MICRO BIOLOGY

WITH DISEASES BY BODY SYSTEM

FIFTH EDITION

Pearson

ROBERT BAUMAN

TABLE OF CONTENTS

VIDEO TUTORS

Please turn to the end of the listed chapters to access relevant video tutors using a QR code reader on your mobile device.

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Invest in your future:
Microbiology Matters

The Fifth Edition of *Microbiology with Diseases by Body System* encourages a deep understanding of why microbiology matters – to health *and* disease. Paired with innovative media including Micro Matters and Dr. Bauman Video Tutors, the Fifth Edition better showcases why micro matters in today's world.

Pearson

A new chapter on the Human Microbiome introduces the rapidly changing and expanding knowledge about the impact microbes have on health and disease.

Understanding microbiology in a clinical context

Many students taking microbiology need to not only master important principles but also apply these to clinical cases and real-world applications. The Fifth Edition of *Microbiology with Diseases by Body System* incorporates all new chapter opening cases and features designed to contextualize chapter concepts and encourage students to problem solve and master material relevant to clinical careers.

MICRO IN THE CLINIC

Cause for Concern?

Since she was a young child, Caroline and her family have traveled to Brazil every year to visit her grandparents. She loves being able to spend time with family, but she also loves being able to go hiking in the mountains, swimming in the ocean, and wandering through the little town near her grandparents' home. It's always a fun, but busy trip, and Caroline usually returns home tired.

After being home a couple of days from her latest trip, Caroline starts having a headache. It isn't too bad at first, but it continues over the next couple of days and gets quite severe. She also has a fever and a sharp pain behind her eyes. and she feels achy all over—her muscl
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MICRO IN THE CLINIC FOLLOW-UP

Cause for Concern?

Caroline's grandmother suspected that she has dengue fever, an infection transmitted via a mosquito bite. Dr. Watson does an initial physical exam, gets a medical history (including recent travel), and draws blood for lab analysis. In addition, Dr. Watson notices some bleeding along Caroline's gum line. Based on Caroline's symptoms and her recent travel to Brazil, Dr. Watson also suspects Caroline may have dengue. He admits her to the hospital, where she can be constantly monitored.

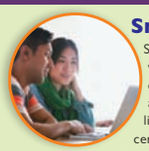
The results of Caroline's blood work confirm the dengue diagnosis. There is no cure for dengue—rest, fluid replacement, pain relievers, and time for the immune system to conquer the infection are all that can be done. Caroline remains in the hospital, and within a week, she has recovered enough to return home. Dr. Watson tells Caroline to thank her grandmother for pushing her to go to the doctor—the relatively early diagnosis allowed for Caroline's quick and complete recovery from dengue.

1. **A sample of Caroline's blood was sent to the Centers for Disease Control and Prevention (CDC) for confirmation of dengue. The CDC uses real-time polymerase chain reaction (PCR) to confirm the presence of dengue virus in a blood sample. Explain how real-time PCR can be used to identify the presence of a specific pathogen in a blood sample.**
2. **The CDC also determines the particular strain of dengue in each sample using genetic analysis.**
3. **Similarities in DNA sequences indicate relatedness of different viruses. What method could the CDC use to determine the DNA sequence of the dengue virus isolated from Caroline's blood sample? Provide a rationale for your choice.**

Check your answers to Micro in the Clinic Follow-Up questions in the MasteringMicrobiology Study Area.

NEW! Solve the Problem boxes explore current microbiologically-relevant challenges in the world. Paired active-learning instructor activities and MasteringMicrobiology assessments are available to encourage critical thinking.

SOLVE THE PROBLEM



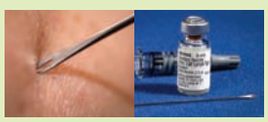
Smallpox: To Be or Not To Be?

Smallpox is likely the worst infectious disease of all time, killing an estimated 300 million people in the 19th century alone. It is a terrifying killer, with a death rate as high as 33% and the survivors carrying lifelong scars.

British medical doctor Edward Jenner is credited with inventing smallpox vaccination—the world's first immunization. On May 14, 1796, Jenner collected secretions from a cowpox sore on the hand of a milkmaid and rubbed them into scratches he made on the skin of an eight-year-old boy. Then, about a month later, he injected the boy with secretions from a lesion on a smallpox patient. The child did not get smallpox; he was immune. Jenner termed his technique vaccination, which comes from the Latin term for cow, *vacca*.

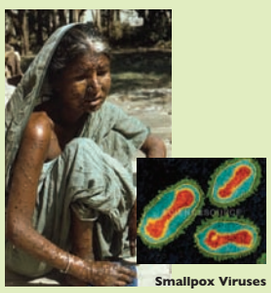
Medical doctors began vaccinating people with special two-pronged needles, and eventually smallpox was eradicated worldwide. The last case was documented on October 26, 1977.

Eradication represents one of the great triumphs of modern medicine, but smallpox virus itself still exists. Stocks are kept frozen in secure laboratories at the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia, and in the State Research Center of Virology and Biotechnology in Koltsovo, Russia.



Imagine you are assigned to be part of a team tasked to determine what to do with the world's remaining stores of smallpox virus.

- **Should governments and laboratories keep them?**
- **Or should they be destroyed? In other words, should we intentionally make a species extinct forever?**



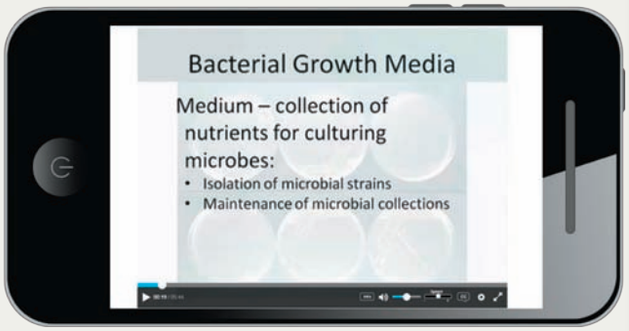
Smallpox Viruses

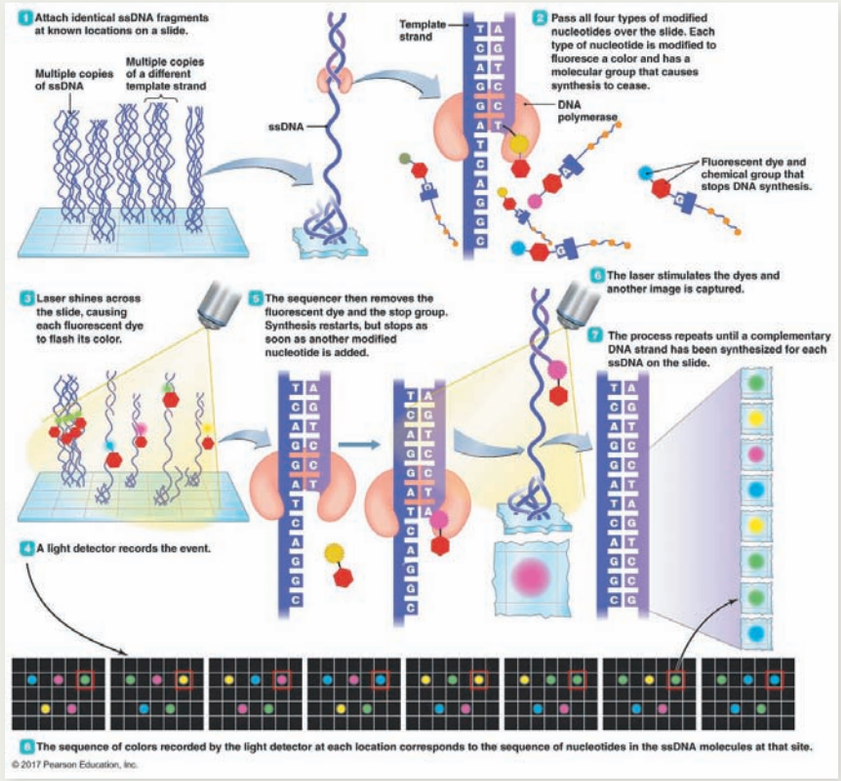
- **What facts do you need to make an informed decision?**
- **If the decision were to be made today, how would you vote?**

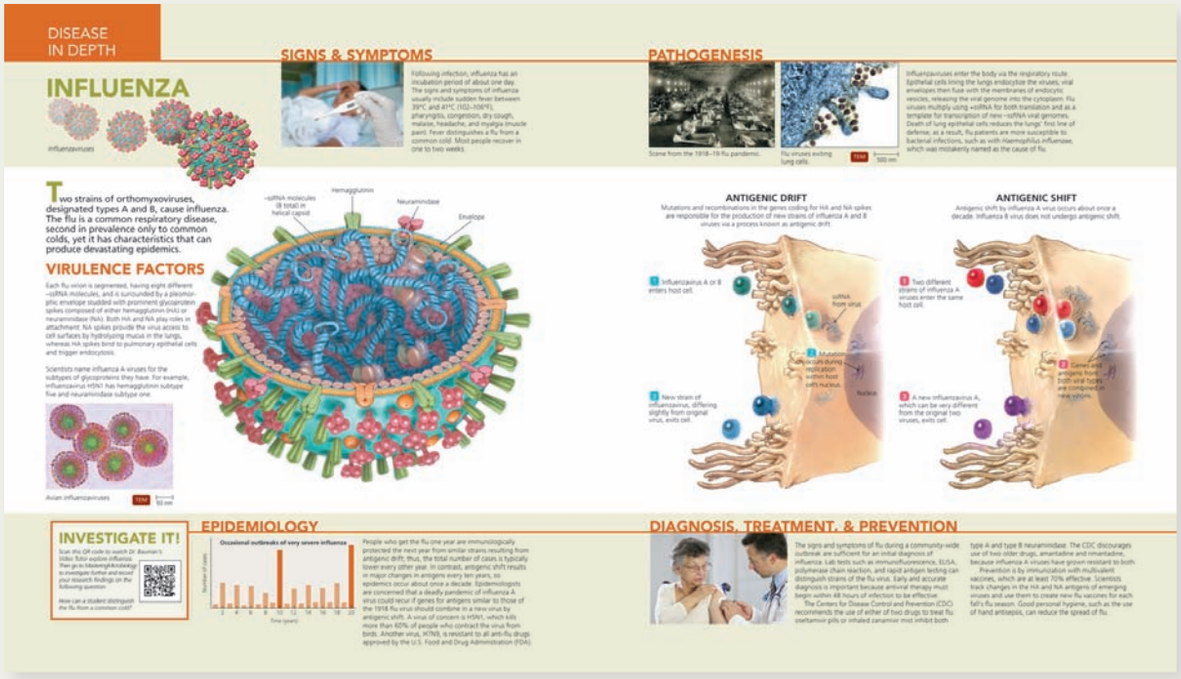
Go to the study area to solve the problem.

Bring microbiology to life with stunning artwork and proven pedagogy and media!

Up-to-date and clear artwork clarifies complex processes while Dr. Bauman Video Tutors deliver author-developed mini-lectures on key concepts







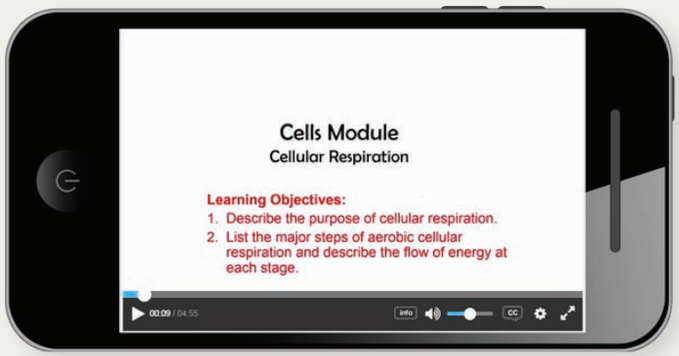
NEW AND UPDATED! Disease in Depth two-page spreads visually summarize important diseases and encourage critical thinking with Video Tutors and Investigate It questions.

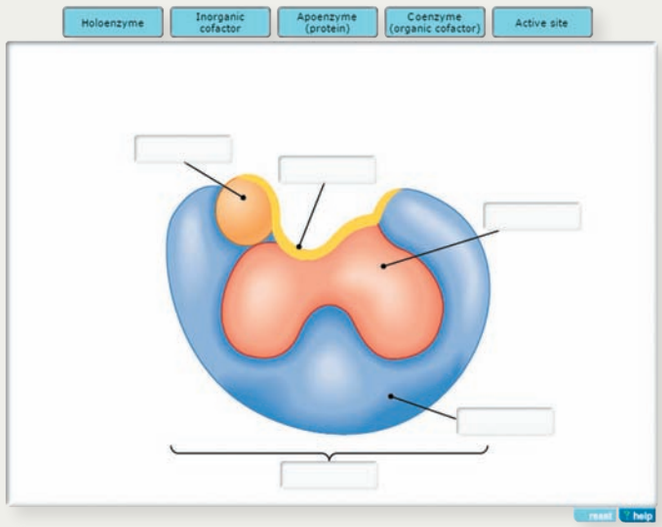
Continuous Learning
Before, During, and After Class

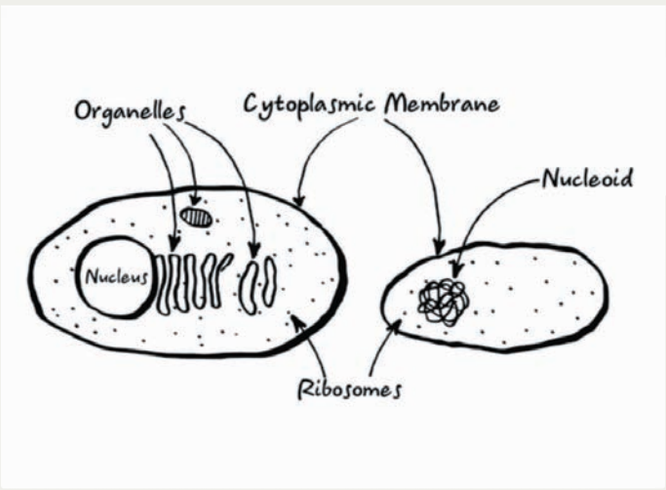
MasteringMicrobiology improves results by engaging students before, during, and after class.

BEFORE CLASS

MicroBooster and Dr. Bauman Video Tutors, animations, reading questions, and art-based activities prepare students for in-depth class discussion.



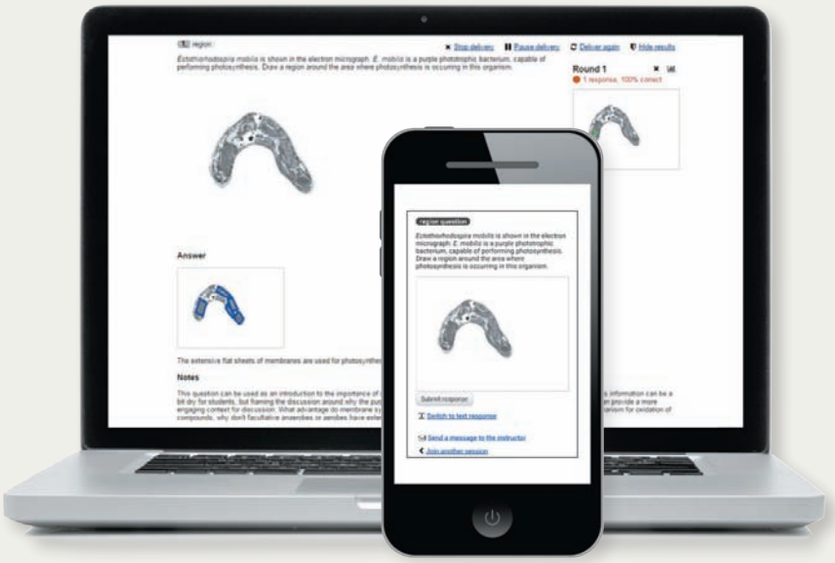




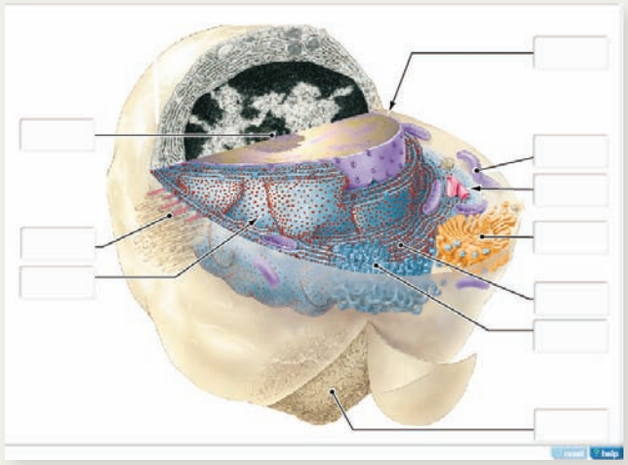
Micro Matters videos and **Connecting Concepts** coaching activities prompt greater understanding and application of core concepts.

with MasteringMicrobiology

DURING CLASS

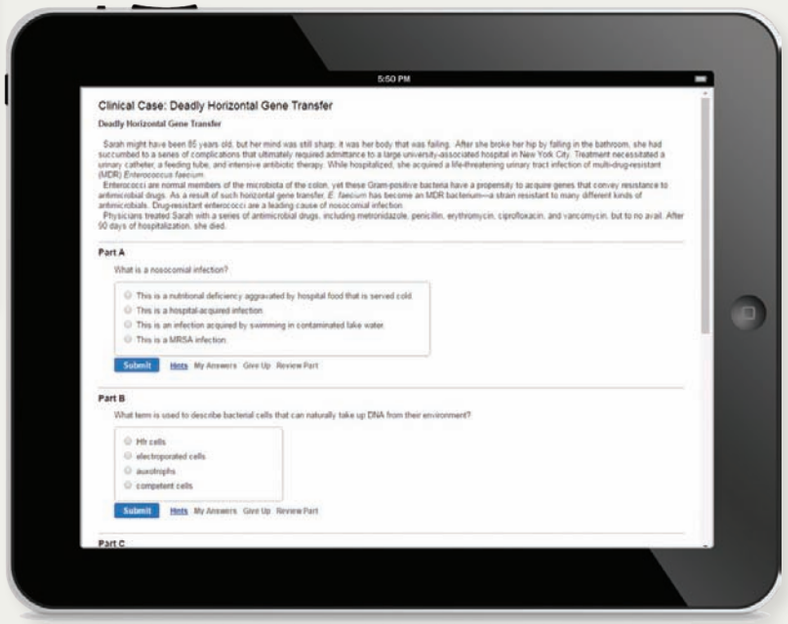


NEW! Learning Catalytics is a "bring your own device" (laptop, smartphone, or tablet) engagement, assessment, and classroom intelligence system. Students use their device to respond to open-ended questions and then discuss answers in groups based on their responses. Visit learningcatalytics.com to learn more.



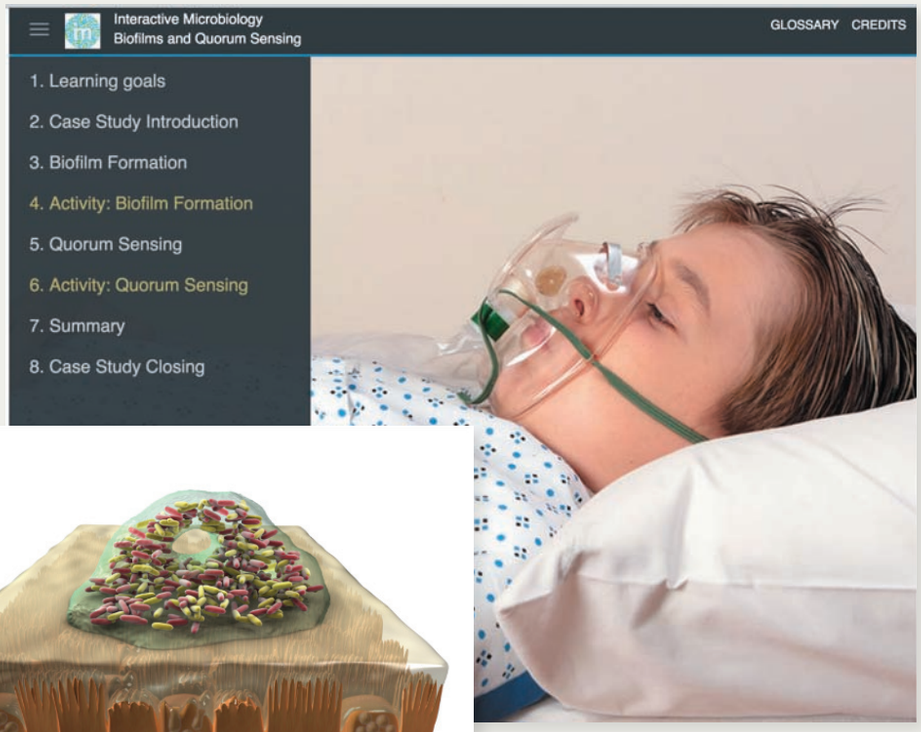
AFTER CLASS

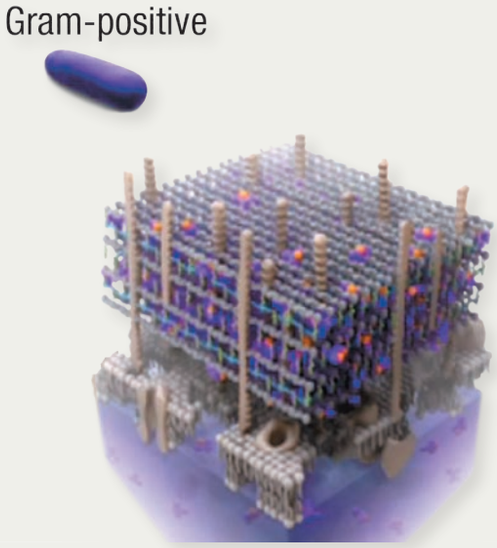
A wide variety of interactive coaching activities as well as high-level assessments can be assigned after class to continue student learning and concept mastery.

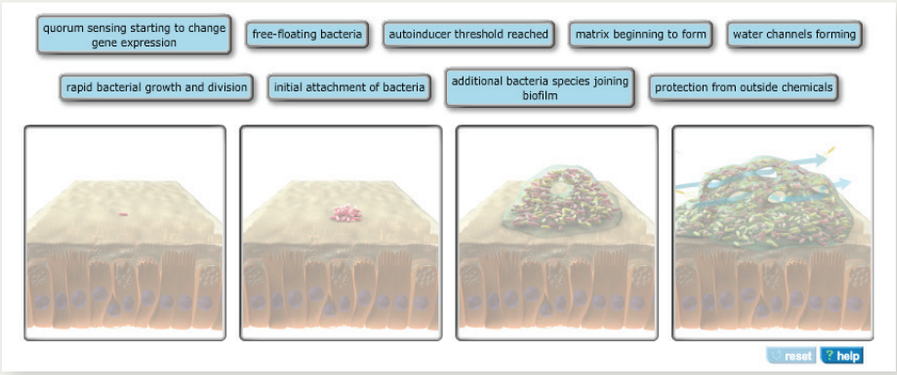


Visualize Microbiology with MasteringMicrobiology

NEW! Interactive Microbiology is a dynamic suite of interactive tutorials and animations that teach key concepts in microbiology, including Operons; Biofilms and Quorum Sensing; Aerobic Respiration in Bacteria; Complement, and more. Students actively engage with each topic via a case study and learn by manipulating variables, predicting outcomes, and answering formative and summative assessment questions.



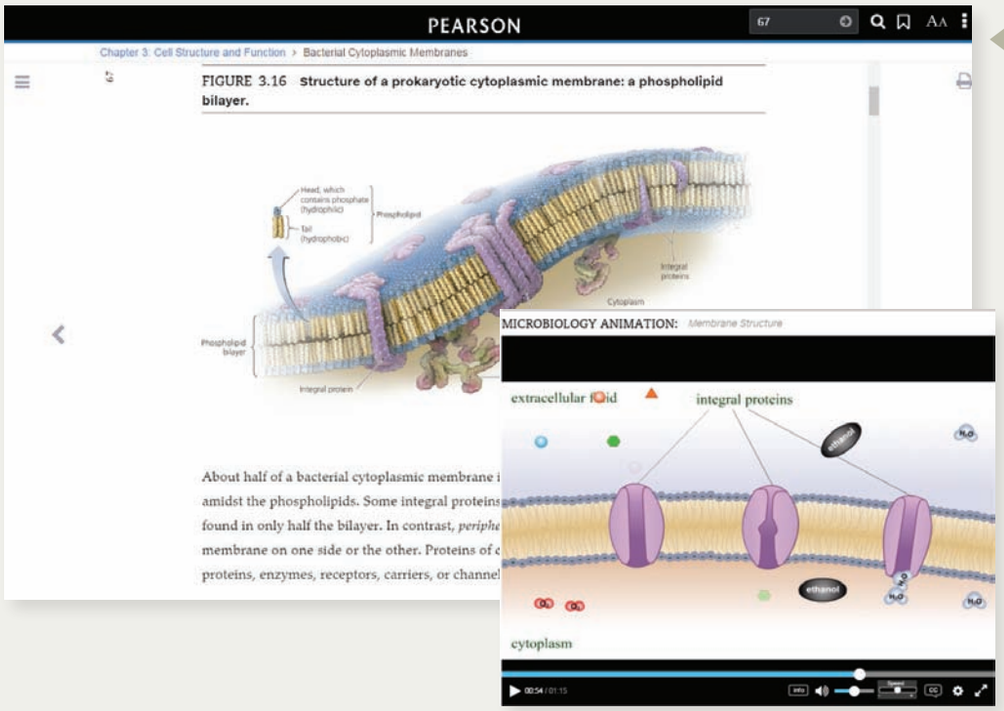




MicroLab Tutors, Lab Technique Videos and Lab Practical Assessments ensure students connect lecture concepts with lab techniques and protocol and are better prepared for lab work.

Access the complete textbook on and offline with eText 2.0

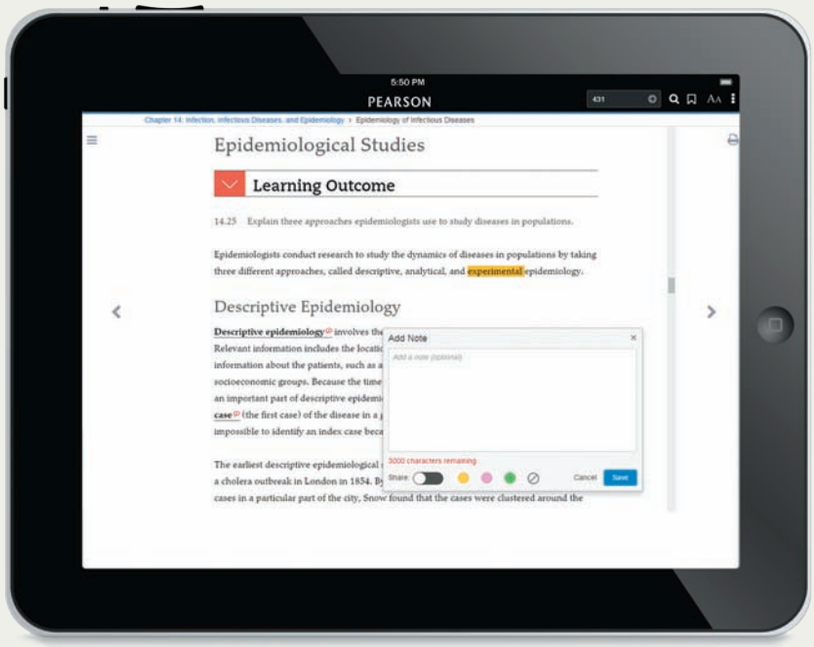
NEW! The **Fifth Edition** is available in Pearson's fully-accessible eText 2.0 platform.*



NEW! Interactive eText 2.0 gives students access to the text whenever they can access the internet. eText features include:

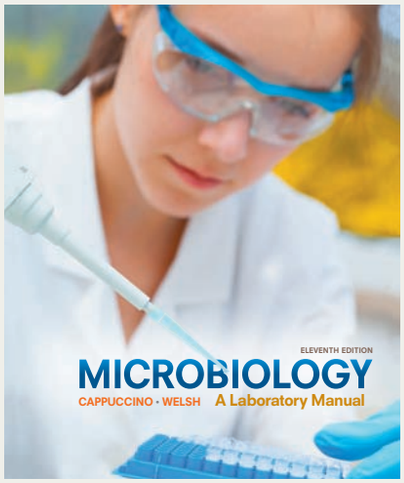
- Available on smartphones and tablets
- Seamlessly integrated videos and other rich media
- Accessible (screen-reader ready)
- Configurable reading settings, including resizable type and night reading mode

Powerful interactive and customization functions include instructor and student note-taking, highlighting, bookmarking, search, and links to glossary terms.



*eText 2.0 will be available beginning Fall 2017

Additional Support for Students and Instructors



NEW! ***Microbiology: A Laboratory Manual***
Eleventh Edition

James G. Cappuccino and Chad T. Welsh

Flexible and comprehensive, *Microbiology: A Laboratory Manual,* is known for its thorough coverage, straightforward procedures, and minimal equipment requirements. The Eleventh Edition incorporates **UPDATED** safety protocols from governing bodies such as the EPA, ASM, and AOAC and offers alternate organisms for Biosafety Level 1 and 2 labs. **NEW** labs on Food Safety, ample introductory material, and engaging clinical applications make this lab manual appropriate for all modern microbiology labs!

Laboratory Experiments in Microbiology
Eleventh Edition
Ted R. Johnson and Christine L. Case

Techniques in Microbiology: A Student Handbook
John M. Lammert

** Contact your Pearson representative for package options and ISBNs*

The Instructor Resources Area in MasteringMicrobiology includes the following downloadable tools:

- all of the figures, photos, and tables from the text in JPEG and PowerPoint® formats, in labeled and unlabeled versions, and with customizable labels and leader lines
- Step-edit Powerpoint slides that present multi-step process figures step-by-step
- Clicker Questions and Quiz Show Game questions that encourage class interaction
- Video Tutors, Interactive Microbiology, MicroFlix ™, MicroBooster and Microbiology Animations
- MicroLab Tutors and Lab Technique Videos to help prepare students for lab and make the connection between lecture and lab
- Customizable PowerPoint® lecture outlines with tables, figures, and links to animations and videos
- A comprehensive Instructor's Manual including active learning Solve the Problem worksheets, chapter summaries to aid in class preparation as well as the answers to the end-of-chapter review and application questions.
- Test Bank with hundreds of customizable multiple choice, true/false and short answer/essay questions correlated to the book's Learning Outcomes and Bloom's Taxonomy. Questions are available in Microsoft® Word and TestGen® formats.

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WITH DISEASES BY BODY SYSTEM
BIOLOGY

FIFTH EDITION

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To Michelle:
My best friend, my closest confidant, my cheerleader, my partner, my love. Thirty-four years! I love you more now than then.

—Robert

About the Author

ROBERT W. BAUMAN is a professor of biology and past chairman of the Department of Biological Sciences at Amarillo College in Amarillo, Texas. He has taught microbiology, human anatomy and physiology, and botany for over 30 years. In 2004, the students of Amarillo College selected Dr. Bauman as the recipient of the John F. Mead Faculty Excellence Award, and he has been nominated yearly, but winning has been limited to one time. He received an M.A. degree in botany from the University of Texas at Austin and a Ph.D. in biology from Stanford University. His research interests have included the morphology and ecology of freshwater algae, the cell biology of marine algae (particularly the deposition of cell walls and intercellular communication), environmentally triggered chromogenesis in butterflies, and terrestrial oil pollution remediation by naturally occurring bacteria. He is a member of the American Society of Microbiology (ASM) where he has held national offices; Texas Community College Teachers Association (TCCTA), where he serves in a statewide position of leadership; American Association for the Advancement of Science (AAAS); Human Anatomy and Physiology Society (HAPS); and the Lepidopterists' Society. When he is not writing books, he enjoys spending time with his family: gardening, hiking, camping, rock climbing, backpacking, cycling, skiing, and reading by a crackling fire in the winter and in a gently swaying hammock in the summer.

TODD P. PRIMM (contributor) is a professor at Sam Houston State University, where he teaches pre-nursing and general microbiology. He also serves as director of the Professional and Academic Center for Excellence, which focuses on improving teaching and learning on campus. In 2010, he was Distinguished Alumnus of the Graduate School of Biomedical Sciences of Baylor College of Medicine, where he earned a Ph.D. in biochemistry. He received a B.S. from Texas A&M University. He is very active in the American Society for Microbiology and received the Texas Branch 2015 Faculty Teaching Award. He was chair of the organizing committee for the 2013 ASM Conference for Undergraduate Educators, participated in the 2012 Research Residency of the ASM/NSF Biology Scholars Program, and currently serves on the editorial board for the *Journal of Microbiology & Biology Education*. He is also an affiliate staff member with the international organization Cru. He loves teaching and mentoring students and spending time with his wonderful wife of 25 years and their five children.

About the Clinical Consultants

CECILY D. COSBY is nationally certified as both a family nurse practitioner and physician assistant. She is a professor of nursing, currently teaching at Samuel Merritt University in Oakland, California, and has been in clinical practice since 1980. She received her Ph.D. and M.S. from the University of California, San Francisco; her BSN from California State University, Long Beach; and her P.A. certificate from the Stanford Primary Care program. She is the Director of Samuel Merritt University's Doctor of Nursing Practice Program.

JEAN E. MONTGOMERY is a registered nurse formerly teaching in the associate degree nursing program at Austin Community College in Texas. She received her MSN from the University of Texas Health Science Center at San Antonio, Texas.

Preface

The reemergence of whooping cough, mumps, and measles and the emergence of Zika virus infections, spotted fever rickettsioses, Middle East respiratory syndrome, and other diseases; cases of strep throat, MRSA, and tuberculosis; the progress of research into microbial genetics; the challenge of increasingly drug-resistant pathogens; the continual discovery of microorganisms previously unknown—these are just a few examples of why exploring microbiology has never been more exciting, or more important. Welcome!

I have taught microbiology to undergraduates for over 30 years and witnessed firsthand how students struggle with the same topics and concepts year after year. To address these challenging topics, I have created new Video Tutors: four in addition to those already incorporated into the first 18 chapters of the text and ten that cover the Disease in Depth features. The Video Tutors and Disease in Depth features walk students through key concepts in microbiology, bringing the art of the textbook to life and important concepts into view. In creating this textbook, my aim was to help students see complex topics of microbiology—especially metabolism, genetics, and immunology—in a way that they can understand, while at the same time presenting a thorough and accurate overview of microbiology. I also wished to highlight the many positive effects of microorganisms on our lives, along with the medically important microorganisms that cause disease.

New to This Edition

In approaching the fifth edition, my goal was to build upon the strengths and success of the previous editions by updating it with the latest scientific and educational research and data available and by incorporating many terrific suggestions received from colleagues and students alike. The feedback from instructors who adopted previous editions has been immensely gratifying and is much appreciated. Seven new Solve the Problem! features use problem-based learning, encouraging students to put knowledge into practice. The Disease at a Glance features have been widely praised by instructors and students, so I, along with art editor Kelly Murphy, developed six new Disease in Depth features, most as two-page spreads, that use compelling art and photos to provide a detailed, visually unsurpassed overview of a specific disease. Each Disease in Depth feature includes an Investigate It! question with a QR code directing students to a Video Tutor that explores the topic. These activities are assignable in MasteringMicrobiology®. Another goal for this edition was to provide additional instruction on important foundational concepts and processes. To that end, I developed and narrated three new core concept Video Tutors, accessible via QR codes in the textbook and assignable in MasteringMicrobiology®. The result is, once again, a collaborative effort of educators, students, editors, and top scientific illustrators: a textbook that, I hope, continues to improve upon conventional explanations and illustrations in substantive and effective ways.

In this new edition:

- NEW Solve the Problem features carry education to a new level with problem-based learning exercises that excite, inspire, and stimulate students to apply critical thinking skills to current microbiological quandaries. Each of the seven Solve the Problem features challenges students to work together to devise and articulate possible resolutions. Solve the Problem exercises can stand alone or be expanded with ambitious extensions and resources available in MasteringMicrobiology®.
- NEW Disease in Depth features highlight important diseases: Rocky Mountain spotted fever, candidiasis, malaria, papillomas, Ebola hemorrhagic fever, and influenza, extending the visual

impact of the art program. Each of these new Disease in Depth features contains infographics, provides in-depth coverage of the selected disease, and includes a QR code and Investigate It! question that directs students to a Video Tutor exploring the topic and prompting further inquiry and critical thinking. New assignable Disease in Depth coaching activities in MasteringMicrobiology® encourage students to apply and test their understanding of key concepts.

- NEW Video Tutors developed and narrated by the author walk students through key concepts. New to this edition are Video Tutors on glycolysis, protein translation, and antigen processing. These Video Tutors bring the textbook art to life and help students visualize and understand tough topics and important processes. Thirty-two video tutorials are accessible via QR codes in the textbook and are accompanied by multiple-choice questions, assignable in MasteringMicrobiology®.
- NEW Micro Matters features tie together subjects from different chapters to encourage students to apply and synthesize new knowledge as they explore medical cases and answer pertinent questions. Each of the five Micro Matters video tutorials is accessible via QR code and paired with assessments in MasteringMicrobiology®.
- The genetics and immunology chapters (Chapters 7, 8, 15, and 16) have been reviewed and revised by genetics specialists. These now reflect the most current understanding of this rapidly evolving field, including new discussion of next-generation DNA sequencing.
- Over 300 NEW and revised micrographs, photos, and figures enhance student understanding of the text and boxed features.
- NEW AND EXPANDED MasteringMicrobiology® includes: NEW Interactive Microbiology, a dynamic suite of interactive tutorials and animations that teach key concepts in the context of a clinical setting. Students actively engage with each topic and learn from manipulating variables, predicting outcomes, and answering formative and summative assessments. Topics include Operons; Complement; Biofilms and Quorum Sensing; Antibiotic Resistance, Mechanisms; Antibiotic Resistance, Selection; and more.
  - NEW Micro Matters case tutorials and assessments connect chapter concepts and coach students through applying and synthesizing new knowledge.
  - NEW MicroBoosters pair video tutorials and assessments covering key concepts that students often need to review, including Basic Chemistry, Cell Biology, Biology and more!
  - The Microbiology Lab resources include MicroLab Tutors, which use lab technique videos, 3-D molecular animations, and step-by-step tutorials to help students make connections between lecture and lab.
  - Lab Technique Videos and pre-lab quizzes ensure students come prepared for lab time.
  - Lab Practical and post-lab quizzes reinforce what students have learned.

MasteringMicrobiology® also provides access to Dynamic Study Modules to help students acquire, retain, and recall information faster and more efficiently than ever before, with textbook-specific explanations and art. Dynamic Study Modules are available for use as a self-study tool or as assignments. Instructors also now have the option to give Adaptive Follow-Up assignments that provide student-specific additional coaching and practice. These question sets continuously adapt to each student's needs, making efficient use of homework time. Additionally, MasteringMicrobiology® includes Learning Catalytics—a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics, instructors can assess students in real time using open-ended tasks to probe student understanding using Pearson's library of questions or designing their own.

The following section provides a detailed outline of this edition's chapter-by-chapter revisions.

Chapter-by-Chapter Revisions

1 A Brief History of Microbiology

- New chapter opener case study and photo
- Two other new photos (1.3, 1.6b)
- Two figures revised for better pedagogy, clarity, and accuracy [1.5 (2)]
- Updated map showing countries having transmission of variant Creutzfeldt-Jakob disease (vJCD)
- Introduced discussion of the success of gene therapy in treating several inherited immune deficiencies
- Deleted the Highlight box covering emerging and reemerging diseases, placed the discussion of this topic within the chapter text, and expanded coverage to include Middle East Respiratory Syndrome (MERS), Zika fever, Ebola, and chikungunya
- Spelling of Semmelweis corrected in Figure 1.19
- New **Clinical Case Study: Can Spicy Foods Cause Ulcers?** with questions
- New **Solve the Problem: Smallpox: To Be or Not to Be?** (problem-based learning exercise concerning complete smallpox virus destruction)
- Expanded list of current problems in microbiology to include Ebola control, biofilms, rapid testing for infections, and antimicrobial-drug resistance by persistent cells
- Added fill-in **Concept Mapping** exercise on types of microbes and some of their major characteristics

2 The Chemistry of Microbiology

- New chapter opener case study and photo
- Five figures revised for better pedagogy (2.6, 2.21, 2.22, ether bond and amino group in Table 2.3)
- New **Learning Outcomes** concerning terms regarding elements, valence electrons and chemical bonding, organic compounds, contrasting ionic and covalent bonds, lipids
- Clarified that most organisms code for 21 amino acids, though 20 are more common
- Added fill-in **Concept Mapping** exercise on nucleotide structure and function

3 Cell Structure and Function

- New chapter opener case study and photo
- Five other new/upgraded photos (3.5a, 3.5b, 3.8a, 3.24, 3.28a)
- Revised and enhanced artwork in nine figures for enhanced pedagogy (3.13, 3.15, 3.18, 3.20, 3.22, 3.23, 3.29, 3.30, 3.33b)
- Removed the Highlight box on biofilms and incorporated pertinent information into this chapter and into Chapter 6, including a new figure on quorum sensing
- Enhanced discussions of flagella and cilia structure and function, definition of endotoxin, comparison of and contrast between the outer and cytoplasmic membranes of Gram-negative cells, movement across cell membranes, and chemistry and function of lipids in archaeal cytoplasmic membranes
- Clarified that *endotoxin* refers to lipopolysaccharide (LPS), which contains the toxic molecule lipid A
- Added **Clinical Case Study: The Big Game** about strep throat
- Added fill-in **Concept Mapping** exercise on bacteria cell wall structure

4 Microscopy, Staining, and Classification

- New chapter opener case study and photo
- One other new photo (4.18)
- Revised one figure for enhanced pedagogy (4.11)
- Revised **Learning Outcome** regarding simple stains, which now include Gomori methenamine silver stain and hematoxylin and eosin stains
- Removed the Highlight box on microscopy of living biofilms and incorporated relevant information, including the figure, into the text
- Added one new critical thinking question to **Emerging Disease Case Study: Necrotizing Fasciitis** box
- Revised coverage of history of taxonomy
- Expanded discussion of resolution, immersion oil, mordants, definition of microbial species, and role of George Fox in the discovery of the archaea and three domains of life
- Revised section on microbial taxonomy to more fully address genomic techniques in taxonomy
- At request of reviewers and instructors, reduced complexity and chapter length by removing detailed figures for dark-field, phase, and scanning electron microscopy
- Added fill-in **Concept Mapping** exercise on Gram stain and cell wall structure

5 Microbial Metabolism

- New chapter opener case study and photo
- Revised twelve figures for greater clarity and better pedagogy (5.9, 5.11, 5.12, 5.13, 5.14, 5.16, 5.17, 5.18, 5.19, 5.21, 5.25, 5.28)
- Removed the Highlight box on trimethylamine oxide (fishy smell) from the chapter
- Removed the Highlight box on glowing bacteria
- Clarified and expanded discussion of the importance of redox reactions, the uses of ATP in cell, enzymatic activation through allosteric sites, competitive and noncompetitive inhibition of enzyme activity, and lipid catabolism and anbolism
- Expanded discussion of diverse metabolic pathways
- Changed the term *Embden-Meyerhof pathway* to *Embden-Meyerhof-Parnas* pathway to reflect the contribution of Jakub Karol Parnas in elucidating the glycolytic pathway
- New **Tell Me Why** critical thinking question over analogous structures of electron carriers and nucleotides
- Added **Learning Outcome** concerning metabolic diversity in bacteria
- New **Solve the Problem: The Microbes Ate My Homework** (problem-based learning investigation concerning use of genetic modification of microbes to reduce the amount of waste paper in landfills)
- Added fill-in **Concept Mapping** exercise on aerobic respiration

6 Microbial Nutrition and Growth

- New chapter opener case study and photo
- Two other new photos (6.13, 6.24b)
- Six figures revised for greater clarity and better pedagogy (6.4, 6.6, 6.8, 6.17, 6.21, 6.24)
- Removed the Highlight box on sulfur-metabolizing microbes in Yellowstone's springs
- One new figure on quorum sensing (6.7)

- Expanded discussions of singlet oxygen and superoxide radicals as oxidizing agents, the nature of extracellular matrix in biofilms, and quorum sensing
- Clarified the method of counting microbes using a cell counter
- Added fill-in **Concept Mapping** exercise on culture media

7 Microbial Genetics

- New chapter opener case study and photo
- Upgraded 20 figures for greater clarity, accuracy, ease of reading, and better pedagogy (7.1, 7.5b, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, 7.13, 7.14, 7.20, 7.21, 7.22, 7.26, 7.27, 7.28, 7.32, 7.34, 7.35, 7.36)
- Removed the Highlight box on RNA interference
- Updated and expanded text covering DNA replication, the smallest cellular genome at 112,091 bp (Candidatus *Nasuia deltocephalinicola*), alternative splicing in eukaryotes, the recent discovery that chloroplast chromosomes are linear rather than circular, and the use of methylation in mismatch repair
- Increased discussion of use of RNA as enzymes (ribozymes)
- Expanded table comparing and contrasting DNA replication, transcription, and translation
- Added discussion of codon and tRNA for 21st amino acid, selenocysteine
- Enhanced and clarified discussion of *lac* and *trp* operons and of the action of cAMP and CAP as activators
- Expanded and reorganized discussion of DNA repair systems
- Clarified events in conjugation, particularly with Hfr cells
- Expanded and clarified coverage of nucleotides and pyrophosphate (diphosphate)
- Revised the chapter to better explain differences between archaeal, bacterial, and eukaryotic genetics
- Added fill-in **Concept Mapping** exercise on point mutations

8 Recombinant DNA Technology

- New chapter opener case study and photo
- Added six **Learning Outcomes** concerning uses of synthetic nucleic acids, PCR, fluorescent *in situ* hybridization (FISH), functional genomics, Sanger sequencing, and next-generation sequencing
- One other new figure (8.10)
- Modified Figure 8.7 for better pedagogy
- Deleted figures for Southern blots and Sanger automated DNA sequencing, as these techniques are more historical than current
- Removed the Highlight box on edible vaccines and added its material to the text
- Enhanced or added discussion of real-time PCR (RT-PCR); Sanger sequencing methods; next-generation DNA sequencing (NGS), including pyrosequencing and fluorescent methods; functional genomics; microbiomes; biomedical animal models; and successful gene therapies
- Added Beneficial Microbes box: Our Other Organ on the sequencing and identification of human microbiomes
- Added fill-in **Concept Mapping** exercise on recombinant DNA technology

9 Controlling Microbial Growth in the Environment

- New chapter opener case study and photo
- Five figures revised for better accuracy, currency, and pedagogy (9.2, 9.7, 9.10, 9.15, 9.16)
- New photo (9.4)
- Removed the Highlight box on healthy processing of sushi
- Material from the Highlight box on the overuse of antimicrobial soaps into new Solve the Problem learning exercise
- Revised definition of heavy-metal ions
- Updated coverage of techniques for deactivating prions; thimerosal in vaccines; and activity of AOAC International in developing disinfection standards
- Added critical thinking question concerning salmonellosis pandemic from smoked salmon
- New **Solve the Problem: How Clean is Too Clean?** (problem-based learning investigation concerning the potential overuse of household and industrial disinfectants)
- Added fill-in **Concept Mapping** exercise on use of moist heat in microbial control

10 Controlling Microbial Growth in the Body: Antimicrobial Drugs

- New chapter opener case study and photo
- Seven figures revised for greater clarity, accuracy, ease of reading, and better pedagogy (10.2; 10.3; 10.4; 10.6; 10.7; 10.15; map of worldwide community-associated MRSA)
- Three other new photos (box showing antimicrobial drug capsules, Figure 10.10, clinical case study on opportunistic thrush)
- Removed the Highlight box on reasons microbes make antimicrobials
- Updated and revised tables of antimicrobials to include all new antimicrobials mentioned in disease chapters, including the antibacterial capreomycin and the anthelmintic bithionol; updated sources of drugs, modes of action, clinical considerations, and methods of resistance
- New **Clinical Case Studies: Antibiotic Overkill**, concerning opportunistic candidiasis, and **Battling the Enemy**, concerning semisynthetic antimicrobials and diffusion susceptibility testing
- Enhanced and clarified discussion of the action and importance of aminoacyl-tRNA synthetases; topical antibiotic mupirocin; the mechanism of resistance against quinolone antibacterial drugs; adverse effects of aminoglycosides; therapeutic index andtherapeutic range; and adverse effects of gramicidin
- Removed mention of amantadine as a treatment for influenza A
- New section on drugs that interfere with the charging of tRNA molecules, including one new **Learning Outcome** on action of mupirocin
- Added fill-in **Concept Mapping** exercise on resistance to antimicrobial drugs

11 Characterizing and Classifying Prokaryotes

- New chapter opener case study and photo
- Two new **Learning Outcomes** addressing epsilonproteobacteria and zetaproteobacteria
- Ten new photos [11.1 (2), 11.2a, 11.5, 11.11a, 11.17, 11.19, 11.21, 11.23, 11.27b]
- Seven figures revised for better pedagogy (11.1, 11.4, 11.6, 11.10, 11.21, 11.26, 11.27)
- Removed the Highlight box on possible microbial cause of obesity; added abbreviated discussion to text
- Removed the Highlight box on possible connection between cyanobacteria and dementia
- Clarified and expanded coverage of (1) "snapping division," which is a distinctive characteristic of corynebacteria, including *C. diphtheriae*; (2) floc formation and its use in sewage treatment; and (3) methicillin-resistant strains of *Staphylococcus aureus*

- Updated with new discoveries in bacterial and bacterial systematics: five phyla of archaea (rather than two), six classes of proteobacteria rather than five
- Removed box on Botox
- Removed box on possible link between cyanobacteria and brain disease
- Three new critical thinking questions added to **Emerging Disease Case Study: Pertussis**
- Added six new **Learning Outcomes** to section on proteobacteria.
- Added fill-in **Concept Mapping** exercise on domain Archaea

12 Characterizing and Classifying Eukaryotes

- New chapter opener case study and photo
- Ten other new photos (12.11a and b, 12.12a and b, 12.13c, 12.14, 12.18, 12.19, 12.25, 12.27, 12.29f, 12.29g)
- Six figures revised for more accurate and lucid pedagogy (12.3, 12.7a, 12.8, 12.17, 12.23, map for aspergillosis)
- Per reviewers' requests, shortened chapter by eliminating detailed discussion and artwork of ciliate (*Paramecium*) conjugation and details of sexual reproduction of zygomycetes, ascomycetes, and basidiomycetes
- Updated algal, fungal, protozoan, water mold, and slime mold taxonomy; removed euglenids and dinoflagellates from Table 12.4, Characteristics of Various Algae
- Clarified and expanded coverage of meiosis, alveoli in alveolate protists, use of radiation as an energy source for some fungi, and the tripartite nature of lichens (both ascomycete and basidiomycete fungi and a photosynthetic symbiont)
- Switched to American English plural of *amoeba* (*amoebas* rather than *amoebae*)
- Added fill-in **Concept Mapping** exercise on types of eukaryotic microbes

13 Characterizing and Classifying Viruses, Viroids, and Prions

- New chapter opener case study and photo
- Five new photos (13.7b, 13.17, 13.21, 13.24a&b)
- One new figure (13.23) showing prion templating
- Upgraded nine figures for better pedagogy and currency (13.5c, 13.12, 13.13, 13.14, 13.16, 13.18, 13.20, 13.22, map showing range of chikungunya)
- Removed the Highlight box on the threat of avian influenza
- Two new **Learning Outcomes** concerning (1) naming viruses and viral structure and (2) control of prions
- Updated viral nomenclature to correspond to changes approved by the International Committee on Taxonomy of Viruses (ICTV) in 2014
- Added discussion on the benefits and costs to a virus of having an envelope versus being naked
- Clarified and expanded text discussion concerning lytic cycle of phage replication; use of phage typing; replication of animal viruses, particularly ssDNA viruses; link between viruses and human cancers; viroids; and prions
- Updated discussion of techniques for deactivating prions and treating prion disease
- New **Solve the Problem: Manufacture a Better Mosquito?** (problem-based learning investigation concerning genetic modification of mosquitoes so as to reduce the transmission of viral diseases such as Zika)
- Added fill-in **Concept Mapping** exercise on replication strategies of eukaryotic viruses

14 Infection, Infectious Diseases, and Epidemiology

- New chapter opener case study and photo
- Seven figures modified for better pedagogy, timeliness, quality, or clarity (14.3, 14.4, 14.5, 14.7,14.14, 14.16, 14.19)
- Revised and updated coverage of number of human cells in a body and the number of cellular microbiota, the microbiome, symbioses (added the terms *symbiont* and *amensalism*), and endotoxins
- Updated epidemiology charts, tables, maps, and graphs
- Updated terminology: *microbiome* is now used in place of *normal microbiota* or *microbial flora*
- Updated list of nationally notifiable infectious diseases (changed AIDS to HIV Stage III; added campylobacteriosis, leptospirosis; deleted *Streptococcus pneumoniae* invasive disease and chickenpox (varicella)
- New **Solve the Problem: Microbes in the Produce Aisle** (problem-based learning investigation concerning an epidemiological investigation of legionellosis)
- Added fill-in **Concept Mapping** exercise on disease transmission

15 Innate Immunity

- New chapter opener case study and photo
- One other new photo (15.5b)
- Seven figures modified for enhanced clarity and better pedagogy (15.3, 15.6, 15.7, 15.8, 15.9, 15.12, 15.14)
- Updated terminology: *microbiome* is now used in place of *normal microbiota* or *microbial flora*; and expanded coverage of the composition and action of the microbiome, siderophores, antimicrobial peptides (defensins), blood stem cells, phagocytosis, Toll-like receptor 10 (TLR10), complement activation, complement cascade, membrane attack complexes, and inflammatory mediators
- Enhanced discussion of type I interferons
- New figure question and answer concerning identification of white blood cells
- Added fill-in **Concept Mapping** exercise on phagocytosis

16 Specific Defense: Adaptive Immunity

- New chapter opener case study and photo
- Twelve figures revised for enhanced pedagogy (16.2, 16.3, 16.4, 16.6, 16.7, 16.8, 16.9, 16.12, 16.14, 16.18)
- Removed the Highlight box on the loss of CD4+ cells in AIDS patients
- Removed the Highlight box on fighting cancer with lab grown T cells
- Incorporated all the material from the Highlight box on BCR diversity into the text, including a revised figure
- Revised and clarified discussions of general characteristics of adaptive immunity, function and structure of tonsils, flow of lymph, mucosa-associated lymphoid tissue, terminology for $CD8^+$ and $CD4^+$ cells, genetic basis for creation of BCR and TCR diversity, binding capability of MHC
- Reordered the discussion of topics in adaptive immunity to align more closely with the progression of events; for example, MHC and antigen processing are discussed before T cells and cell-mediated immunity, which are discussed before B cells and antibody-mediated immunity
- Clarified the discovery and structure of MHC
- Removed discussion of T-independent antibody immunity as too advanced for beginning students
- Added three critical thinking questions to and updated incidence map for **Emerging Disease Case Study: Microsporidiosis**
- Added fill-in **Concept Mapping** exercise on antibodies

17 Immunization and Immune Testing

- New chapter opener case study and photo
- Five figures revised for better pedagogy (17.2, 17.3, 17.6, 17.11, 17.14)
- Removed the Highlight box on lack of cold vaccines
- Updated chapter to include newly revised CDC 2016 vaccination schedule for children, adolescents, and adults
- Updated table of vaccine-preventable diseases in USA
- Enhanced discussion of development of attenuated viral vaccines
- Added two points to **Chapter Summary** about use of recombinant gene technology in vaccine production and about vaccine safety
- New **Solve the Problem: Should You Vaccinate?** (problem-based learning investigation concerning the efficacy and perceived dangers of vaccinations)
- Added fill-in **Concept Mapping** exercise on vaccines

18 Hypersensitivities, Autoimmune Diseases, and Immune Deficiencies

- New chapter opener case study and photo
- Revised five figures for greater clarity, accuracy, or pedagogical value (18.1, 18.2, 18.17, 18.19, 18.20)
- Material from the Highlight box on hygiene hypothesis into new Solve the Problem learning exercise
- Removed the Highlight box on allergies triggered during kissing
- Removed the Highlight box on the "bubble boy" (SCIDS)
- Expanded coverage of type III hypersensitivity and the relationship between hypersensitivities and autoimmune disorders
- Removed figure and text covering the rare disease immune thrombocytopenic purpura
- Added fill-in **Concept Mapping** exercise on immediate hypersensitivities

19 Microbial Diseases of the Skin and Wounds

- New chapter opener case study and photo
- Twenty-two new photos [Disease at a Glance: *Pseudomonas* infection, Disease in Depth: RMSF (7), Disease at a Glance: Anthrax, Disease in Depth: Papillomas (4), Disease at a Glance: Chickenpox and Shingles, Disease at a Glance: Measles, Emerging Disease Case Study: Monkeypox, 19.1, 19.3, 19.7, 19.12, 19.14, 19.21]
- Updated diagnoses, maps, and incidence data for all diseases
- Updated coverage of types of vaccines; infectivity and epidemiology of herpesviruses; epidemiology and pathogenesis of measles; and chickenpox and shingles vaccine
- Updated treatment regimens for staphylococcal scalded skin syndrome, impetigo, cat scratch disease, *Pseudomonas* infection, cutaneous anthrax, and herpes skin infections
- New true/false question over acne
- Added new **Tell Me Why** critical thinking question over use of antibiotics to treat leishmaniasis
- Updated terminology to the use of *microbiome* in place of *normal microbiota* or *microbial flora*
- New **Disease in Depth: Rocky Mountain Spotted Fever**
- New **Disease in Depth: Papillomas**
- New **Emerging Disease Case Study: A New Cause of Spots** concerning *Rickettsia parkeri* rickettsiosis
- Added fill-in **Concept Mapping** exercise on herpes simplex virus

20 Microbial Diseases of the Nervous System and Eyes

- New chapter opener case study and photo
- Nine new photos (20.3, 20.4, 20.7, 20.9, 20.12, 20.13, 20.14, Disease at a Glance: Rabies, Emerging Disease Case Study: A Deadly Mosquito Bite?)
- Seven figures revised for better pedagogy or newer data (20.8, 20.10, 20.11, 20.14, 20.15, 20.16, map for melioidosis)
- Removed the Highlight box on Nipah virus
- Expanded coverage of bacterial meningitis, listeriosis, botulism, polio, tetanus, arboviral encephalitis, cryptococcal meningitis, African trypanosomiasis (sleeping sickness), variant Creutzfeldt-Jakob disease
- Updated diagnoses and incidence data and maps
- Updated epidemiology and etiology of meningococcal meningitis, leprosy, and tetanus
- Updated treatment regimens for bacterial meningitis, leprosy, botulism, tetanus, African trypanosomiasis, primary amebic meningoencephalopathy
- Switched to American English plural of *amoeba* (*amoebas* instead of *amoebae*)
- Updated terminology to the use of *microbiome* in place of *normal microbiota* or *microbial flora*
- New **Tell Me Why** critical thinking question over cryptococcal meningitis
- Replaced **Emerging Disease Case Study: Tick-Borne Encephalitis** with **Emerging Disease Case Study: A Deadly Mosquito Bite?** addressing Zika virus microcephaly
- Added fill-in **Concept Mapping** exercise on bacterial meningitis

21 Cardiovascular and Systemic Diseases

- New chapter opener case study and photo
- Eleven new photos (21.7, 21.17, Disease at a Glance boxes: Tularemia and Bubonic Plague, Disease in Depth: Ebola (7))
- Twelve figures revised for better pedagogy (21.6, 21.9, 21.10, 21.11, 21.12, 21.14, 21.18, 21.19, 21.20, Disease at a Glance boxes on yellow fever and toxoplasmosis; Disease in Depth: Malaria)
- Removed the Highlight box on search for malaria vaccines
- Expanded coverage of septicemia, streptococcal toxic shock syndrome (TSS) [formerly streptococcal toxic-shock-like syndrome (TSLS)], EPA-approved insect and tick repellents, vectors of plague, Epstein-Barr virus and mononucleosis and nasopharyngeal cancer, yellow fever, dengue and dengue hemorrhagic fever, Ebola hemorrhagic fever, and toxoplasmosis
- Updated diagnoses, epidemiology, treatment, and prevention data for all diseases
- Updated terminology to the use of *microbiome* in place of *normal microbiota* or *microbial flora*
- Three new **Multiple Choice** questions and three new **Fill in the Blanks** questions added to the end-of-chapter **Questions for Review**
- New **Disease in Depth: Ebola**
- New **Emerging Disease Case Study: Babesiosis**
- Added fill-in **Concept Mapping** exercise on Lyme disease

22 Microbial Diseases of the Respiratory System

- New chapter opener case study and photo
- Ten new photos [22.2, 22.5, 22.10a, 22.14, 22.17, Disease in Depth box over flu (5)]
- Five figures revised for better pedagogy [22.11, 22.12, 22.13, Disease in Depth box over flu (2)]

- Expanded coverage of pathogenesis and epidemiology of diseases, particularly healthcare-associated pneumonia (including ventilator-associated pneumonia), community-acquired pneumonia, reemerging pertussis and pertussis vaccines, tuberculosis, influenza, coronavirus respiratory syndromes (SARS and MERS), histoplasmosis
- Expanded coverage of influenza, severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS)
- Updated diagnoses and incidence data for all diseases
- Changed discussion of *ornithosis* to *psittacosis*—the preferred terminology
- Updated treatment regimens for streptococcal pharyngitis, diphtheria, common colds, otitis media, bacterial pneumonias, pneumonic plague, psittacosis (ornithosis), chlamydial pneumonia, legionellosis, drug-susceptible tuberculosis (TB), multi-drug resistant TB (MDR-TB), pertussis, inhalational anthrax, coccidioidomycosis, blastomycosis, and histoplasmosis.
- Expanded coverage of multi-drug-resistant tuberculosis (MDR-TB) and extensively-drug-resistant TB (XDR-TB)
- Added discussion of emerging pathogen *Sapovirus*, which causes gastroenteritis
- Updated terminology to the use of *microbiome* in place of *normal microbiota* or *microbial flora*
- New **Disease in Depth: Influenza**
- Added fill-in **Concept Mapping** exercises on tuberculosis

23 Microbial Diseases of the Digestive System

- New chapter opener case study and photo
- Nine new photos (23.5, 23.12, 23.18b, and Disease at a Glance boxes: Dental Caries, Bacterial Diarrhea, Peptic Ulcer Disease, Cholera, Mumps, and Amebiasis)
- Five revised, updated, enhanced, and pedagogically more effective figures (23.1, 23.4, 23.15, 23.19, Disease in Depth: Giardiasis)
- Updated diagnoses and incidence data
- Updated treatment regimens for peptic ulcers, traveler's diarrhea, *Campylobacter diarrhea*, typhoid fever, cholera, *C. diff.* diarrhea, oral herpes, and hepatitis B and C
- Discussion of yellow fever moved so as to make it more distinguishable from discussion of dengue fever
- Expanded coverage of the danger zone of temperatures for food service; enterotoxigenic and enterohemorrhagic *E. coli*, including hemolytic uremic syndrome; hepatitis B and C; *Taenia saginata* and *T. solium*
- Updated terminology to the use of *microbiome* in place of *normal microbiota* or *microbial flora*
- Updated terminology to the new recommended plural of *amoeba*: *amoebas*
- Added fill-in **Concept Mapping** exercise on viral hepatitis

24 Microbial Diseases of the Urinary and Reproductive Systems

- New chapter opener case study and photo
- Sixteen new figures [24.6b, Disease at a Glance: Pelvic Inflammatory Disease, Disease in Depth: Candidiasis (13), Disease at a Glance: Trichomoniasis]
- Six revised, updated, and enhanced figures (24.1, 24.3, 24.5, 24.7, 24.9a, Disease in Depth: Bacterial Urinary Tract Infections)
- New **Learning Outcome** (24.26) for *Chlamydia* pelvic inflammatory disease
- Two new **Disease in Depth** features: Candidiasis, Papillomas
- Removed discussion of chancroid (rare in Europe and the Americas, and worldwide cases have declined)
- Updated diagnoses and incidence data for all diseases
- Updated treatment regimens for staphylococcal toxic shock syndrome, pelvic inflammatory disease, gonorrhea
- Expanded coverage of pelvic inflammatory disease, chlamydial infections
- Updated terminology to the use of *microbiome* in place of *normal microbiota* or *microbial flora*
- Added fill-in **Concept Mapping** exercise on syphilis

25 Applied and Industrial Microbiology

- Chapter now devoted solely to applied and industrial microbiology; microbial ecology now covered in the new Chapter 26
- New chapter opener case study and photo
- Two figures revised, updated, or enhanced for better pedagogy (Emerging Disease: Primary Amebic Meningoencephalitis map and Figure 25.6; removed figure of collection of methane from a landfill)
- Removed the Highlight box on search for a more ecological friendly source of indigo dye
- Revised and enhanced discussion of live yogurt, rennin, butanol as an alternative fuel, biosensors, water contamination versus water pollution
- Added four **Fill in the Blanks** questions and two new **Visualize It!** questions to the end-of-chapter **Questions for Review**
- Added fill-in **Concept Mapping** exercise on microbial roles in food production

26 Microbial Ecology and Microbiomes

- New chapter expanding coverage of microbial ecology to provide more emphasis on the ecology of the human body and its microbiome
- New chapter opener case study and photo
- Five figures revised, updated, or enhanced for better pedagogy (26.1, 26.4, 26.5, 26.6, 26.9)
- One new photos (26.7)
- Removed the Highlight box on development of a viral biote3rrorism agent
- Updated list of bioterrorist threats to include additions to Category C
- New **Clinical Case Study: Bioterrorism in the Mail** concerning anthrax
- New **Solve the Problem: Fecal Microbiome Transfer: Medicine or Magic?** (problem-based learning investigation concerning the use of fecal transplants to change the colonic microbiome)
- One new **Multiple Choice** question, one new **Modified True/False** question, one new **Fill in the Blanks** question, and three new **Critical Thinking** questions added to the end-of-chapter **Questions for Review**
- Added fill-in **Concept Mapping** exercise on microbial ecology and biogeochemical cycles

Reviewers for the Fifth Edition

I wish to thank the hundreds of instructors and students who participated in reviews, class tests, and focus groups for earlier editions of the textbook. Your comments have informed this book from beginning to end, and I am deeply grateful. For the fifth edition, I extend my deepest appreciation to the following reviewers.

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Robert W. Bauman
Amarillo, Texas

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DISEASE AT A GLANCE

DISEASE IN DEPTH

1 A Brief History of Microbiology

MICRO IN THE CLINIC

Too Much Cake, or Something Worse?

Patty is a mother to 14-year-old twins and works full time. Between her own job, driving her kids to practices and events, and spending time with her husband, Patty is constantly on the go. This past weekend was no exception. On Friday night, her office group went out for happy hour to celebrate a colleague's promotion. They had a great time—eating sushi, drinking wine, and relaxing. Saturday morning, her daughter's soccer team had a brunch, and in the afternoon her son's Little League team had an end-of-the-season barbecue. Saturday night she felt a little bit bloated but thought it was from the all the food she had eaten at the brunch—she was so full from the brunch that she had eaten only fruit salad at the barbecue.

It's late Sunday afternoon, and she and her husband have just returned from a birthday party for his sister. As they start to prepare dinner, Patty starts to have a stomachache and feels a bit nauseated. She suspects it's from eating too much birthday cake; however, when she wakes up in the middle of the night with diarrhea, she thinks that it might be something more than the cake. Monday morning Patty is unable to go to work—she's had diarrhea all night long and has a terrible headache. When she starts vomiting early Monday afternoon, she decides that she needs to go to the doctor.

1. **Is it just a case of too much cake?**
2. **What else could be causing Patty's symptoms?**

Turn to the end of the chapter (p. 22) to find out.

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SOLVE THE PROBLEM

Smallpox: To Be or Not To Be?

Smallpox is likely the worst infectious disease of all time, killing an estimated 300 million people in the 19th century alone. It is a terrifying killer, with a death rate as high as 33% and the survivors carrying lifelong scars.

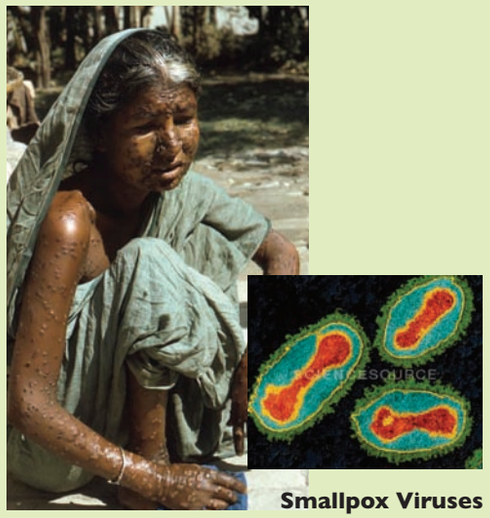
British medical doctor Edward Jenner is credited with inventing smallpox vaccination—the world's first immunization. On May 14, 1796, Jenner collected secretions from a cowpox sore on the hand of a milkmaid and rubbed them into scratches he made on the skin of an eight-year-old boy. Then, about a month later, he injected the boy with secretions from a lesion on a smallpox patient. The child did not get smallpox; he was immune. Jenner termed his technique vaccination, which comes from the Latin term for cow, *vacca*.

Medical doctors began vaccinating people with special two-pronged needles, and eventually smallpox was eradicated worldwide. The last case was documented on October 26, 1977.

Eradication represents one of the great triumphs of modern medicine, but smallpox virus itself still exists. Stocks are kept frozen in secure laboratories at the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia, and in the State Research Center of Virology and Biotechnology in Koltsovo, Russia.

Imagine you are assigned to be part of a team tasked to determine what to do with the world's remaining stores of smallpox virus.

- **Should governments and laboratories keep them?**
- **Or should they be destroyed? In other words, should we intentionally make a species extinct forever?**



Smallpox Viruses

- **What facts do you need to make an informed decision?**
- **If the decision were to be made today, how would you vote?**

Go to the study area to solve the problem.

Science is the study of nature that proceeds by posing questions about observations. Why are there seasons? What is the function of the nodules at the base of this plant? Why does this bread taste sour? What does plaque from between teeth look like when magnified? What causes the spread of diseases?

Many early written records show that people have always asked questions like these. For example, the Greek physician Hippocrates (ca. 460–ca. 377 B.C.) wondered whether there is a link between environment and disease, and the Greek historian Thucydides (ca. 460–ca. 404 B.C.) questioned why he and other survivors of the plague could have close contact with victims and not fall ill again. For many centuries, the answers to these and other fundamental questions about the nature of life remained largely unanswered. But about 350 years ago, the invention of the microscope began to provide some clues.

In this chapter, we'll see how one man's determination to answer a fundamental question about the nature of life—What does life really look like?—led to the birth of a new science called *microbiology*. We'll then see how the search for answers to other questions—such as those concerning spontaneous generation, the reason fermentation occurs, and the cause of disease—prompted advances in this new science. Finally, we'll look briefly at some of the key questions microbiologists are asking today.

The Early Years of Microbiology

The early years of microbiology brought the first observations of microbial life and the initial efforts to organize them into logical classifications.

What Does Life Really Look Like?

LEARNING OUTCOMES

1.1 Describe the world-changing scientific contributions of Leeuwenhoek.
1.2 Define microbes in the words of Leeuwenhoek and as we know them today.

A few people have changed the world of science forever. We've all heard of Galileo, Newton, and Einstein, but the list also includes Antoni van Leeuwenhoek (lā'vĕn-huk; 1632–1723), a Dutch tailor, merchant, and lens grinder, and the man who first discovered the bacterial world **(FIGURE 1.1)**.

Leeuwenhoek was born in Delft, the Netherlands, and lived most of his 90 years in the city of his birth. What set Leeuwenhoek apart from many other men of his generation was an

▲ **FIGURE 1.1 Antoni van Leeuwenhoek.** Leeuwenhoek reported the existence of protozoa in 1674 and of bacteria in 1676. *Why did Leeuwenhoek discover protozoa before bacteria?*

Figure 1.1 *Protozoa are generally larger than bacteria.*

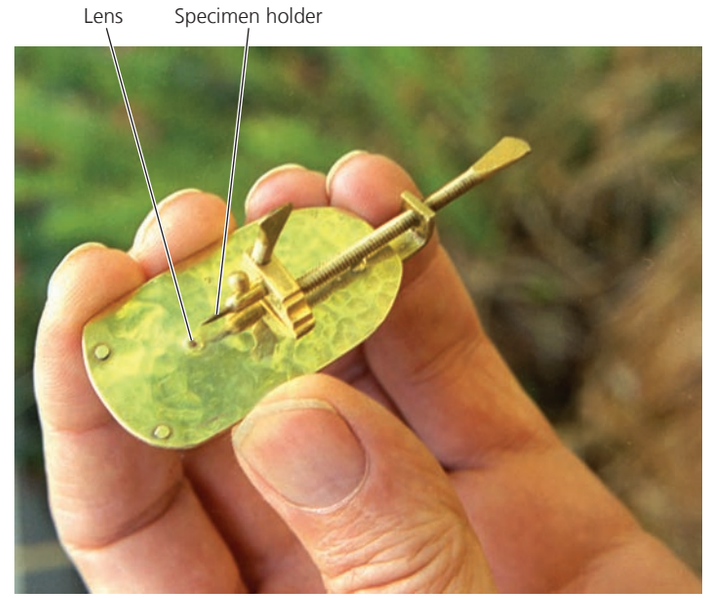
insatiable curiosity coupled with an almost stubborn desire to do everything for himself. His journey to fame began simply enough, when as a cloth merchant he needed to examine the quality of cloth. Rather than merely buying a magnifying lens, he learned to make glass lenses of his own **(FIGURE 1.2)**. Soon he began asking, "What does it really look like?" of everything in his world: the stinger of a bee, the brain of a fly, the leg of a louse, a drop of blood, flakes of his own skin. To find answers, he spent hours examining, reexamining, and recording every detail of each object he observed.

Making and looking through his simple microscopes, really no more than magnifying glasses, became the overwhelming passion of his life. His enthusiasm and dedication are evident from the fact that he sometimes personally extracted the metal for a microscope from ore. Further, he often made a new microscope for each specimen, which remained mounted so that he could view it again and again. Then one day, he turned a lens onto a drop of water. We don't know what he expected to see, but certainly he saw more than he had anticipated. As he reported to the Royal Society of London[1] in 1674, he was surprised and delighted by

> some green streaks, spirally wound serpent-wise, and orderly arranged. . . . Among these there were, besides, very many little animalcules, some were round, while others a bit bigger consisted of an oval. On these last, I saw two little legs near the head, and two little fins at the hind most end of the body. . . . And the motion of most of these animalcules in the water was so swift, and so various, upwards, downwards, and round about, that 'twas wonderful to see.[2]

[1]The Royal Society of London for the Promotion of Natural Knowledge, granted a royal charter in 1662, is one of the older and more prestigious scientific groups in Europe.

[2]Antoni von Leeuwenhoek, in a letter to the Royal Society of London for the Promotion of Natural Knowledge.



▲ **FIGURE 1.2 Reproduction of Leeuwenhoek's microscope.** This simple device is little more than a magnifying glass with screws for manipulating the specimen, yet with it, Leeuwenhoek changed the way we see our world. The lens, which is convex on both sides, is about the size of a pinhead. The object to be viewed was mounted either directly on the specimen holder or inside a small glass tube, which was then mounted on the specimen holder.

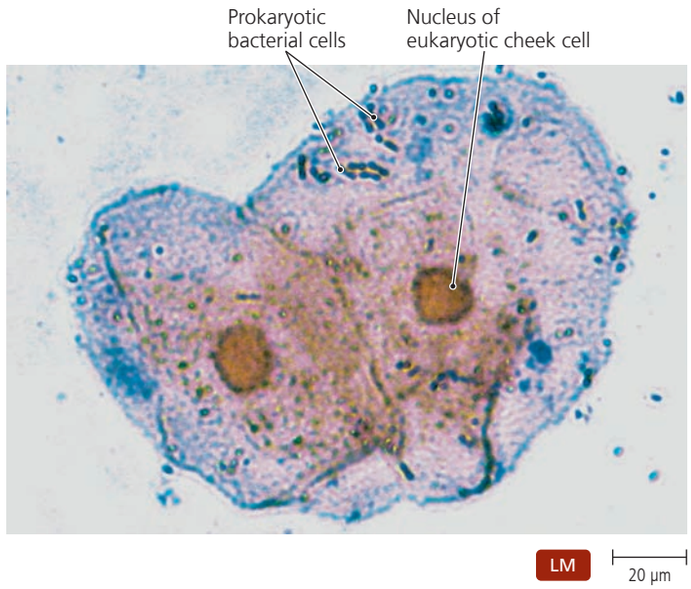
Leeuwenhoek had discovered the previously unknown microbial world, which today we know to be populated with tiny animals, fungi, algae, and single-celled protozoa **(FIGURE 1.3)**. In a later report to the Royal Society, he noted that

> the number of these animals in the plaque of a man's teeth, are so many that I believe they exceed the number of men in a kingdom. . . . in a quantity of matter no bigger than the 1/100 part of a [grain of] sand.

▲ **FIGURE 1.3 The microbial world.** Leeuwenhoek reported seeing a scene very much like this, full of numerous fantastic, cavorting creatures.

From the figure accompanying his report and the precise description of the size of these organisms from between his teeth, we know that Leeuwenhoek was reporting the existence of bacteria. By the end of the 19th century, Leeuwenhoek's "beasties," as he sometimes dubbed them, were called **microorganisms**, and today we also know them as **microbes**. Both terms include all organisms that are too small to be seen without a microscope.

Because of the quality of his microscopes, his profound observational skills, his detailed reports over a 50-year period, and his report of the discovery of many types of microorganisms, Antoni van Leeuwenhoek was elected to the Royal Society in 1680. He was one of the more famous scientists of his time.



▲ **FIGURE 1.4 Cells of the bacterium *Streptococcus* (dark blue) and two human cheek cells.** Notice the size difference.

How Can Microbes Be Classified?

LEARNING OUTCOMES

- **1.3** List six groups of microorganisms.
- **1.4** Explain why protozoa, algae, and nonmicrobial parasitic worms are studied in microbiology.
- **1.5** Differentiate prokaryotic from eukaryotic organisms.

Shortly after Leeuwenhoek made his discoveries, the Swedish botanist Carolus Linnaeus (1707–1778) developed a **taxonomic system**—a system for naming plants and animals and grouping similar organisms together. For instance, Linnaeus and other scientists of the period grouped all organisms into either the animal kingdom or the plant kingdom. Today, biologists still use this basic system, but they have modified Linnaeus's scheme by adding categories that more realistically reflect the relationships among organisms. For example, scientists no longer classify yeasts, molds, and mushrooms as plants but instead as fungi. (We examine taxonomic schemes in more detail in Chapter 4.)

The microorganisms that Leeuwenhoek described can be grouped into six basic categories: bacteria, archaea, fungi, protozoa, algae, and small multicellular animals. The only types of microbes not described by Leeuwenhoek are *viruses*,[3] which are too small to be seen without an electron microscope. We briefly consider organisms in the first five categories in the following sections.

Bacteria and Archaea

Bacteria and **archaea** are **prokaryotic**,[4] meaning that their cells lack nuclei; that is, their genes are not surrounded by a membrane. Bacterial cell walls are composed of a polysaccharide called *peptidoglycan*, though some bacteria lack cell walls. The cell walls of archaea lack peptidoglycan and instead are composed of other chemicals. Members of both groups reproduce asexually. (Chapters 3, 4, and 11 examine other differences between bacteria and archaea, and Chapters 19–24 discuss pathogenic [disease-causing] bacteria.)

Most archaea and bacteria are much smaller than eukaryotic cells **(FIGURE 1.4)**. They live singly or in pairs, chains, or clusters in almost every habitat containing sufficient moisture. Archaea are often found in extreme environments, such as the highly saline and arsenic-rich Mono Lake in California, acidic hot springs in Yellowstone National Park, and oxygen-depleted mud at the bottom of swamps. No archaea are known to cause diseases in humans.

Though bacteria may have a poor reputation in our world, the great majority do not cause disease in animals, humans, or crops. Indeed, bacteria are beneficial to us in many ways. For example, without beneficial bacteria, our bodies would be much more susceptible to disease. Also, bacteria (and fungi) degrade dead plants and animals to release phosphorus, sulfur, nitrogen, and carbon back into the air, soil, and water to be used by new generations of organisms. Without microbial recyclers, the world would be buried under the corpses of uncountable dead organisms.

Fungi

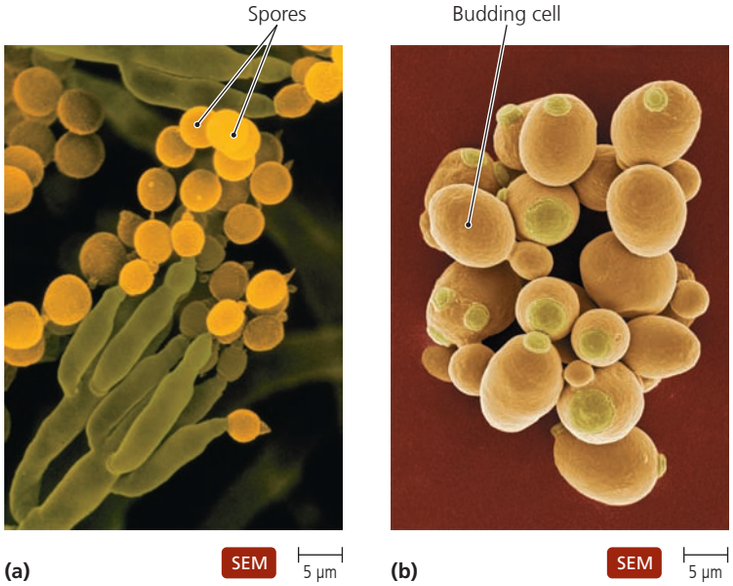
Fungi (fŭn′jī)[5] are **eukaryotic**;[6] that is, each of their cells contains a nucleus composed of genetic material surrounded by a distinct membrane. Fungi are different from plants because fungi obtain their food from other organisms (rather than making it for themselves). They differ from animals by having cell walls.

[3]Technically, viruses are not "organisms," because they neither replicate themselves nor carry on the chemical reactions of living things.

[4]From Greek *pro,* meaning "before," and *karyon*, meaning "kernel" (which, in this case, refers to the nucleus of a cell).

[5]Plural of the Latin *fungus*, meaning "mushroom."

[6]From Greek *eu*, meaning "true," and *karyon*, meaning "kernel."



▲ **FIGURE 1.5 Fungi. (a)** The mold *Penicillium chrysogenum*, which produces penicillin, has long filaments that intertwine to form its body (not shown). It reproduces by spores. **(b)** The yeast *Saccharomyces cerevisiae*. Yeasts are round to oval and typically reproduce by budding.

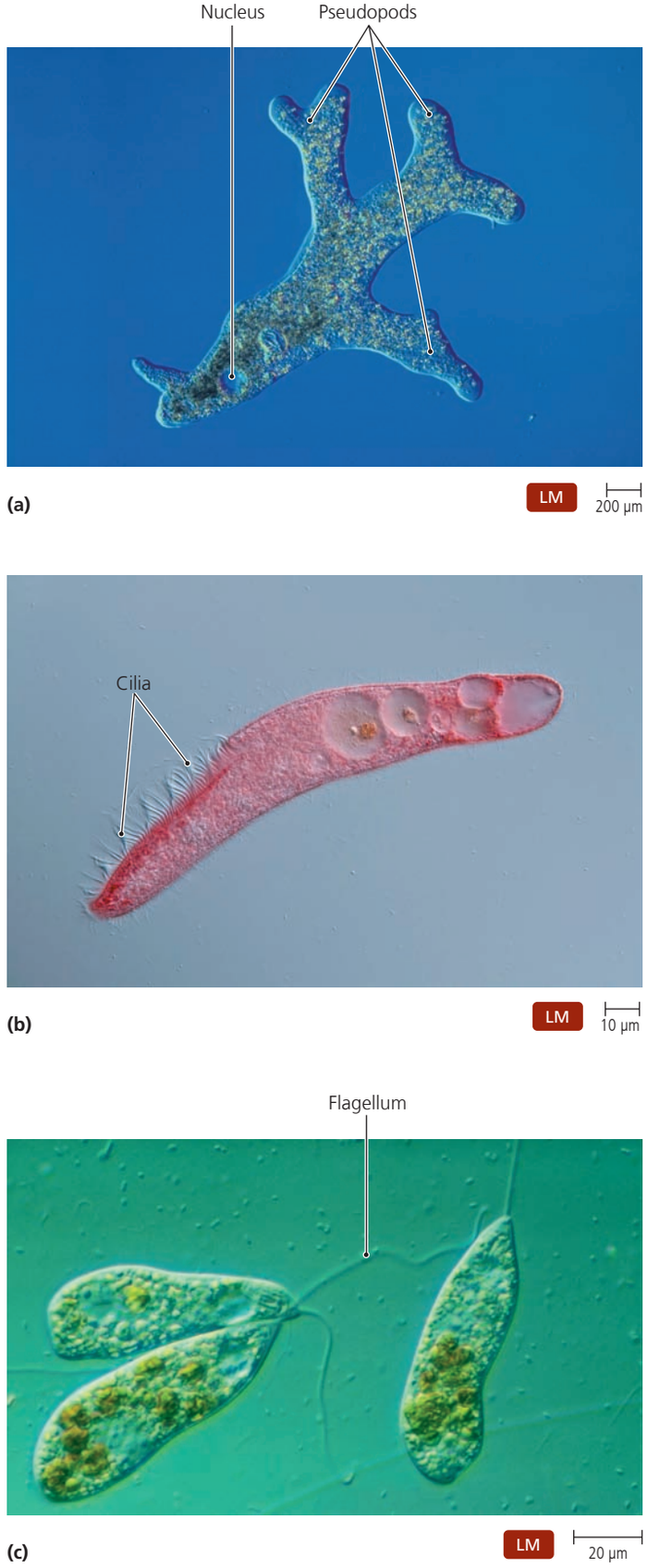
Microscopic fungi include some molds and yeasts. **Molds** are typically multicellular organisms that grow as long filaments that intertwine to make up the body of the mold. Molds reproduce by sexual and asexual spores, which are cells that produce a new individual without fusing with another cell **(FIGURE 1.5a)**. The cottony growths on cheese, bread, and jams are molds. *Penicillium chrysogenum* (pen-i-sil′ē-ŭm krī-so′jĕn-ŭm) is a mold that produces penicillin.

Yeasts are unicellular and typically oval to round. They reproduce asexually by *budding*, a process in which a daughter cell grows off the mother cell. Some yeasts also produce sexual spores. An example of a useful yeast is *Saccharomyces cerevisiae* (sak-ă-rō-mī′sēz se-ri-vis′ē-ī; **FIGURE 1.5b**), which causes bread to rise and produces alcohol from sugar (see **Beneficial Microbes: Bread, Wine, and Beer** on p. 8). Another example of a yeast is *Candida albicans* (kan′did-ă al′bi-kanz), which causes most cases of yeast infections in women. (Chapters 12 and 19–25 discuss fungi and their significance in the environment, in food production, and as agents of human disease.)

Protozoa

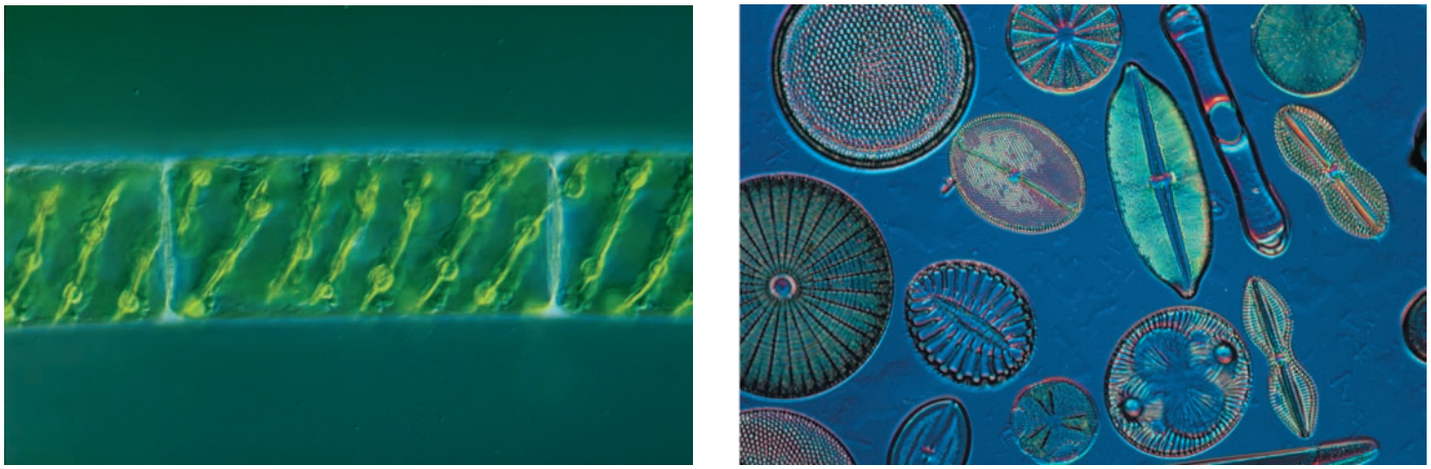
Protozoa are single-celled eukaryotes that are similar to animals in their nutritional needs and cellular structure. In fact, *protozoa* is Greek for "first animals," though scientists today classify them in their own groups rather than as animals. Most protozoa are capable of locomotion, and one way scientists categorize protozoa is according to their locomotive structures: *pseudopods*,[7] *cilia*,[8] or *flagella*.[9] Pseudopods are extensions of a cell that flow in the direction of travel **(FIGURE 1.6a)**. Cilia are

[7]Plural Greek *pseudes*, meaning "false," and *podos*, meaning "foot."
[8]Plural of the Latin *cilium*, meaning "eyelid."
[9]Plural of the Latin *flagellum*, meaning "whip."



▲ **FIGURE 1.6 Locomotive structures of protozoa. (a)** Pseudopods are cellular extensions used for locomotion and feeding, as seen in *Amoeba proteus*. **(b)** *Blepharisma americana* moves by means of cilia. **(c)** Flagella are whiplike extensions that are less numerous and longer than cilia, as seen in *Peranema*. *How do cilia and flagella differ?*

Figure 1.6 *Cilia are short and numerous and often cover the cell, whereas flagella are long and relatively few in number.*



▲ **FIGURE 1.7 Algae. (a)** *Spirogyra.* These microscopic algae grow as chains of cells containing helical photosynthetic structures. **(b)** Diatoms. These beautiful algae have glasslike cell walls.

numerous short protrusions of a cell that beat rhythmically to propel the protozoan through its environment **(FIGURE 1.6b)**. Flagella are also extensions of a cell but are fewer, longer, and more whiplike than cilia **(FIGURE 1.6c)**. Some protozoa, such as the malaria-causing *Plasmodium* (plaz-mōʹdē-ŭm), are nonmotile in their mature forms.

Many protozoa live freely in water, but some live inside animal hosts, where they can cause disease. Most protozoa reproduce asexually, though some are sexual as well. (Chapters 12 and 19–24 further examine protozoa and some diseases they cause.)

Algae

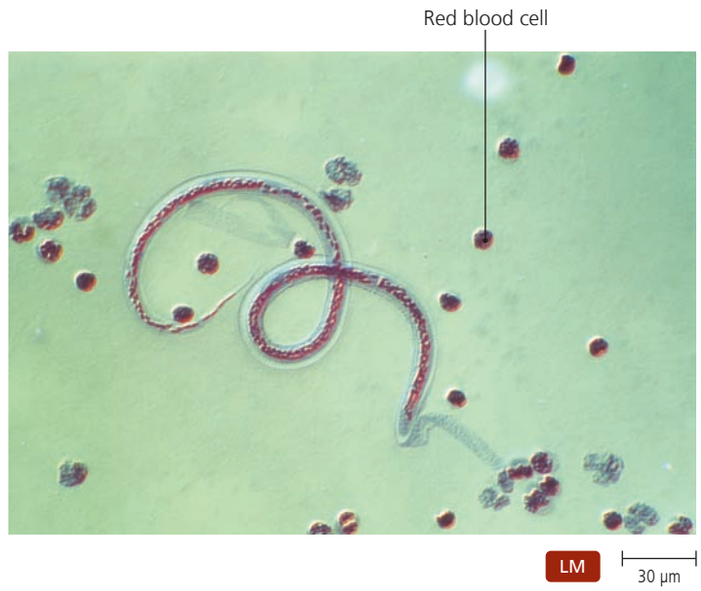
Algae[10] are unicellular or multicellular *photosynthetic* eukaryotes; that is, like plants, they make their own food from carbon dioxide and water using energy from sunlight. They differ from plants in the relative simplicity of their reproductive structures. Algae are categorized on the basis of their pigmentation and the composition of their cell walls.

Large algae, commonly called seaweeds and kelps, are common in the world's oceans. Manufacturers use gelatinous chemicals from the cell walls of some large algae as thickeners and emulsifiers in many foods and cosmetics. Scientists use the algae-derived chemical called *agar* to solidify laboratory media.

Unicellular algae **(FIGURE 1.7)** are common in freshwater ponds, streams, and lakes and in the oceans as well. They are the major food of small aquatic and marine animals and provide most of the world's oxygen as a by-product of photosynthesis. The glasslike cell walls of diatoms provide grit for many polishing compounds. (Chapter 12 discusses other aspects of the biology of algae.)

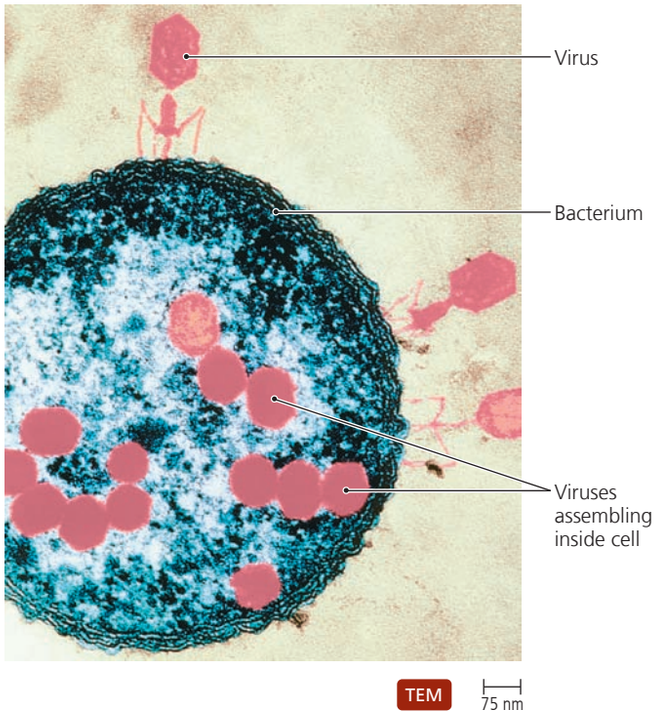
Other Organisms of Importance to Microbiologists

Microbiologists also study parasitic worms, which range in size from microscopic forms **(FIGURE 1.8)** to adult tapeworms over 10 meters (approximately 33 feet) in length. Even though most parasitic worms are not microscopic as adults, many of them cause diseases that were studied by early microbiologists, so microbiology books and classes often discuss parasitic worms. Further, laboratory scientists diagnose infections of parasitic



▲ **FIGURE 1.8 An immature stage of a parasitic worm in blood.**

[10]Plural of the Latin *alga*, meaning "seaweed."



▲ FIGURE 1.9 A colorized electron microscope image of viruses infecting a bacterium. Viruses, which are acellular obligatory parasites, are generally too small to be seen with a light microscope. Notice how small the viruses are compared to the bacterium.

worms by finding microscopic eggs and immature stages in blood, fecal, urine, and lymph specimens. (Chapter 23 discusses parasitic worms.)

The only type of microbe that remained hidden from Leeuwenhoek and other early microbiologists was the virus, which is typically much smaller than the smallest prokaryote and is not usually visible by light microscopy **(FIGURE 1.9)**. Viruses were not seen until the electron microscope was invented in 1932. All viruses are acellular (not composed of cells) obligatory parasites composed of small amounts of genetic material (either DNA or RNA) surrounded by a protein coat. (Chapter 13 examines the general characteristics of viruses, and Chapters 18–24 discuss specific viral pathogens.)

Leeuwenhoek first reported the existence of most types of microorganisms in the late 1600s, but microbiology did not develop significantly as a field of study for almost two centuries. There were a number of reasons for this delay. First, Leeuwenhoek was a suspicious and secretive man. Though he built over 400 microscopes, he never trained an apprentice, and he never sold or gave away a microscope. In fact, he never let *anyone*—not his family or such distinguished visitors as the czar of Russia—so much as peek through his very best instruments. When Leeuwenhoek died, the secret of creating superior microscopes was lost. It took almost 100 years for scientists to make microscopes of equivalent quality.

Another reason that microbiology was slow to develop as a science is that scientists in the 1700s considered microbes to be curiosities of nature and insignificant to human affairs. But in the late 1800s, scientists began to adopt a new philosophy, one that demanded experimental evidence rather than mere acceptance of traditional knowledge. This fresh philosophical foundation, accompanied by improved microscopes, new laboratory techniques, and a drive to answer a series of pivotal questions, propelled microbiology to the forefront as a scientific discipline.

TELL ME WHY

Some people consider Leeuwenhoek the "Father of Microbiology." Explain why this moniker makes sense.

The Golden Age of Microbiology

LEARNING OUTCOME

1.6 List and answer four questions that propelled research in what is called the "Golden Age of Microbiology."

For about 50 years, during what is sometimes called the "Golden Age of Microbiology," scientists and the blossoming field of microbiology were driven by the search for answers to the following four questions:

- Is spontaneous generation of microbial life possible?
- What causes fermentation?
- What causes disease?
- How can we prevent infection and disease?

Competition among scientists who were striving to be the first to answer these questions drove exploration and discovery in microbiology during the late 1800s and early 1900s. These scientists' discoveries and the fields of study they initiated continue to shape the course of microbiological research today.

In the next sections, we consider these questions and how the great scientists accumulated the experimental evidence that answered them.

Does Microbial Life Spontaneously Generate?

LEARNING OUTCOMES

1.7 Identify the scientists who argued in favor of spontaneous generation.
1.8 Compare and contrast the investigations of Redi, Needham, Spallanzani, and Pasteur concerning spontaneous generation.
1.9 List four steps in the scientific method of investigation.

A dry lake bed has lain under the relentless North African desert sun for eight long months. The cracks in the baked, parched mud are wider than a man's hand. There is no sign of life anywhere in the scorched terrain. With the abruptness characteristic of desert storms, rain falls in a torrent, and a raging flood

BENEFICIAL MICROBES

Bread, Wine, and Beer

Microorganisms play important roles in people's lives; for example, pathogens have undeniably altered the course of history. However, what may be the most important microbiological event—one that has had a greater impact on culture and society than that of any disease or epidemic—was the domestication of the yeast used by bakers and brewers. Its scientific name, *Saccharomyces cerevisiae*, translates from Latin as "sugar fungus [that makes] beer."

The earliest record of the use of yeast comes from Persia (modern Iran), where archaeologists have found the remains of grapes and wine preservatives in pottery vessels more than 7000 years old. Brewing of beer likely started even earlier, its beginnings undocumented. The earliest examples of leavened bread are from Egypt and show that bread making was routine about 6000 years ago. Before that time, bread was unleavened and flat.

It is likely that making wine and brewing beer occurred earlier than the use of leavened bread because *Saccharomyces* is naturally found on grapes, which can begin to ferment while still on the vine. Historians hypothesize that early bakers may have exposed bread dough to circulating air, hoping that the invisible and inexplicable "fermentation principle" would inoculate the bread. Another hypothesis is that bakers learned to add small amounts of beer or wine to the bread, intentionally inoculating the dough with yeast. Of course, all those years before Leeuwenhoek and Pasteur, no one knew that the fermenting ingredient of wine was a living organism.

Besides its role in baking and in making alcoholic beverages, *S. cerevisiae* is an important tool for the study of cells. Scientists use yeast to delve into the mysteries of cellular function, organization, and genetics, making *Saccharomyces* the most intensely studied eukaryote. In fact, molecular biologists published the complete sequence of the genes of *S. cerevisiae* in 1996—the first complete sequence published for any eukaryotic cell.

Today, scientists are working toward using *S. cerevisiae* in novel ways. For example, some nutritionists and gastroenterologists are examining the use of *Saccharomyces* as a *probiotic*, that is, a microorganism intentionally taken to ward off disease and promote good health. Research suggests that the yeast helps treat diarrhea and colitis and may even help prevent these and other gastrointestinal diseases.

of roiling water and mud crashes down the dry streambed and fills the lake. Within hours, what had been a lifeless, dry mudflat becomes a pool of water teeming with billions of shrimp; by the next day it is home to hundreds of toads. Where did these animals come from?

Many philosophers and scientists of past ages thought that living things arose via three processes: through asexual reproduction, through sexual reproduction, or from nonliving matter. The appearance of shrimp and toads in the mud of what so recently was a dry lake bed was seen as an example of the third process, which came to be known as *abiogenesis*,[11] or **spontaneous generation**. The theory of spontaneous generation as promulgated by Aristotle (384–322 B.C.) was widely accepted for over 2000 years because it seemed to explain a variety of commonly observed phenomena, such as the appearance of maggots on spoiling meat. However, the validity of the theory came under challenge in the 17th century.

Redi's Experiments

In the late 1600s, the Italian physician Francesco Redi (1626–1697) demonstrated by a series of experiments that when decaying meat was kept isolated from flies, maggots never developed, whereas meat exposed to flies was soon infested with maggots **(FIGURE 1.10)**. As a result of experiments such as these, scientists began to doubt Aristotle's theory and adopt the view that animals come only from other animals.

[11]From Greek *a*, meaning "not"; *bios*, meaning "life"; and *genein*, meaning "to produce."

▲ **FIGURE 1.10 Redi's experiments.** When the flask remained unsealed, maggots covered the meat within a few days. When the flask was sealed, flies were kept away, and no maggots appeared on the meat. When the flask opening was covered with gauze, flies were kept away, and no maggots appeared on the meat, although a few maggots appeared on top of the gauze.

Needham's Experiments

The debate over spontaneous generation was rekindled when Leeuwenhoek discovered microbes and showed that they appeared after a few days in freshly collected rainwater. Though scientists agreed that larger animals could not arise spontaneously, they disagreed about Leeuwenhoek's "wee animalcules"; surely they did not have parents, did they? They must arise spontaneously.

The proponents of spontaneous generation pointed to the careful demonstrations of British investigator John T. Needham

(1713–1781). He boiled beef gravy and infusions[12] of plant material in vials, which he then tightly sealed with corks. Some days later, Needham observed that the vials were cloudy, and examination revealed an abundance of "microscopical animals of most dimensions." As he explained it, there must be a "life force" that causes inanimate matter to spontaneously come to life because he had heated the vials sufficiently to kill everything. Needham's experiments so impressed the Royal Society that they elected him a member.

Spallanzani's Experiments

Then, in 1799, the Italian Catholic priest and scientist Lazzaro Spallanzani (1729–1799) reported results that contradicted Needham's findings. Spallanzani boiled infusions for almost an hour and sealed the vials by melting their slender necks closed. His infusions remained clear unless he broke the seal and exposed the infusion to air, after which they became cloudy with microorganisms. He concluded three things:

- Needham either had failed to heat his vials sufficiently to kill all microbes or had not sealed them tightly enough.
- Microorganisms exist in the air and can contaminate experiments.
- Spontaneous generation of microorganisms does not occur; all living things arise from other living things.

Although Spallanzani's experiments would appear to have settled the controversy once and for all, it proved difficult to dethrone a theory that had held sway for 2000 years, especially when so notable a man as Aristotle had propounded it. One of the criticisms of Spallanzani's work was that his sealed vials did not allow enough air for organisms to thrive; another objection was that his prolonged heating destroyed the "life force." The debate continued until the French chemist Louis Pasteur **(FIGURE 1.11)** conducted experiments that finally laid the theory of spontaneous generation to rest.

Pasteur's Experiments

Louis Pasteur (1822–1895) was an indefatigable worker who pushed himself as hard as he pushed others. As he wrote his sisters, "To *will* is a great thing dear sisters, for Action and Work usually follow Will, and almost always Work is accompanied by Success. These three things, Work, Will, Success, fill human existence. Will opens the door to success both brilliant and happy; Work passes these doors, and at the end of the journey Success comes to crown one's efforts." When his wife complained about his long hours in the laboratory, he replied, "I will lead you to fame."

Pasteur's determination and hard work are apparent in his investigations of spontaneous generation. Like Spallanzani, he boiled infusions long enough to kill everything. But instead of sealing the flasks, he bent their necks into an S-shape, which allowed air to enter while preventing the introduction of dust and microbes into the broth **(FIGURE 1.12)**.

[12]Infusions are broths made by heating water containing plant or animal material.

▲ **FIGURE 1.11 Louis Pasteur.** Often called the Father of Microbiology, he disproved spontaneous generation. In this depiction, Pasteur examines some bacterial cultures.

Crowded for space and lacking funds, he improvised an incubator in the opening under a staircase. Day after day, he crawled on hands and knees into this incommodious space and examined his flasks for the cloudiness that would indicate the presence of living organisms. In 1861, he reported that his "swan-necked flasks" remained free of microbes even 18 months later. Because the flasks contained all the nutrients (including air) known to be required by living things, he concluded, "Never will spontaneous generation recover from the mortal blow of this simple experiment."

Pasteur followed this experiment with demonstrations that microbes in the air were the "parents" of Needham's microorganisms. He broke the necks off some flasks, exposing the liquid in them directly to the air, and he carefully tilted others so that the liquid touched the dust that had accumulated in their necks. The next day, all of these flasks were cloudy with microbes. He concluded that the microbes in the liquid were the progeny of microbes that had been on the dust particles in the air.

The Scientific Method

The debate over spontaneous generation led in part to the development of a generalized **scientific method** by which questions are answered through observations of the outcomes of carefully controlled experiments instead of by conjecture or according to the opinions of any authority figure. The scientific method, which provides a framework for conducting an investigation rather than a rigid set of specific "rules," consists of four basic steps **(FIGURE 1.13)**:

1. A group of observations leads a scientist to ask a question about some phenomenon.
2. The scientist generates a hypothesis—that is, a potential answer to the question.
3. The scientist designs and conducts an experiment to test the hypothesis.
4. Based on the observed results of the experiment, the scientist either accepts, rejects, or modifies the hypothesis.