Biology and Biotechnology

Science, Applications, and Issues
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To Anne, Lloyd, and Bob with gratitude and love
About the Authors

Helen Kreuzer is a scientist and an educator. She received her Ph.D. degree in molecular genetics and microbiology from Duke University Medical Center and has taught numerous biology courses to undergraduate students. From 1991 to 1994, she worked with Adrianne Massey at the North Carolina Biotechnology Center, where she designed classroom activities and wrote curriculum materials for teaching about molecular biology and biotechnology in high school. These activities were later published in the book she coauthored with Dr. Massey, *Recombinant DNA and Biotechnology: A Guide for Teachers*, and the accompanying *Guide for Students*. She has taught numerous courses and workshops for high school teachers and developed additional laboratory exercises, models, and videos for molecular biology instruction. Dr. Kreuzer is a member of the biology faculty at the University of Utah, where she researches the use of stable isotope ratios to answer forensic as well as basic biological questions. She and her husband live in Salt Lake City with their basset hounds, TJ and Rosebud, and their dachshunds, Daisy and Pete. In their free time, they perform volunteer work on behalf of homeless dogs and enjoy camping, hiking, and kayaking.

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Old habits die hard. Perhaps surprisingly, this is nowhere more true than in academia—supposedly a bastion of rational, analytical thought. In the last century, science and technology have utterly transformed our lives. Today, a citizen who does not understand the nature of science and its unique, highly productive way of learning about the world (“science as a way of knowing”) cannot claim to be truly educated—any more than someone who cannot write a clear essay. But in our colleges and universities, history is rarely taught to reflect the dramatic ways in which scientific and technological advances have shaped our societies, as well as the course of human events. And most of our science and engineering faculty continue to teach their subject as if it were important only for those who seek to become professionals in their own or a related field.

Even for majors in the subject, we often teach science poorly. Should the purpose of an introductory science course be to commit to memory a large mass of facts that scientists have discovered about the natural world? Life is very different from a quiz show, and anyone with access to the Internet can find almost any fact that he or she wants to know in a few seconds on Google. We need to teach science to all of our students in a way that gives them a clear understanding of how scientific knowledge is accumulated, with its emphasis on logical argument and its insistence on openly presenting evidence—along with details of the methods used to obtain it—so that each scientist’s observations can be confirmed (or refuted) by any other scientist. Science is a marvelous community endeavor that enables new knowledge to be built upon old knowledge in ways that have enabled us to gain a tremendous understanding of the physical world. The understanding has in turn enabled humans to manipulate this world in ways that produce great benefits for humanity.

All of those who teach science in our colleges and universities should think carefully about the fact, cited at the beginning of chapter 22, that “only
30 percent of the consumers in the seven largest EU countries know that all crop plants have genes”—or the fact that half of Americans believe in astrology. How can we hope to maintain a rational society when a majority of our citizens are so disconnected from reality? I would contend that, in every science course that is taught, our primary aim should be to encourage the students to engage in the excitement of the subject and to understand deeply the manner in which science is carried out and its relevance for society.

Despite the arguments just presented, we continue to teach biology to college freshmen from massive textbooks that attempt to cover all of biology in a single year. In such courses there is not enough time to delve into any one aspect of biology in enough detail for students to get a feeling for the fabric of science—or to appreciate how powerfully the science connects to technologies that shall continue to change their lives.

Fortunately, *Biology and Biotechnology: Science, Applications, and Issues* is a different type of textbook for a different type of course. By not attempting to explain all of biology and instead focusing on biotechnology and its many applications, the authors have been able to pursue arguments and present case studies in enough depth to give students a real feeling for the nature of science in its modern context. This course also explicitly aims to connect science to the students’ lives and the decisions that they will have to make as citizens in a democratic society. The authors display the many connections between science and technology, using carefully chosen, beautifully explained examples. Students can thereby begin to understand the source of many of the changes that they have already experienced during their lifetime.

In closing, I would like to congratulate Helen Kreuzer and Adrienne Massey, as well as their publisher, ASM Press, for having the courage to produce a new kind of textbook. The inertia in academia stems in part from the fact that textbook publishers naturally concentrate on producing books that will be sold in large numbers. They therefore design their new books to match the prevailing large courses. But if all of the attention, energy, and talent are devoted to producing materials for these broad survey courses—a mile wide and an inch deep—there is no hope for a change in academia.

Rarely, a new kind of textbook like this one comes along that creates a “tipping point,” triggering a widespread change in how we teach a particular subject. I contend that we are way past the time for a tipping point in the way that we teach introductory biology to college students. Hopefully, this bold new textbook by Kreuzer and Massey will help pave the way for others, thereby catalyzing the spread of many new courses that can inspire students with the wonder and power of modern science.

Bruce Alberts, President
National Academy of Sciences
Washington, D.C.
March 2005
In the course of our professional lives, we have had many opportunities to talk about aspects of biotechnology with audiences from diverse walks of life: lawyers, farmers, businesspeople, school teachers, students, restaurant chefs, and the general public, to name a few. These people genuinely sought to understand issues that they had heard about in the media and brought a high level of interest, intelligence, and thoughtfulness to the task. Often, their motivation was to become an informed consumer of biotechnology. For example, did they want to purchase and eat genetically modified food, to grow genetically modified crops, to support stem cell research, to favor genetic testing? Sometimes they were merely curious, seeking answers to questions such as how does DNA fingerprinting work? What is cloning? What is recombinant DNA? Our task has been to explain the science and to provide sufficient information about the issues to enable people to formulate their own opinions about them.

This book is an outgrowth of these experiences. Our goal was to create a text that would give readers the foundation they needed for understanding the many inevitable advances in biotechnology that the coming years will bring and a context for making decisions about them as potential consumers. We wrote it for students and readers who have not necessarily chosen biology as their major field of study, although we believe it may offer unique perspectives to biology students as well. The book is self-contained. Readers do not need to have taken a college biology course prior to using it, although since its focus is quite different from that of a typical introductory biology course, the information presented will not be redundant to those who have. Because of its blending of science, consumer applications, regulatory information, and social issues, we believe that the book will be of interest to students and other readers from many disciplines.

We begin our text with a perspective on the interrelationship between science, technology, and society. These three realms have reciprocal effects on
one another. Science leads to technologies that provide new tools for doing science. At the same time, technologies are evaluated by society, often in the form of market forces, influencing the future direction of scientific research and technological development. The interweaving of these threads is particularly well illustrated in the case of biotechnology because the social debate about biotechnology products is so public and because the links between scientific and technological advances are so immediate. At the same time, the use by human beings of biology and biological organisms to make products and improve their environment is ancient, giving us a historical context in which to view modern biotechnologies. The perspective offered in the first part of the book infuses the discussion of biotechnology applications presented later on.

Before we discuss applications of biotechnology, we provide the scientific foundation necessary to understand them in the second part of the book, “The Foundational Science.” Modern biotechnology concerns the use and manipulation of cells and their subcomponents to make products and solve problems, and the biotechnological manipulation of whole organisms starts with the manipulation of individual cells. Thus, the first subpart of this part is a primer on cell biology titled “From Atoms to Organisms,” in which we look at the life processes of cells and how those processes translate to the organism level.

Cell biology alone, however, is not sufficient for understanding many of the applications of biotechnology, which can go beyond individual cells and organisms to affect the progeny of the manipulated organisms. Biotechnologies such as genetic testing look at parents and offspring in context. Agricultural and environmental biotechnologies evoke ecological and evolutionary questions concerning how the characteristics of one member of a community can affect its other members both immediately and over time. The second subpart of this part of the book, titled “From Organisms to Ecosystems,” introduces genetics, ecology, and evolution: the transmission of genes from one generation to the next, the interaction of genes and environment to produce traits, the interaction of organisms in communities and ecosystems, and finally, the evolutionary response of organisms and ecosystems to environmental changes.

Throughout “The Foundational Science,” we present examples of how the scientific knowledge being explained has been translated into technologies used to solve problems in medical and everyday settings. Also imbedded within this part are a few narratives of the history of particular scientific developments. We include these as examples of how science progresses and to illustrate the impact of society and social context on science.

Having laid this scientific foundation, we can now focus on biotechnology in the third major part of the book, “Biotechnology Applications and Issues.” Although the title of this part would probably cause most people to think of commercial applications, so far the most significant applications of biotechnology have been in the research laboratory, enabling scientists to gain new knowledge about the natural world at an ever-increasing pace. We begin with a look at this impact of technology upon science in a subpart titled “Research Applications,” which describes biotechnology techniques and shows how these methods are used to gain new scientific knowledge in scientific fields from archaeology to zoology. The two chapters in this subpart will also address “how do they do that” questions.

The second subpart of this part, “Commercial Applications,” looks at biotechnology products in society at large. We begin this subpart with a dis-
discussion of issues that arise when scientific advances are moved from the research laboratory into society, the concepts of risk and regulation. We present a framework and process for thinking about risk that readers can use to put new technologies and products into perspective in comparison with older ones.

In the following chapters, we look specifically at biotechnology in medicine, food, agriculture, and the environment. These chapters are not simply laundry lists of products and potential products. Rather, we show the scientific basis of a few specific products, as well as the complexity surrounding their introduction into the market. We also discuss how product introductions are regulated and the process that regulators go through in making decisions.

Biotechnology applications can trigger ethical dilemmas in which there are no easy or perfect answers. Our goal in these chapters is not to provide readers with an opinion but rather to provide them with tools for conducting their own informed, critical evaluations. To that end, we attempt to provide the essential information required for understanding both the science and the issues involved in each chapter’s example applications. As we discuss the issues raised by each application, we use the framework presented earlier to analyze them. We hope that these thorough examples will illustrate what kinds of questions need to be asked and how the answers can be put into perspective as the readers think about any new technology.

In the past, technologies were usually adopted without consideration of their potential impact on society and the environment. In recent decades, the impact of technology on society and the environment has become an issue of great concern to many, and biotechnology as a whole is one of the first broad categories of technology to receive public scrutiny before its widespread introduction. Societal decisions about which technologies to adopt may have profound implications for humanity in terms both of what technological options are available to us today and of the impact that our decisions have on the future direction of scientific and technological advances.

Readers, the decisions you make about biotechnology will contribute to our societal decisions as a whole and thus to the future of science, technology, and society. We hope that this book will empower you to evaluate issues independently and critically.

Helen Kreuzer and Adrianne Massey
April 2005
Writing this book was a long and difficult task. Many people supported and encouraged us in many different ways during the process, and it is now our pleasure to thank those who helped this book come to be.

First, we thank Jeff Holtmeier, the director of ASM Press. Jeff gently prodded us to write a college-level textbook, based on our first book on biotechnology, which was also published by ASM Press. Early in the process we realized that we wanted to write a textbook that bears little resemblance to our other book, and without hesitation Jeff allowed us to do this. As Bruce Alberts notes in the foreword, publishing a textbook that differs significantly from existing textbooks that are geared to familiar, well-established markets requires courage. Jeff, we thank you for your courage and for your faith in us.

We also thank the ASM Press staff, particularly Susan Birch, Laura Ledbetter, and Jennifer Adelman. In addition to providing highly professional assistance in every way, they also offered emotional support and enthusiasm for the project. We are fortunate to work with such a thoughtful and generous group of people. Thanks also to Elizabeth McGillicuddy, who copyedited the book; Susan Schmidler, who did the cover and interior design; and Patrick Lane, who rendered the art.

Many members of the scientific community improved the content and visual quality of the book. A number of anonymous reviewers read the first draft of the entire book, and other scientists, including Harold Coble, Fred Gould, Karyn Hede, and Ron Kuhr, read selected chapters. Reviewing is a time-consuming task, and we are grateful for your time and effort. Your conscientious reviews led to numerous improvements in the manuscript. Other scientists allowed free use of their photographs. Some exceeded our requests and found additional images that they thought might be useful. We thank all of you for your generosity, especially Steven Baskauf, Carol and Dennis Gonzales, Nasser Rusan, Kent Schweigerle, Hans and Petra Sommer, George Seidel, and Michael Vernon.
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A special note of thanks goes to Bruce Alberts, president of the National Academy of Sciences, for his willingness to write the foreword. We are honored that you found the time to read the book and gratified that you saw so clearly the heart of our intentions in writing it.

Finally, we could not have finished this project without the moral support and encouragement of our friends and loved ones. You know who you are. Thanks, y’all.

Helen Kreuzer and Adrianne Massey
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