we will discuss in the next section, old and new practices in biotechnology make this field one of the most rapidly changing and exciting areas of science. It affects our everyday lives and will become even more important during this century—what some have called the "century of biotechnology."

A Brief History of Biotechnology

If you ask your friends and family to define biotechnology, their answers may surprise you. They may have no idea about what biotechnology is. Perhaps they might tell you that biotechnology involves serious-looking scientists in white lab coats carrying out sophisticated and secretive gene-cloning experiments in expensive laboratories. When pressed for details, however, they probably will not be able to tell you how these "experiments" are done, what information is gained from such work, and how this knowledge is used. While DNA cloning and the genetic manipulation of organisms are exciting modern-day techniques, biotechnology is not a new science. In fact, many applications represent old practices with new methodologies. Humans have been using organisms for their benefit in many processes for several thousand years. Historical accounts have shown that the Chinese, Greeks, Romans, Babylonians, and Egyptians, among many others, have been involved in biotechnology since nearly 2000 B.C.!

Biotechnology does not mean hunting and gathering animals and plants for food; however, domesticating animals such as sheep and cattle for use as livestock is a classic example of biotechnology. Our early ancestors also took advantage of microorganisms and used **fermentation** to make breads, cheeses, yogurts, and alcoholic beverages such as beer and wine. During fermentation, some strains of yeast decompose sugars to derive energy, and in the process they produce ethanol (alcohol) as a waste product. When bread dough is being made, yeast (*Saccharomyces cerevisiae*, commonly called baker's yeast) is added to make the dough rise. This occurs because the yeast ferments sugar releasing carbon dioxide, which causes the dough to rise and creates holes in the bread. Alcohol produced by the yeast evaporates when the bread is cooked—but the remnants of alcohol remain in the semi-sweet taste of most bread. If you make bread or pizza dough at home, you have probably added store-bought *S. cerevisiae* from an envelope or jar to your dough mix. As you will discover when we discuss microbial biotechnology in