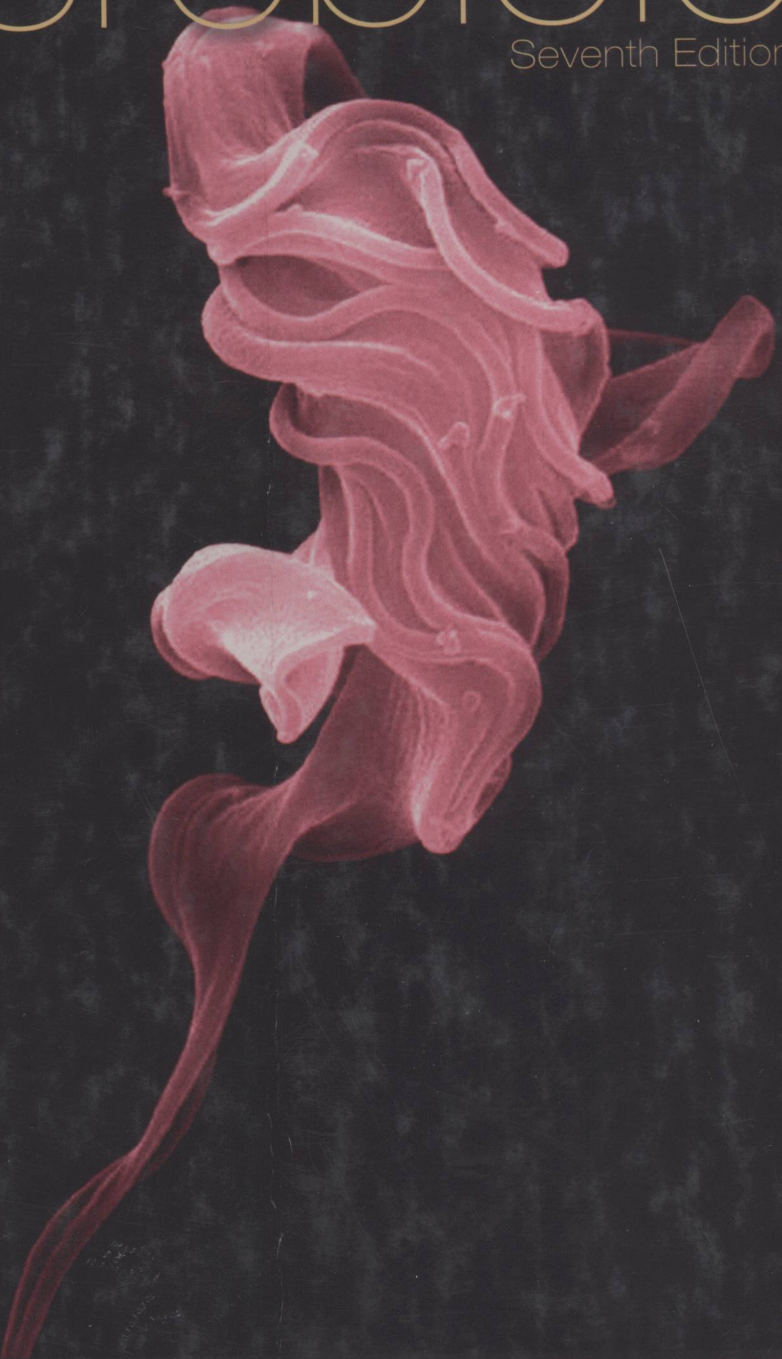
Foundations in

Microbiology

Seventh Edition



Kathleen Park Talaro

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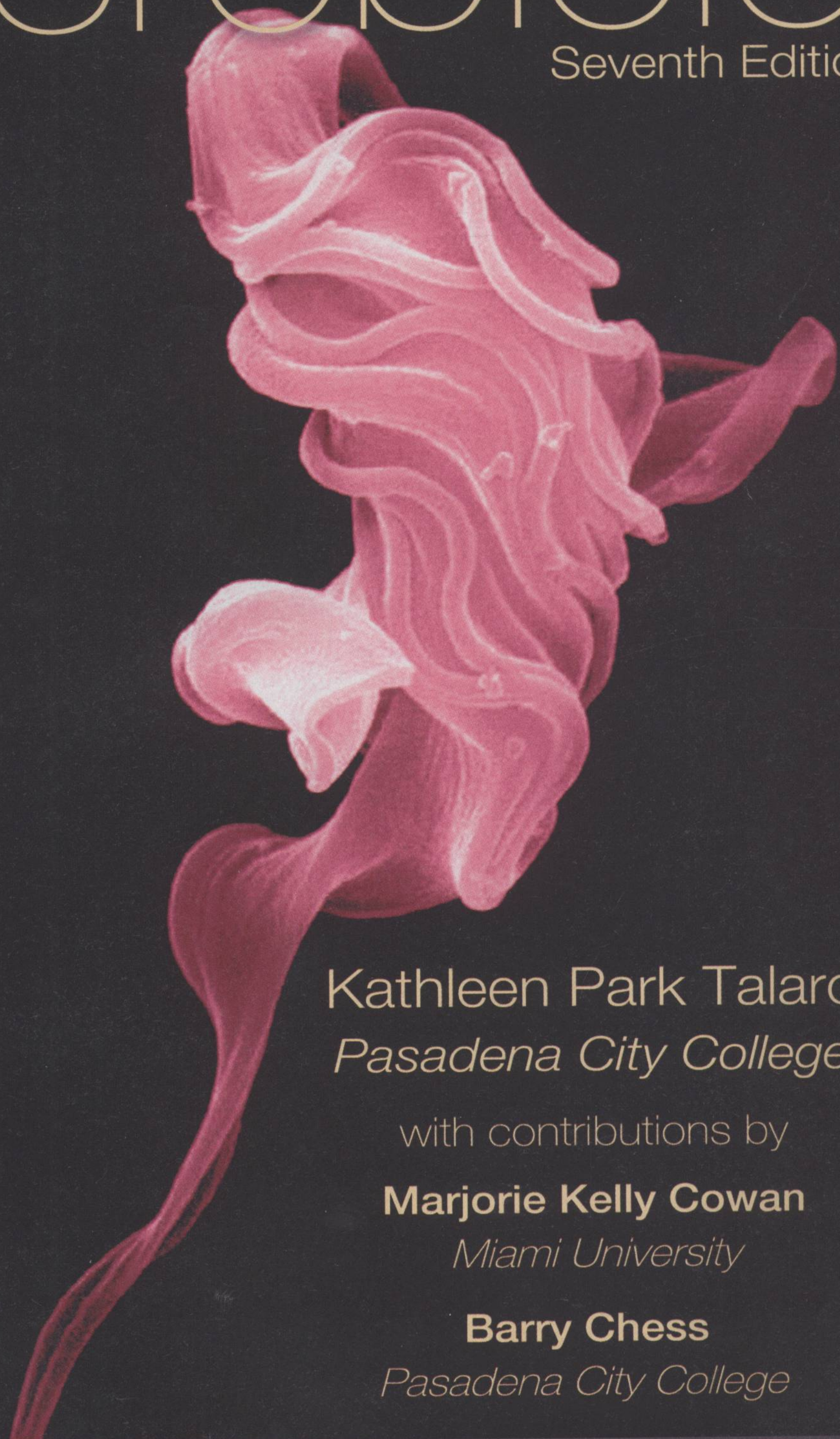

Kathleen Park Talaro
Pasadena City College

with contributions by

Marjorie Kelly Cowan
Miami University

Barry Chess
Pasadena City College

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FOUNDATIONS IN MICROBIOLOGY, SEVENTH EDITION

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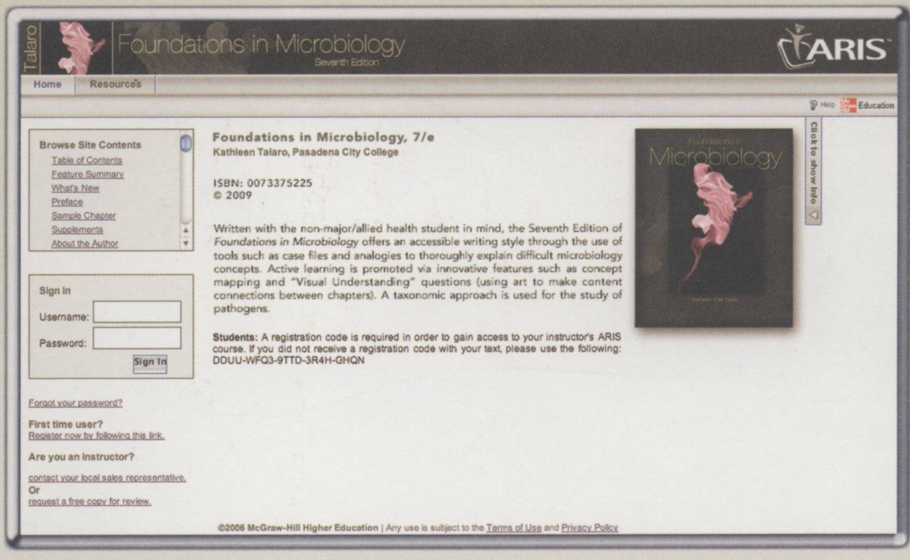

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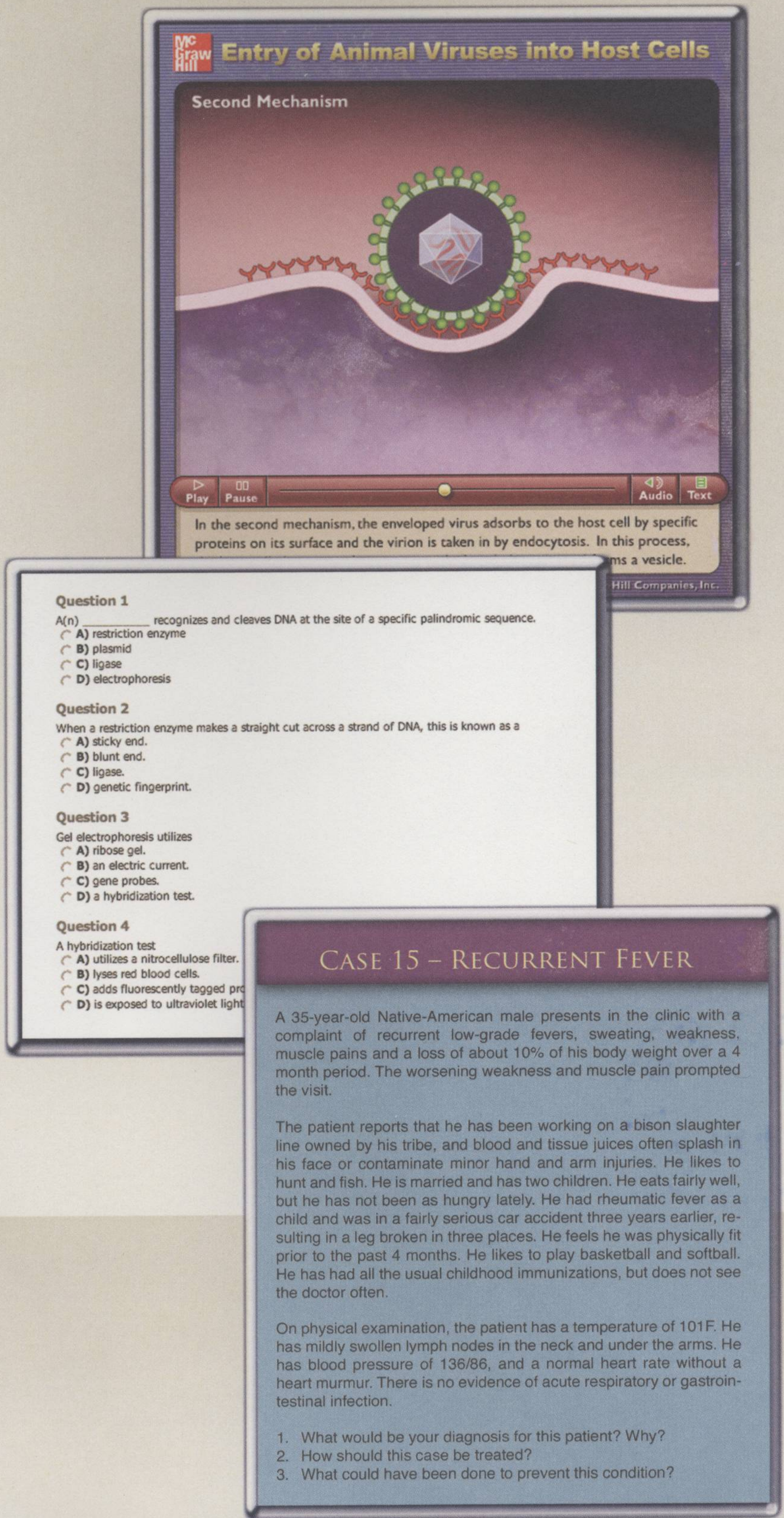
Foundations in Microbiology



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Notifiable Diseases—Summary of Reported Cases, United States, 1996–2007

Disease/Year	1996	1997	1998	1999	2000	2001
AIDS	66,885*	58,492	46,521	44,823	36,091	42,092
Botulism, total (including wound and unsp.)	119	132	116	110	100	156
Foodborne	25	26	24	23	18	39
Infant	80	91	88	82	75	97
Brucellosis	112	98	79	49	63	136
Chancroid	386§	243	189	146	161	38
Chlamydia¶	498,884§	526,671	604,420	658,026	642,588	781,614
Cholera	4	6	17	3	2	6
Coccidioidomycosis	–	–	–	–	–	–
Cryptosporoidosis	–	–	3,793	2,379	3,128	3,496
Escherichia coli O157:H7	2,741	2,555	3,161	4,513	4,410	3,291
Giardiasis	–	–	–	–	–	–
Gonorrhea	325,883§	324,907	355,642	360,637	335,098	360,906
Haemophilus influenzae, invasive	1,170	1,162	1,194	1,309	1,212	1,597
Hansen disease (leprosy)	112	122	108	98	63	79
Hepatitis A	31,032	30,021	23,229	17,047	12,275	10,609
Hepatitis B	10,637	10,416	10,258	7,694	6,646	7,848
Hepatitis, C/non-A, non-B††	3,716	3,816	3,518	3,328	2,895	3,976
Legionellosis	1,198	1,163	1,355	1,108	969	1,171
Listeriosis	–	–	–	–	–	613
Lyme disease	16,455	12,801	16,801	16,273	13,309	17,029
Malaria	1,800	2,001	1,611	1,666	1,288	1,544
Measles (rubeola)	508	138	100	87	81	116
Meningococcal disease	3,437	3,308	2,725	2,501	2,035	2,333
Mumps	751	603	666	391	330	266
Pertussis (whooping cough)	7,796	6,564	7,405	7,298	6,755	7,580
Plague	5	4	9	8	6	2
Poliomyelitis, paralytic§§	5	3	1	–	11	0
Psittacosis	42	33	47	16	22	25
Rabies, animal	6,982	8,105	7,259	6,730	5,834	7,150
Rabies, human	3	2	1	–	–	1
Rocky Mountain spotted fever	831	409	365	567	424	697
Rubella (German measles)	238	181	364	271	152	23
Salmonellosis, excluding typhoid fever	45,471	41,901	43,694	40,596	36,762	41,257
Shigellosis	25,978	23,117	23,626	17,521	20,721	20,221
Streptococcus, Group A**	–	–	–	2,382	3,144	3,755
Streptococcus pneumoniae, total**	–	–	–	4,618	4,533	3,445
Syphilis, primary and secondary	11,387§	8,550	6,993	6,683	5,894	6,095
Total, all stages	52,976§	46,540	37,977	35,062	33,280	32,284
Tetanus	36	50	41	33	20	37
Toxic-shock syndrome	145	157	138	117	124	128
Trichinellosis	11	13	19	11	15	22
Tuberculosis	21,337¶¶	19,851	18,361	16,607	12,942	15,492
Typhoid fever	396	365	375	299	315	368
Varicella (chickenpox)***	83,511	98,727	82,455	78,250	72,385	22,536
West Nile Fever	–	–	–	19	64	66

Source: Data from Morbidity and Mortality Weekly Report.

*The total number of acquired immunodeficiency syndrome (AIDS) cases includes all cases reported to the Division of HIV/AIDS Prevention, Surveillance, and Epidemiology, National Center for HIV, STD, and TB Prevention (NCHSTP) through December, 2007.

¶Chlamydia refers to genital infection caused by C. trachomatis.

**Not previously nationally notifiable.

2002	2003	2004	2005	2006	2007	Year/Disease
38,878	41,832	43,320	36,552	39,002	40,253	AIDS
179	119	124	122	165	118	Botulism, total
14	18	16	15	20	17	Foodborne
55	70	87	80	97	79	Infant
84	90	115	107	121	118	Brucellosis
67	44	30	25	33	33	Chancroid
780,541	834,640	906,387	929,462	1,030,911	1,025,208	Chlamydia¶
5	1	5	6	9	7	Cholera
4,969	4,184	6,056	5,145	8,916	7,807	Coccidioidomycosis
3,016	3,406	3,372	7,595	5,636	10,243	Cryptosporoidosis
3,574	2,979	2,461	2,544	4,432	4,397	*Escherichia coli* O157:H7
21,206	19,195	18,498	18,126	18,953	17,123	Giardiasis
326,017	318,411	330,132	314,370	358,366	332,511	Gonorrhea
1,479	1,707	2,085	2,028	2,436	2,231	*Haemophilus influenzae*
77	72	105	89	66	60	Hansen disease (leprosy)
8,323	7,254	5,970	4,284	3,579	2,708	Hepatitis A
6,988	6,799	6,741	5,497	4,713	3,936	Hepatitis B
3,585	1,802	708	869	802	775	Hepatitis, C/non-A, non-B††
1,203	2,014	2,125	2,050	2,796	2,371	Legionellosis
665	696	753	906	975	701	Listeriosis
18,181	18,387	19,859	21,304	19,931	20,599	Lyme disease
1,245	1,176	1,468	1,252	1,474	1,085	Malaria
37	42	37	62	55	30	Measles (rubeola)
1,595	1,588	1,242	1,111	1,194	974	Meningococcal disease
238	197	258	265	6,584	715	Mumps
8,296	8,483	25,827	21,003	15,632	9,739	Pertussis (whooping cough)
1	1	3	7	17	6	Plague
0	–	–	1	–	–	Poliomyelitis, paralytic§§
18	15	12	21	21	11	Psittacosis
6,875	5,545	6,346	5,277	5,534	5,316	Rabies, animal
2	3	7	2	3	–	Rabies, human
975	973	1,738	1,843	2,288	2,706	Rocky Mountain spotted fever
14	7	10	16	11	11	Rubella (German measles)
40,518	40,913	42,207	41,820	45,808	43,749	Salmonellosis
20,422	21,641	14,631	13,749	15,503	17,193	Shigellosis
3,956	5,155	4,411	4,263	5,407	4,743	Streptococcus, Group A**
2,538	2,110	3,420	3,296	4,152	3,999	Streptococcus pneumoniae
6,378	6,818	7,980	8,020	9,756	10,417	Syphilis, primary and secondary
32,919	34,289	33,422	33,288	36,935	39,426	Total, all stages
22	14	34	20	41	20	Tetanus
111	128	98	96	101	79	Toxic-shock syndrome
13	6	6	17	15	6	Trichinellosis
12,120	11,619	14,157	11,547	13,779	10,363	Tuberculosis
266	313	322	324	353	319	Typhoid fever
12,261	13,474	32,868	26,532	48,445	34,507	Varicella (chickenpox)***
4,156	1,933	2,539	3,000	2,774	2,334	West Nile Fever

††Anti-HCV antibody test was available as of May, 1990.
§§Numbers may not reflect changes based on retrospective case evaluations or late reports (see MMWR 1986;35:180–2).
¶¶Cases were updated through the Division of Tuberculosis Elimination, NCHSTP, as of December, 2007.
***Varicella was taken off the nationally notifiable disease list in 1991. Many states continue to report these cases to CDC.

Foundations in

Microbiology

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This book is dedicated to the devoted public health workers who introduce medical advances and treatments enjoyed by the industrialized world to all humans.

About the Author

Kathleen Park Talaro is a microbiologist and educator at Pasadena City College. A native of Idaho, she began her college education at Idaho State University in Pocatello. There she found a comfortable niche that fit her particular abilities and interests, spending part of her free time as a scientific illustrator and part as a teaching assistant. After graduation, she started graduate studies at Arizona State University, with an emphasis in the physiological ecology of desert organisms. Additional graduate work was spent participating in research expeditions to British Columbia with the Scripps Institution of Oceanography. Kathy continued to expand her background, first finishing a master's degree at Occidental College and later taking additional specialized coursework in microbiology at the California Institute of Technology and California State University.

Kathy has been teaching medical microbiology and majors' biology courses for over 30 years. She has been involved in developing curricula and new laboratory exercises in microbiology, and she has served as an advisor to the school's medical professions club. Throughout her career Kathy has nurtured a passion for the microbial world and a desire to convey the importance of that world to beginning students. She finds tremendous gratification in watching her students emerge from a budding awareness of microorganisms into a deeper understanding of their significance in natural phenomena.

Kathy is a member of the American Society for Microbiology. She keeps active in self-study and research and continues to attend workshops and conferences to remain current in her field. She also has contributed to science outreach programs by bringing minicourses in microbiology to students from kindergarten to high school.

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Preface

There are a Million Stories in the Microbe Jungle

One measure of a subject's impact on the everyday lives of people is how often it is mentioned in the popular press. By this measure, it seems that microbiology has really come of age. Consider some of the "buzz words" creeping into the tabloids of late: MRSA, *C. diff,* killer cold viruses, bacterial cultures in yogurt, the bird flu, biofilms, cancer vaccines, designer bacteria, and personal gene chips, just to name a few. If a quick glance at some of the latest headlines has inspired you to enhance your understanding of these topics and hundreds of others, this book is a good place to start. Inquiring minds want to know!

It is true that a substantial portion of discoveries in science right now are emerging from the realm of microbiology. In fact, microbiology has entered a new "golden age" that is generating information at a rapid rate. Much of it relates to genetics and infectious disease, but a lot of it comes from discoveries about the activities of microbes in the natural environment. Because microbes are so small, widespread, and largely nonvisible, there will always be some places that have not yet been thoroughly explored where microbes are living and doing their thing. As greater attention is focused on the rainforest, oceans, bedrock, or even the human body, and advanced tools are used in probing these environments, our perspectives on the microbial world are expanded to new and greater dimensions.

What Sets This Book Apart?

Engaging, Straightforward Presentation

The primary aims of this book have been 1) to present guiding principles in a straightforward and readable style that is neither too wordy nor too simplistic, and 2) to explain complex topics clearly and vividly. I have continued to organize the content in a logical order that builds foundations from early chapters to later ones. The text is backed up with numerous tables, flow charts, and other support features. Having many different levels and cognitive styles for students increases retention, understanding, and success in learning.

A Vivid, Self-Explanatory Art Program

My experiences as a teacher, microbiologist, and illustrator have helped me to visualize abstract concepts and transform them into scientifically accurate and attractive illustrations. Vivid, multidimensional art pieces complement self-contained, concept-specific narrative; it is not necessary to read page content surrounding the artwork to grasp concepts being illustrated. Development of the art in this manner further enhances learning and helps to build a solid foundation of understanding.

This seventh edition has given us the opportunity to hone and improve the art even more. In addition to many new and revised figures, the Process Figures are now clearly defined as such and include colored steps that correlate the art to step-by-step explanations. Art has also been pulled into special Visual Understanding study tools to help students make connections between concepts presented in different chapters.

Early Survey of Microbial Groups and Taxonomy

A unique feature of this text's format is the early survey of microbial groups and their taxonomy (chapters 4, 5, and 6). By using general and specific names for microbes from the very beginning students develop a working background that eases them into the later chapters. I have always felt that microbes are the "stars of the show," and that students have a far greater appreciation for later topics of nutrition, metabolism, genetics, and microbial control if they recognize the main characters—bacteria, viruses, and eukaryotic microorganisms—and already know significant facts about them.

Relevant, Up-to-Date Disease Chapters

Unique among microbiology textbooks, chapter 17, "Diagnosing Infections" brings together in one place the current methods used to diagnose infectious diseases. The chapter starts with collecting samples from the patient and details the biochemical, serological, and molecular methods used to identify causative microbes.

The pathogen chapters (18–27) are organized by microbial group (taxonomy) because many users feel this orientation has greater coherence and concentrates more on infectious agents than anatomy and physiology. All characteristics of the microorganism and its diseases may be presented simultaneously. This system will not only be familiar to students from their laboratory work, but it helps them maintain a more distinct separation between microbial groups and their diseases.

Pedagogy Designed for the Way Students Learn

Foundations in Microbiology makes learning easier through its carefully crafted pedagogical system. Following is a closer look at some of the key features that our students have taught us are useful.

- All chapters open with **Case File** mysteries to solve. These real-world case studies help students appreciate and understand how microbiology impacts our lives on a daily basis. The solutions appear later in the chapter, after the necessary elements have been presented.
- A **Chapter Overview** at the beginning of each chapter provides students with a framework from which to begin their study of a chapter.
- In chapters 1–16 and 26–27, major sections of the chapter are followed by **Checkpoints** that repeat and summarize the concepts of that section. In the disease chapters (18–25) the Checkpoints are in the form of the **disease tables** described earlier.
- **Insight** readings allow students to delve into material that goes beyond the chapter concepts and consider the application of those concepts. The Insight readings are divided into four categories: Discovery, Historical, Medical, and Microbiology.
- All chapters end with a **summary,** and a comprehensive array of **end-of-chapter questions** that are not just multiple-choice, but also questions that require writing and critical thinking about topics in the chapter. Considering and answering these questions, and even better, discussing them with fellow students, can make the difference between temporary (or limited) learning and true knowledge of the concepts.
- **Visual Understanding** questions incorporate art to help students connect important concepts from chapter to chapter.
- **Concept Mapping** assists in retention as well as contextual organization.

What's New with This Edition?

Since the science of microbiology is constantly changing and advancing, the textbook must also change and advance to stay current and continue to be useful and relevant. With each edition we will continue to create a current, well-organized, and scientifically accurate book, and provide an active learning opportunity for students.

I have been fortunate to have my colleague Barry Chess, of Pasadena City College and Kelly Cowan of Miami University of Ohio continue in their capacity as significant contributors. They have helped write new sections and Insight boxes, suggested ideas for new and improved figures, edited and updated text, and improved chapter overviews, summaries, and questions. Kelly is instrumental in developing case files and both she and Barry have constructed some of the active learning features in the end-of-chapter sections. Many additions and innovations were done at the request of reviewers and users, whose input continues to be invaluable.

Active Learning Experience

- New **Visual Understanding** Questions supply a photo or a graphic that students have already seen, along with a thought-provoking question. Many of these questions use images from previous chapters and pose queries that require students to combine knowledge from the current chapter with the material they already have learned from previous chapters.
- **Concept Mapping** Exercises ask students to organize information in more meaningful forms than just simple lists. Three different types of concepts maps are used throughout the text. A new Appendix introduces students to concept mapping.
- **Process figures** now have matching numbered steps for easy to see explanations of complex processes.
- **Special icons** correlate over 100 total animations to figures in the text. When students see the icon next to a figure legend, they'll know to check out the accompanying website for a helpful animation to actively illustrate the concept. Additional animations with quizzes are also on the website.
- **Study on the Fly Content**—now students have access to downloadable chapter summaries and animations so they can study anywhere, anytime.

Up-To-Date Content

- The single chapter (26) that covered both environmental and applied microbiology has been split into two separate chapters (26 and 27). Chapter 26 now focuses on ecological principles and the interactions of microbes with the environment, and chapter 27 examines the use of microbes in industry and biotechnology.
- Chapter 9 introduces some of the newer concepts in genetics that have emerged from genome analysis studies. The most significant discovery involves the role of special types of RNA in regulating genes and their expression.
- Applications of regulatory RNA in biotechnology and engineering of transgenic animals have been added to chapter 10.
- To consolidate and streamline the section on chemical control of microorganisms in chapter 11, we have compiled several new tables that summarize and illustrate common applications.
- Now that probiotics have become more widely used and understood, their coverage has been updated and enlarged in chapters 12 and 13.
- Throughout the book there is much more emphasis on polymicrobial infections and biofilms.
- In chapter 17 we have included a more detailed table of specimen collection and increased coverage of PCR technology in diagnosis of infections.
- After much consideration and a number of requests, the spelling of prokaryote and eukaryote and related terms has been revised to the form with a "k" instead of a "c" throughout all chapters.
- The section on photosynthesis that was originally covered in chapter 26 in the section on environmental microbiology has been moved into chapter 8 along with other metabolic and bioenergy concepts.
- Overall, we have added a number of new case studies (called case files), photographs, figures, notes, and boxes.

For a complete listing of chapter-by-chapter changes, please visit the text's ARIS website.

Acknowledgments

My involvement in this textbook goes back over twenty-five years. Throughout this active and fulfilling time, I have had the good fortune to be supported by the best publishing staff in the business. I have collaborated with dozens of top-notch editors, researchers, production staff, illustrators, and designers. It has been clear to me that, from the very beginning, the textbook teams have shared my love for the project, and have brought their own expertise and commitment to maintaining a high quality product. This seventh edition has carried on this tradition.

Several key people made significant contributions to this edition. First, I wish to commend my senior developmental editor, Kathleen Loewenberg, for her enthusiastic support and suggestions. Her experience and thoughtful comments have been a real asset, and she is an awesome "figure wrangler," bringing a fresh perspective and keen eye to the art program. I greatly appreciate the contributions of the editorial coordinator Ashley Zellmer, who cheerfully takes on the sometimes tedious work of preparing and processing manuscript and keeping track of the numerous revisions in text and figures. I am indebted to senior sponsoring editor Jim Connely, who keeps us laughing when we need it, and whose advice "If you put something in, you'll need to take something out" has been a useful guide for many a decision about content, length, and new features. I have received much helpful input from publisher Michelle Watnick, another experienced and well-informed member of the book team. I admire her ability to grasp "the big picture" of book creation. Senior project manager, Jayne Klein, has done a first-rate job of overseeing the minutiae of production. I especially appreciate her flexibility in considering changes I feel strongly about and the detailed efforts from her team. They can actually find an italicized period in a footnote—just to give you an idea of the level of scrutiny this book receives! Other gifted and dedicated personnel that I would like to thank include the photo research coordinator, Carrie Burger; photo researcher, Danny Meldung at Photo Affairs; Jeanne Patterson, the copy editor; and the book designer, Michelle Whitaker. No list of acknowledgments would be complete without mentioning senior marketing manager Tami Petsche, who has to wear several hats, including having to take a crash course in microbiology with each new edition.

Just like the living world, this textbook is evolving. A major force behind this trend relates to the constant discoveries happening in microbiology that must be addressed and updated. But another undeniable force for change is the feedback that we get from users and reviewers. I want to make special mention of Dr. Wan H. Ooi and his colleagues Pramilla Sen, Marsha Turell, and Donna Wiersema of *Houston Community College,* and Dr. Reza Marvdashti of *San Jacinto College* for their insights in several chapters. Other reviewers who have provided substantive comments on content and accuracy are Melissa Rubin, Kelly Gridley, Dana Nayduch, and Davis Prichett. Our team of reviewers for the seventh edition has contributed valuable ideas for new figures, boxes, and coverage. They have helped to fine tune language, terminology, headings, Checkpoints, and pedagogy. These reviewers teach the subject and are interpreters of it to beginning students. It is obvious that they share a passion for knowledge and wish to impart the excitement of microbiology to their classes. We commend you for your dedication.

For the users of this book, we hope that you enjoy our journey into the world of microbiology and nurture a long-term interest in this fascinating science. Though many elaborate steps are taken to weed out errors, the very nature of an evolving book means that "mutations" may slip in without notice. If you detect any missing or misspelled words, missing labels, mistakes in content, or other errata, do not hesitate to contact the publisher, representative, or the author (**ktalaro@aol.com**).

Reviewers

Arden Aspedon, *Southwestern Oklahoma State University*
Dennis A. Bazylinski, *University of Nevada, Las Vegas*
Donald P. Breakwell, *Brigham Young University*
Hoi Huen Chan, *Hong Kong Community College,* The Hong Kong Polytechnic University
James K. Collins, *University of Arizona*
Don C. Dailey, *Austin Peay State University*
Cheryl G. Davis, *Tuskegee University*
Susan A. Gibson, *South Dakota State University*
Kelly Gridley, *Santa Fe Community College*
Janelle Hare, *Morehead State University*
Jennifer Y. Harper, *Coastal Georgia Community College*
Brenda B. Honeycutt, *Armstrong Atlantic State University*
Robert Iwan, *Inver Hills Community College*
Harry W. Kestler, *Lorain County Community College*
Si Wouk Kim, *Chosun University*
Robert Klein, *Owens State Community College*
Peter S. Kourtev, *Central Michigan University*
Susan Forrest, *Butler Community College*
Julie C. Matheny, *Owens State Community College*
Dana Nayduch, *Georgia Southern University*
M. Theresa Pavlovitch, *Pasadena City College*
Jack Pennington, *Forest Park College*
Mary Lou Percy, *Navarro College*
Davis W. Pritchett, *University of Louisiana at Monroe*
Wesley Rakestraw, *Wallace State Community College*
Michael W. Reeves, *Georgia Perimeter College*
Melissa Rubin, *Kent State University*
Michael W. Ruhl, *Vernon College*
Gail A. Stewart, *Camden County College*
John R. Stevenson, *Miami University*
Coe Vander Zee, *Austin Community College*

Symposium Attendees

Chad Brooks, *Austin Peay State University*
Barry Chess, *Pasadena City College*
Erin Christensen, *Middlesex County College*
John Dahl, *Washington State University*
Alison Davis, *East Los Angeles College*
Susan Finazzo, *Broward Community College*
Clifton Franklund, *Ferris State University*
Edwin Gines-Candalaria, *Miami Dade*
Judy Haber, *California State University Fresno*
Eunice Kamunge, *Essex County College*
Amine Kidane, *Columbus State Community College*
Tracey Mills, *Ivy Tech Community College*
Madhura Pradhan, *Ohio State University*
Louise Thai, *University of Missouri*
Delon Washo-Krupps, *Arizona State University*
Samia Williams, *Santa Fe Community College*

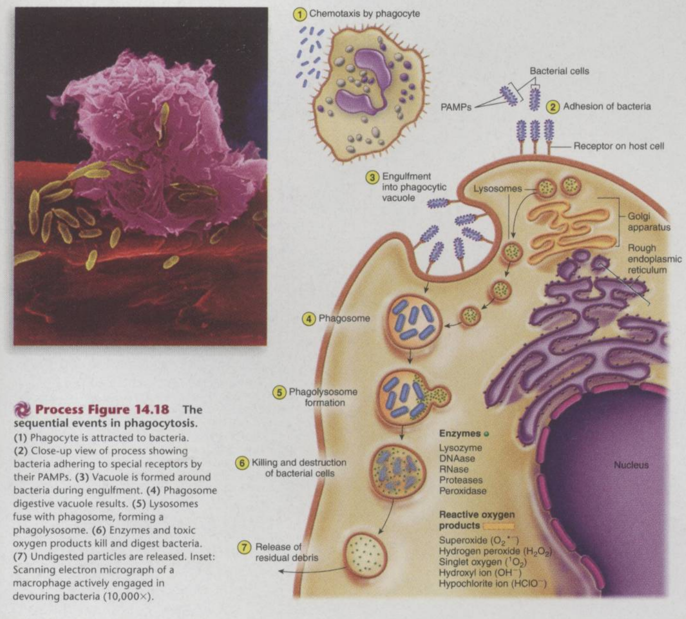
Instructional Art Program Clarifies Concepts

Foundations in Microbiology provides powerful artwork that paints conceptual pictures for students. The art combines vivid colors, multi-dimensionality, and self-contained narrative to help students study the challenging concepts of microbiology from a visual perspective—a proven study technique. Art is often coupled with photographs to enhance visualization and comprehension.

New! Text Art Correlated to Animations

This symbol indicates to readers that the material presented in the text is also accompanied by an animation on the book's website. Students may view the animation on their computers or download it to their portable player and watch it on the fly!

Figure 11.4 Modes of action affecting protein function.
(a) The native (functional) state is maintained by bonds that create active sites to fit the substrate. Some agents denature the protein by breaking all or some secondary and tertiary bonds. Results are **(b)** complete unfolding or **(c)** random bonding and incorrect folding. **(d)** Some agents react with functional groups on the active site and interfere with bonding.



Process Figure 14.18 The sequential events in phagocytosis.
(1) Phagocyte is attracted to bacteria. **(2)** Close-up view of process showing bacteria adhering to special receptors by their PAMPs. **(3)** Vacuole is formed around bacteria during engulfment. **(4)** Phagosome digestive vacuole results. **(5)** Lysosomes fuse with phagosome, forming a phagolysosome. **(6)** Enzymes and toxic oxygen products kill and digest bacteria. **(7)** Undigested particles are released. Inset: Scanning electron micrograph of a macrophage actively engaged in devouring bacteria (10,000×).

Process Figures

Foundations in Microbiology illustrates many difficult microbiological concepts in steps that students find easy to follow. Each step is clearly marked with a yellow, numbered circle and correlated to accompanying narrative to benefit all types of learners. Process Figures are now identified next to the figure number. The accompanying legend provides additional explanation.

Chapter 9 Microbial Genetics

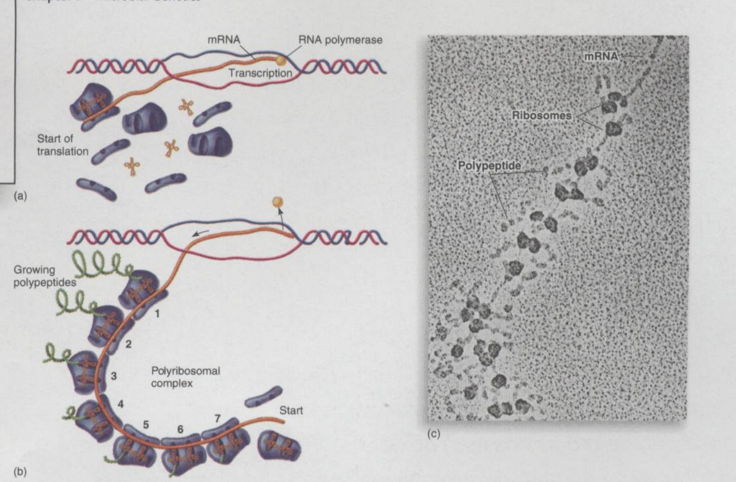


Figure 9.16 Speeding up the protein assembly line in bacteria.
(a) The mRNA transcript encounters ribosomal parts immediately as it leaves the DNA. **(b)** The ribosomal factories assemble along the mRNA in a chain, each ribosome reading the message and translating it into protein. Many products will thus be well along the synthetic pathway before transcription has even terminated. **(c)** Photomicrograph of a polyribosomal complex in action. Note that the protein "tails" vary in length depending on the stage of translation (30,000×).

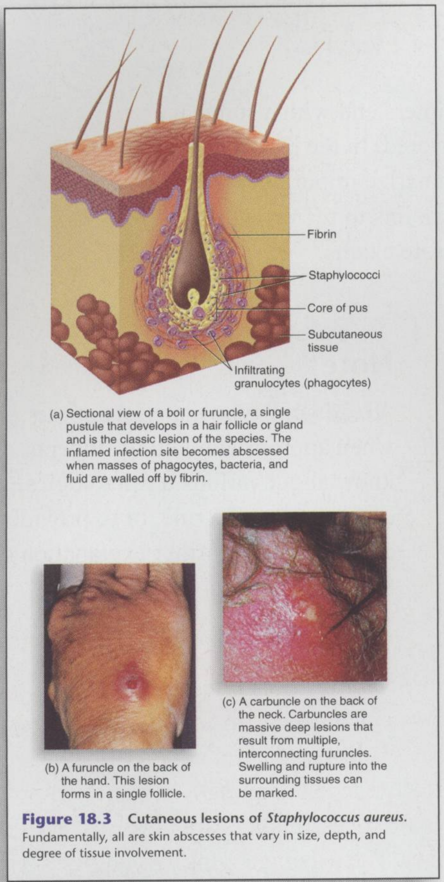
Combination Figures

Line drawings combined with photos give students two perspectives: the realism of photos and the explanatory clarity of illustrations. The authors chose this method of presentation to help students comprehend difficult concepts.

GUIDED TOUR

Clinical Photos

Color photos of individuals affected by disease provide students with a real-life, clinical view of how microorganisms manifest themselves in the human body.



(a) Sectional view of a boil or furuncle, a single pustule that develops in a hair follicle or gland and is the classic lesion of the species. The inflamed infection site becomes abscessed when masses of phagocytes, bacteria, and fluid are walled off by fibrin.

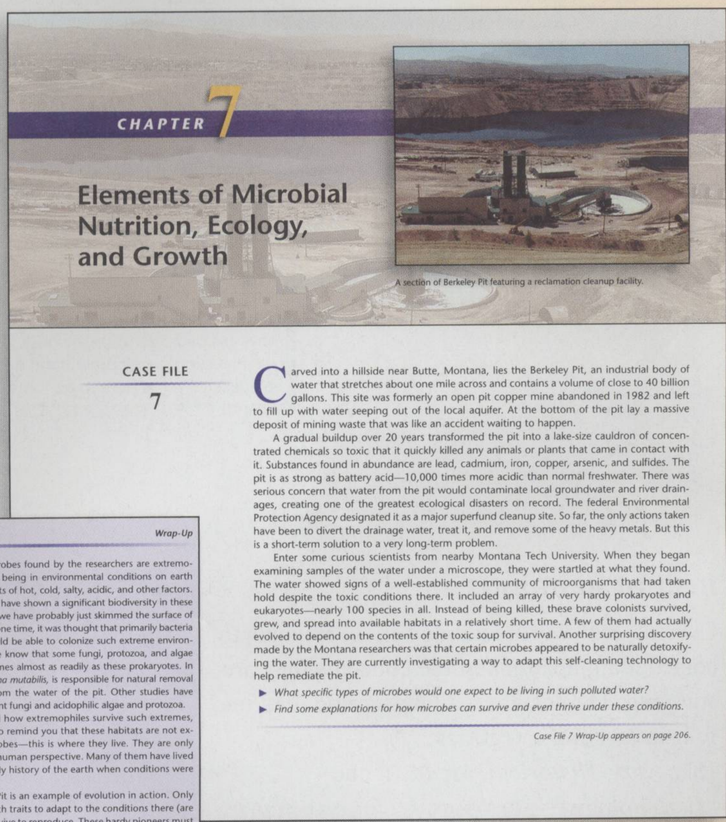
(b) A furuncle on the back of the hand. This lesion forms in a single follicle.

(c) A carbuncle on the back of the neck. Carbuncles are massive deep lesions that result from multiple, interconnecting furuncles. Swelling and rupture into the surrounding tissues can be marked.

Figure 18.3 **Cutaneous lesions of *Staphylococcus aureus*.** Fundamentally, all are skin abscesses that vary in size, depth, and degree of tissue involvement.

Overview Figures

Many challenging concepts of microbiology consist of numerous interrelated activities. *Foundations in Microbiology* visually summarizes these concepts to help students piece the activities together for a complete, conceptual picture.


CHAPTER 7

Elements of Microbial Nutrition, Ecology, and Growth

A section of Berkeley Pit featuring a reclamation cleanup facility.

CASE FILE 7

Carved into a hillside near Butte, Montana, lies the Berkeley Pit, an industrial body of water that stretches about one mile across and contains a volume of close to 40 billion gallons. This site was formerly an open pit copper mine abandoned in 1982 and left to fill up with water seeping out of the local aquifer. At the bottom of the pit lay a massive deposit of mining waste that was like an accident waiting to happen.

A gradual buildup over 20 years transformed the pit into a lake-size cauldron of concentrated chemicals so toxic that it quickly killed any animals or plants that came in contact with it. Substances found in abundance are lead, cadmium, iron, copper, arsenic, and sulfides. The pit is as strong as battery acid—10,000 times more acidic than normal freshwater. There was serious concern that water from the pit would contaminate local groundwater and river drainages, creating one of the greatest ecological disasters on record. The federal Environmental Protection Agency designated it as a major superfund cleanup site. So far, the only actions taken have been to divert the drainage water, treat it, and remove some of the heavy metals. But this is a short-term solution to a very long-term problem.

Enter some curious scientists from nearby Montana Tech University. When they began examining samples of the water under a microscope, they were startled at what they found. The water showed signs of a well-established community of microorganisms that had taken hold despite the toxic conditions there. It included an array of very hardy prokaryotes and eukaryotes—nearly 100 species in all. Instead of being killed, these brave colonists survived, grew, and spread into available habitats in a relatively short time. A few of them had actually evolved to depend on the contents of the toxic soup for survival. Another surprising discovery made by the Montana researchers was that certain microbes appeared to be naturally detoxifying the water. They are currently investigating a way to adapt this self-cleaning technology to help remediate the pit.

- *What specific types of microbes would one expect to be living in such polluted water?*
- *Find some explanations for how microbes can survive and even thrive under these conditions.*

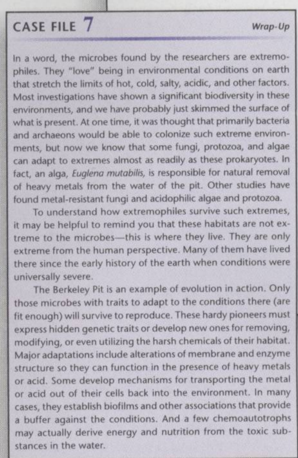
Case File 7 Wrap-Up appears on page 206.

Pedagogical Aids Promote Active Learning

Foundations in Microbiology organizes every chapter with consistent pedagogical tools. These visual and content-related elements enable students to develop a consistent learning strategy and learn in more than one way, creating a higher retention rate. Let's look at the pedagogical features within each chapter:

Case Files

All chapters open with a real-world case file to help students appreciate and understand how microbiology impacts lives on a daily basis. The solution to the case file appears later in the chapter, near where relevant material is being discussed. These relevant "stories" pique interest and help students understand just how important it is to learn and retain the chapter's content.


CASE FILE 7 *Wrap-Up*

In a word, the microbes found by the researchers are extremophiles. They "love" being in environmental conditions on earth that stretch the limits of hot, cold, salty, acidic, and other factors. Most investigations have shown a significant biodiversity in these environments, and we have probably just skimmed the surface of what is present. At one time, it was thought that primarily bacteria and archaeons would be able to colonize such extreme environments, but now we know that some fungi, protozoa, and algae can adapt to extremes almost as readily as these prokaryotes. In fact, an alga, *Euglena mutabilis,* is responsible for natural removal of heavy metals from the water of the pit. Other studies have found metal-resistant fungi and acidophilic algae and protozoa.

To understand how extremophiles survive such extremes, it may be helpful to remind you that these habitats are not extreme to the microbes—this is where they live. They are only extreme from the human perspective. Many of them have lived there since the early history of the earth when conditions were universally severe.

The Berkeley Pit is an example of evolution in action. Only those microbes with traits to adapt to the conditions there (are fit enough) will survive to reproduce. These hardy pioneers must express hidden genetic traits or develop new ones for removing, modifying, or even utilizing the harsh chemicals of their habitat. Major adaptations include alterations of membrane and enzyme structure so they can function in the presence of heavy metals or acid. Some develop mechanisms for transporting the metal or acid out of their cells back into the environment. In many cases, they establish biofilms and other associations that provide a buffer against the conditions. And a few chemoautotrophs may actually derive energy and nutrition from the toxic substances in the water.

"I really like the illustrations in this chapter. They are clearly tied to the text and are effective in presenting the information. I found them easy to understand. The photographs are great too."

—Carola Wright, Mt. San Antonio College

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