FIFTH EDITION

MICROBIOLOGY

A SYSTEMS APPROACH

MARJORIE KELLY COWAN | HEIDI SMITH

Mc Graw Hill Education

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Microbiology

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Marjorie Kelly Cowan
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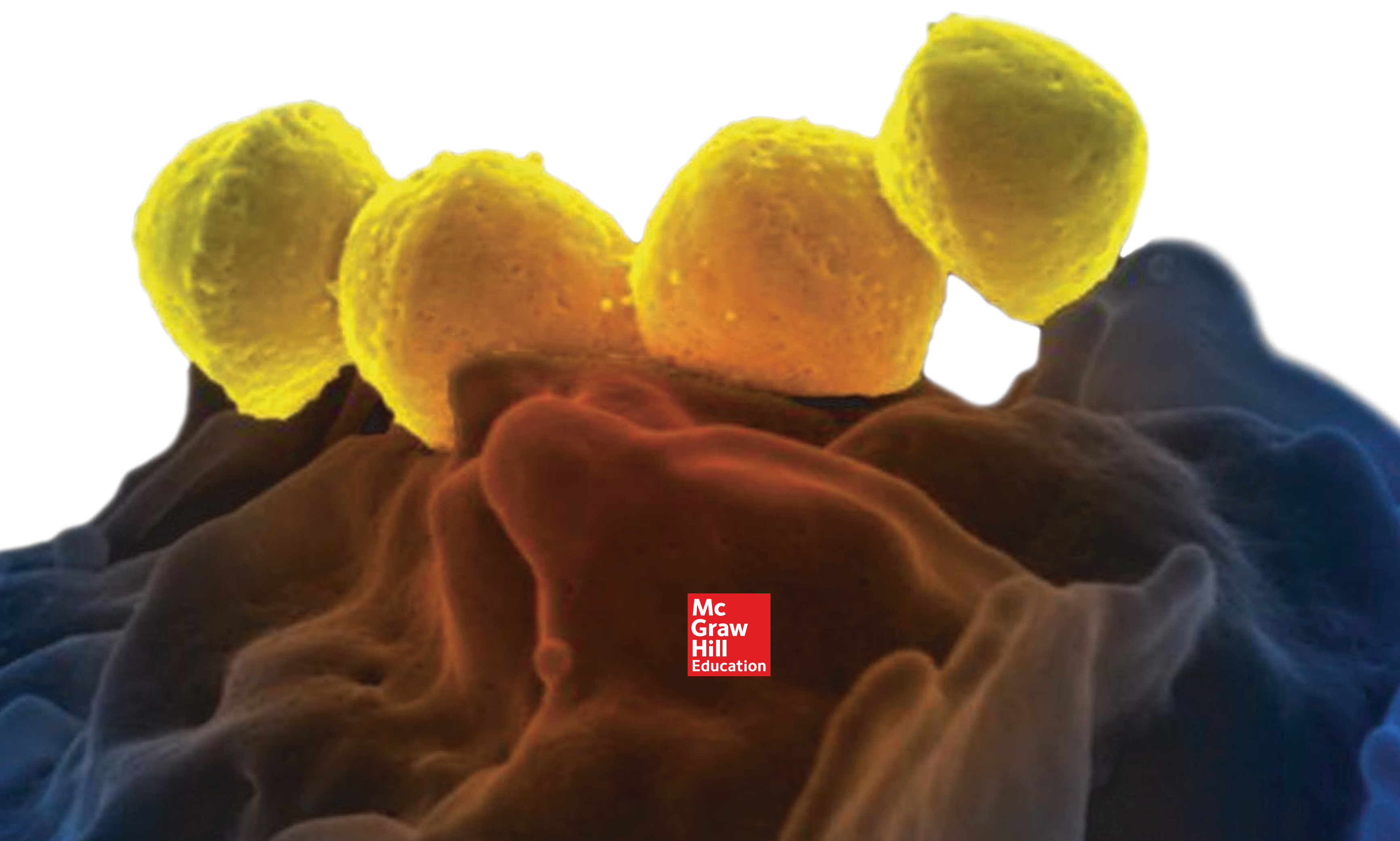

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MICROBIOLOGY: A SYSTEMS APPROACH, FIFTH EDITION

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Brief Contents

About the Authors

© Ted Light

Kelly Cowan has taught microbiology to pre-nursing and allied health students for over 20 years. She received her PhD from the University of Louisville and held postdoctoral positions at the University of Maryland and the University of Groningen in the Netherlands. Her campus, Miami University Middletown, is an open admissions regional campus of Miami University in Ohio. She has also authored over 25 basic research papers with her undergraduate and graduate students. For the past several years, she has turned her focus to studying pedagogical techniques that narrow the gap between underresourced students and well-resourced students. She is past chair of the American Society for Microbiology's Undergraduate Education committee, and past chair of ASM's education division, Division W.

Having a proven educator as an integrated digital author makes a *proven* learning system even better.

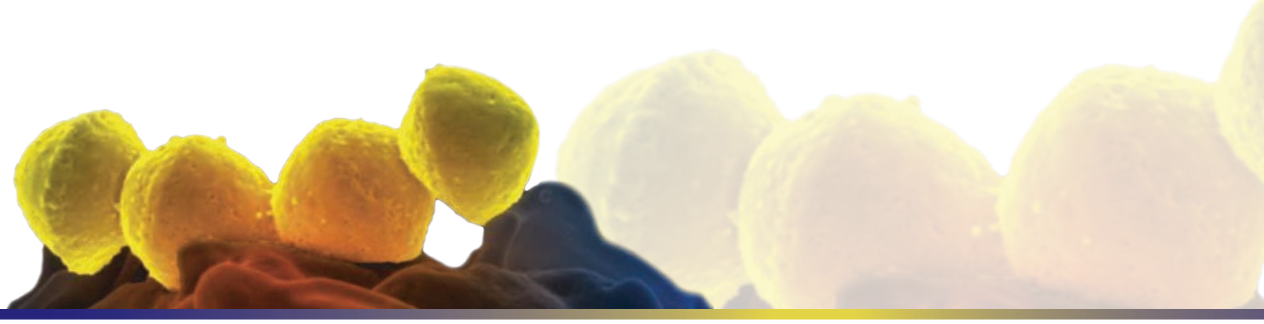
With this fifth edition, we are pleased to have Heidi Smith on the team. Heidi works hand-in-hand with the textbook author, creating online tools that truly complement and enhance the book's content. Because of Heidi, we offer you a robust digital learning program, tied to Learning Outcomes, to enhance your lecture and lab, whether you run a traditional, hybrid, or fully online course.

© Heidi Smith

Heidi Smith leads the microbiology department at Front Range Community College in Fort Collins, Colorado. Collaboration with other faculty across the nation, the development and implementation of new digital learning tools, and her focus on student learning outcomes have revolutionized Heidi's face-to-face and online teaching approaches and student performance in her classes. The use of digital technology has given Heidi the ability to teach courses driven by real-time student data and with a focus on active learning and critical thinking activities.

Heidi is an active member of the American Society for Microbiology and participated as a task force member for the development of their Curriculum Guidelines for Undergraduate Microbiology Education. At FRCC, Heidi directs a federal grant program designed to increase student success in transfer and completion of STEM degrees at the local university as well as facilitate undergraduate research opportunities for underrepresented students.

Off campus, Heidi spends as much time as she can enjoying the beautiful Colorado outdoors with her husband and three young children.



Preface

Students:

Welcome to the microbial world! I think you will find it fascinating to understand how microbes interact with us, and with our environment. The interesting thing is that each of you has already had a lot of experience with microbiology. For one thing, you are thoroughly populated with microbes right now, and much of your own genetic material actually came from viruses and other microbes. And while you have probably had some bad experiences with quite a few microbes in the form of diseases, you have certainly been greatly benefited by them as well.

This book is suited for all kinds of students and doesn't require any prerequisite knowledge of biology or chemistry. If you are interested in entering the health care profession in some way, this book will give you a strong background in the biology of microorganisms, without overwhelming you with unnecessary details. Don't worry if you're not in the health professions. A grasp of this topic is important for everyone—and can be attained with this book.

—Kelly Cowan

I dedicate this book to my husband, Ted; our grandbaby, Molly Rose; and all of our family members in-between.

–Kelly

I dedicate this book to my favorite person in the world, my husband and best friend, Ryan.

–Heidi

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Required=Results

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Connect is a teaching and learning platform that is proven to deliver better results for students and instructors.

Connect empowers students by continually adapting to deliver precisely what they need, when they need it, and how they need it, so your class time is more engaging and effective.

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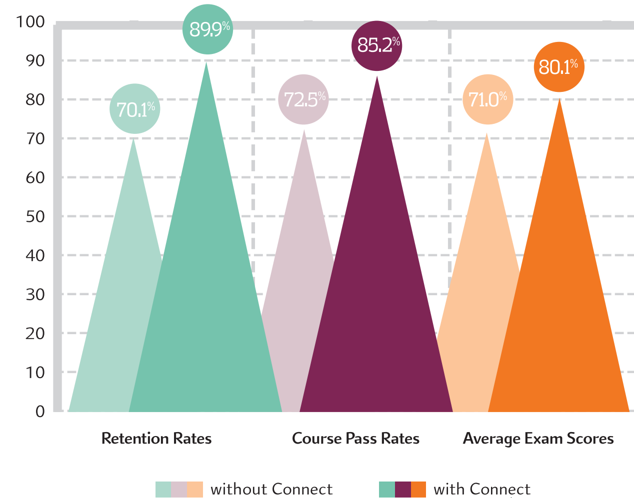

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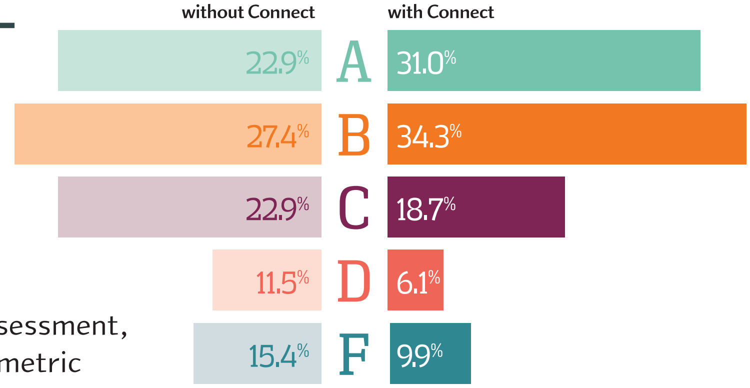

Analytics

Connect Insight®

Connect Insight is Connect's new one-of-a-kind visual analytics dashboard—now available for both instructors and students—that provides at-a-glance information regarding student performance, which is immediately actionable. By presenting assignment, assessment, and topical performance results together with a time metric that is easily visible for aggregate or individual results, Connect Insight gives the user the ability to take a just-in-time approach to teaching and learning, which was never before available. Connect Insight presents data that empowers students and helps instructors improve class performance in a way that is efficient and effective.

> Students can view their results for any **Connect** course.

Mobile

Connect's new, intuitive mobile interface gives students and instructors flexible and convenient, anytime–anywhere access to all components of the Connect platform.

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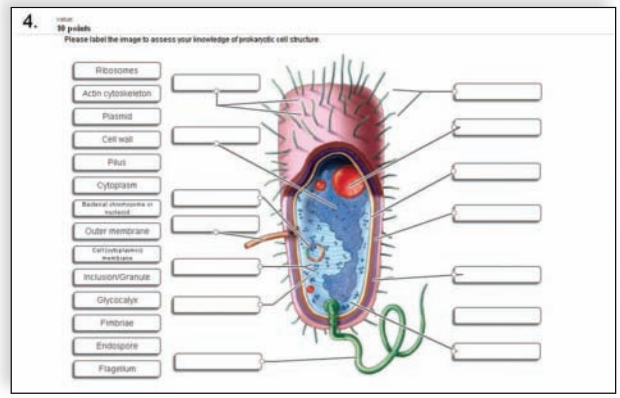
Digital Tools for Your Success

McGraw Hill Education connect®

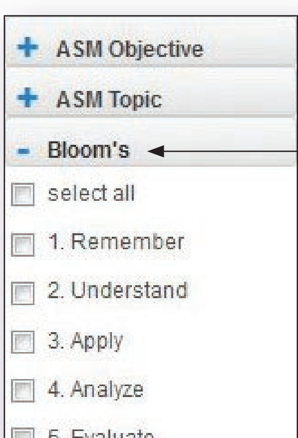
Save time with auto-graded assessments. Gather powerful performance data.

McGraw-Hill Connect for Cowan's Microbiology provides online presentation, assignment, and assessment solutions, connecting your students with the tools and resources they'll need to achieve success.



Homework and Assessment

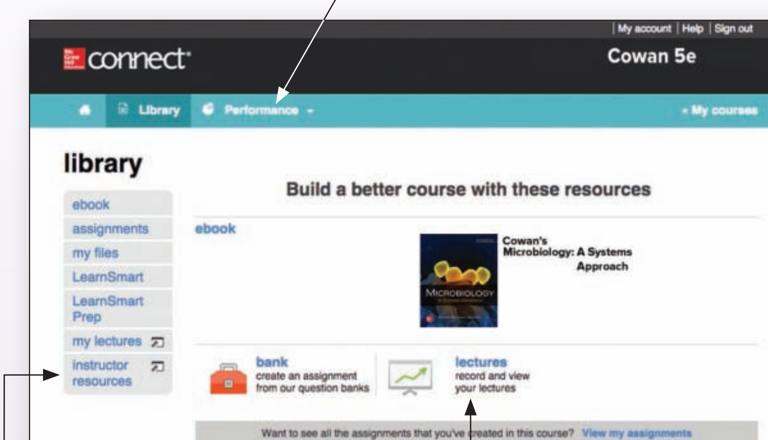
With **Connect for Cowan's Microbiology,** you can deliver auto-graded assignments, quizzes, and tests online. Choose from a robust set of interactive questions and activities using high-quality art from the textbook and animations. Assignable content is available for every Learning Outcome in the book and is categorized according to the **ASM Curriculum Guidelines.** As an instructor, you can edit existing questions and author entirely new ones.



Significant faculty demand for content at higher Bloom's levels led us to examine assessment quality and consistency of our Connect content, to develop a scientific approach to systemically increase critical-thinking levels, and develop balanced digital assessments that promote student learning. The increased challenge at higher Bloom's levels will help the student grow intellectually and be better prepared to contribute to society.

Detailed Reports

Track individual student performance—by question, by assignment, or in relation to the class overall—with detailed grade reports. Integrate grade reports easily with your Learning Management Systems (LMS).



Instructor Resources

Customize your lecture with tools such as PowerPoint® presentations, animations, and editable art from the textbook. An instructor's manual for the text saves you time in developing your course.

Lecture Capture

McGraw-Hill Tegrity® records and distributes your class lecture with just a click of a button. Students can view anytime, anywhere via computer or mobile device. Indexed as you record, students can use keywords to find exactly what they want to study.

Learn more at connect.mheducation.com.

Unique Interactive Question Types in Connect® Tagged to ASM's Curriculum Guidelines for Undergraduate Microbiology and to Bloom's Taxonomy

- **Case Study:** Case studies come to life in a learning activity that is interactive, self-grading, and assessable. The integration of the cases with videos and animations adds depth to the content, and the use of integrated questions forces students to stop, think, and evaluate their understanding.
- **Media Under The Microscope:** The opening cases in the textbook help students read science articles in the popular media with a critical eye. Questions in Connect are designed to extend these cases in a manner that promotes active student learning, either at home or in the classroom.
- **Concept Maps:** Concept maps allow students to manipulate terms in a hands-on manner in order to assess their understanding of chapter-wide topics. Students become actively engaged and are given immediate feedback, enhancing their understanding of important concepts within each chapter.
- **What's the Diagnosis:** Specifically designed for the disease chapters of the text, this is an integrated learning experience designed to assess the student's ability to utilize information learned in the preceding chapters to successfully culture, identify, and treat a disease-causing microbe in a simulated patient scenario. This question type is true experiential learning and allows the students to think critically through a real-life clinical situation.
- **Animations:** Animation quizzes pair our high-quality animations with questions designed to probe student understanding of the illustrated concepts.
- **Tutorial Animation Learning Modules:** Making use of McGraw-Hill Education's collection of videos and animations, this question type presents an interactive, self-grading, and assessable activity. Pre- and post-testing are used to assess shifts in student comprehension. These tutorials take a stand-alone, static animation and turn it into an interactive learning experience for your students with real-time remediation.
- **Labeling:** Using the high-quality art from the textbook, check your students' visual understanding as they practice interpreting figures and learning structures and relationships. Easily edit or remove any label you wish!
- **Classification:** Ask students to organize concepts or structures into categories by placing them in the correct "bucket."
- **Sequencing:** Challenge students to place the steps of a complex process in the correct order.
- **Composition:** Fill in the blanks to practice vocabulary, and then reorder the sentences to form a logical paragraph (these exercises may qualify as "writing across the curriculum" activities!).

All McGraw-Hill Connect content is tagged to Learning Outcomes for each chapter as well as topic, section, Bloom's Level, and ASM Curriculum Guidelines to assist you in customizing assignments and in reporting on your students' performance against these points. This will enhance your ability to assess student learning in your courses by allowing you to align your learning activities to peer-reviewed standards from an international organization.

Lab Resources

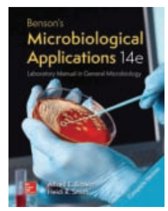
Need a lab manual for your microbiology course? Customize any of these manuals—add your text material—and *Create* your perfect solution!

McGraw-Hill Education offers several lab manuals for the microbiology course. Contact your McGraw-Hill Education learning technology representative for packaging options with any of our lab manuals.

Brown/Smith: *Benson's Microbiological Applications: Laboratory Manual in General Microbiology,* 14th edition

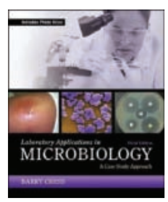
Concise Version (978-1-259-70523-6)

Complete Version (978-1-259-91979-4)

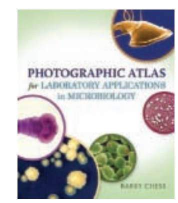


Morello: *Laboratory Manual and Workbook in Microbiology: Applications to Patient Care,* 11th edition (978-0-07-340239-0)

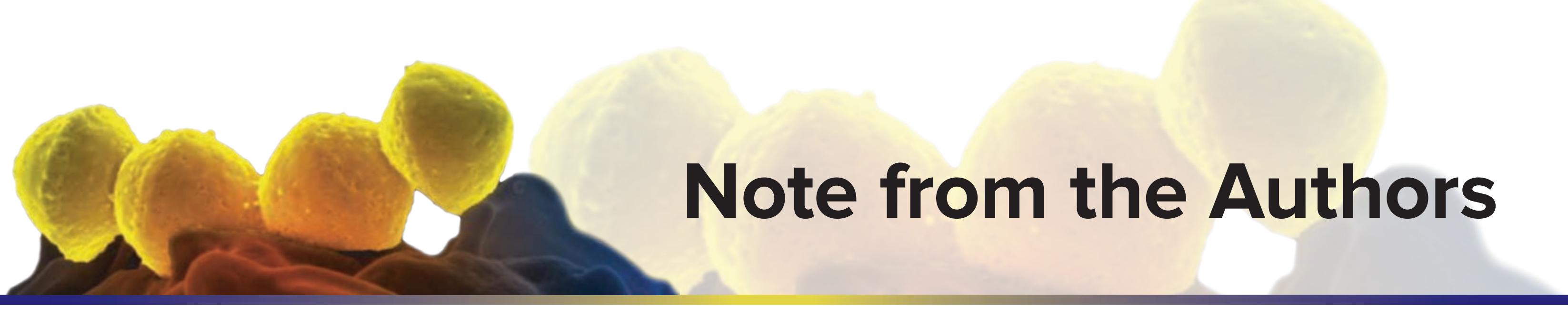
Chess: *Laboratory Applications in Microbiology: A Case Study Approach,* 3rd edition (978-0-07-340242-0)



Chess: *Photographic Atlas for Laboratory Applications in Microbiology* (978-0-07-737159-3)



LearnSmart Labs® is a super-adaptive simulated lab experience that brings meaningful scientific exploration to students. Through a series of adaptive questions, LearnSmart Labs identifies a student's knowledge gaps and provides resources to quickly and efficiently close those gaps. Once the student has mastered the necessary basic skills and concepts, he or she engages in a highly realistic simulated lab experience that allows for mistakes and the execution of the scientific method.



Note from the Authors

This Text's Most Important Distinguishing Features:

These are the features we feel most strongly about. They represent proven methods for enabling our students to learn and we have seen them work in the classroom. The Cowan books have always been built around logical and clear organization, a factor that is critical when non-majors are attempting to learn a science full of new vocabulary and concepts.

- SYSTEMATIC ORGANIZATION of the disease chapters that groups microbes by the conditions they cause.
- EPIDEMIOLOGY in every disease table
- OPENING CASES that teach students how to read science articles in the popular media with a critical eye
- MICROBIOME findings in all 25 chapters—in form of Microbiome Insight boxes as well as in the text. This reinforces how game changing the microbiome findings are.

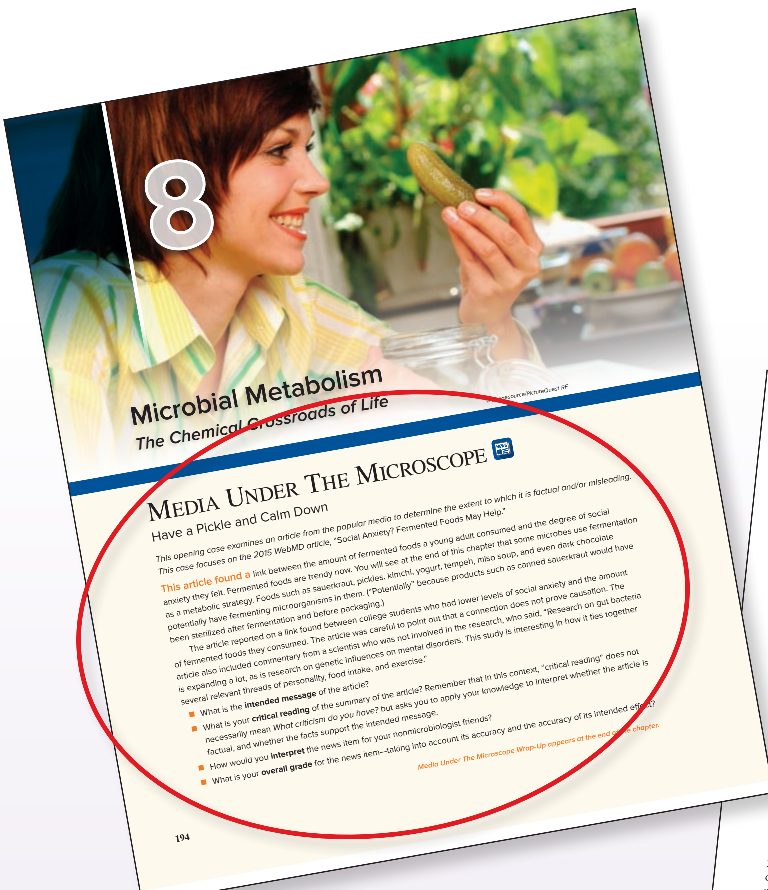
- VISUAL feature on the difference between the deadliness and the contagiousness of various microbes that appears in every disease chapter
- CLEAN, uncluttered, and predictable sequence of chapter content
- CONNECT UPDATES
  - CRITICAL THINKING applied through higher Bloom's level questions added to the Connect Question Bank
  - SMARTBOOK LEARNING RESOURCES have been added based on heat map results from areas where students struggle the most. Help when they need it, with a library of resources available for refresher
  - SUB-SECTION LEARNSMART assignability to allow for a more narrowed focus of chapters or further ability to assign chapter content in smaller chunks for student understanding

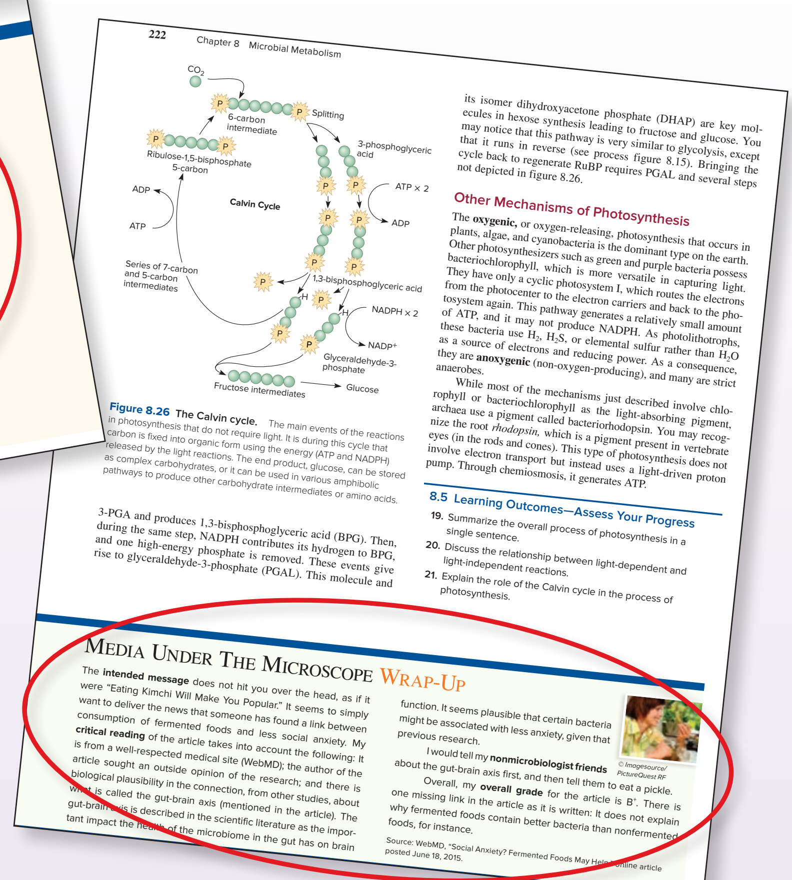
—Kelly Cowan
—Heidi Smith

Capturing Students' Attention and Learning

Chapter Opening Case Files That Teach Students How to Judge Popular Media Articles About Science!

Each chapter opens with a revolutionary kind of case study. Titled "Media Under The Microscope," these are summaries of actual news items about microbiology topics. Students are walked through the steps of judging the relative accuracy of the popular media stories. Chapter by chapter, they learn how to critically assess the journalistic accounts. They encounter the principles of causation vs. correlation, biological plausibility, and the importance of not overstating experimental results. It is a critical need among the public today, and this textbook addresses it.





Active learning activities are assignable in Connect to extend these case files in or outside of the classroom.

Student Focused Instructional Art

Effective science illustrations not only look pretty but help students visualize complex concepts and processes and paint a conceptual picture for them. The art combines vivid colors, multidimensionality, and self-contained narrative to help students study the challenging concepts of microbiology from a visual perspective. Drawings are often paired with photographs or micrographs to enhance comprehension.

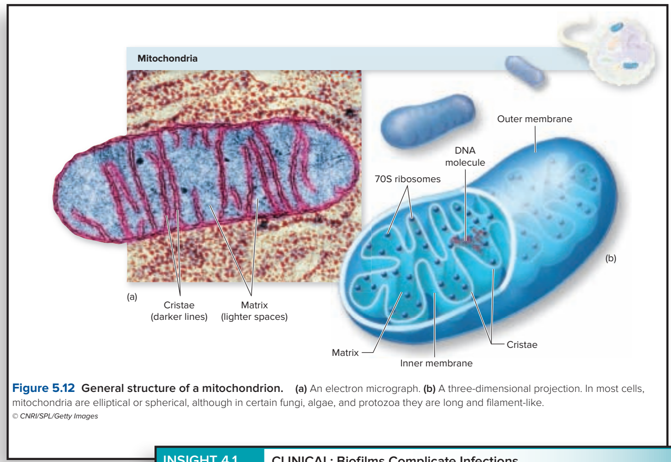
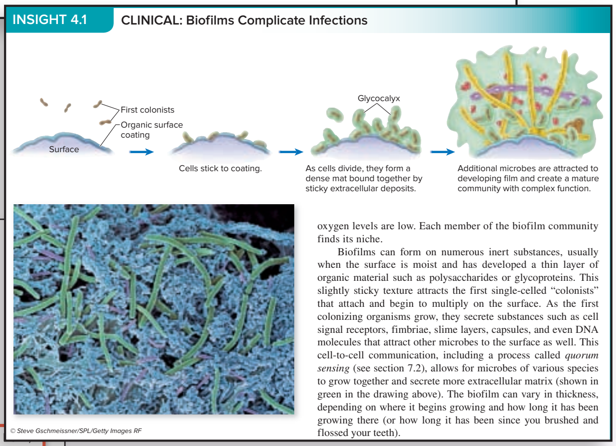
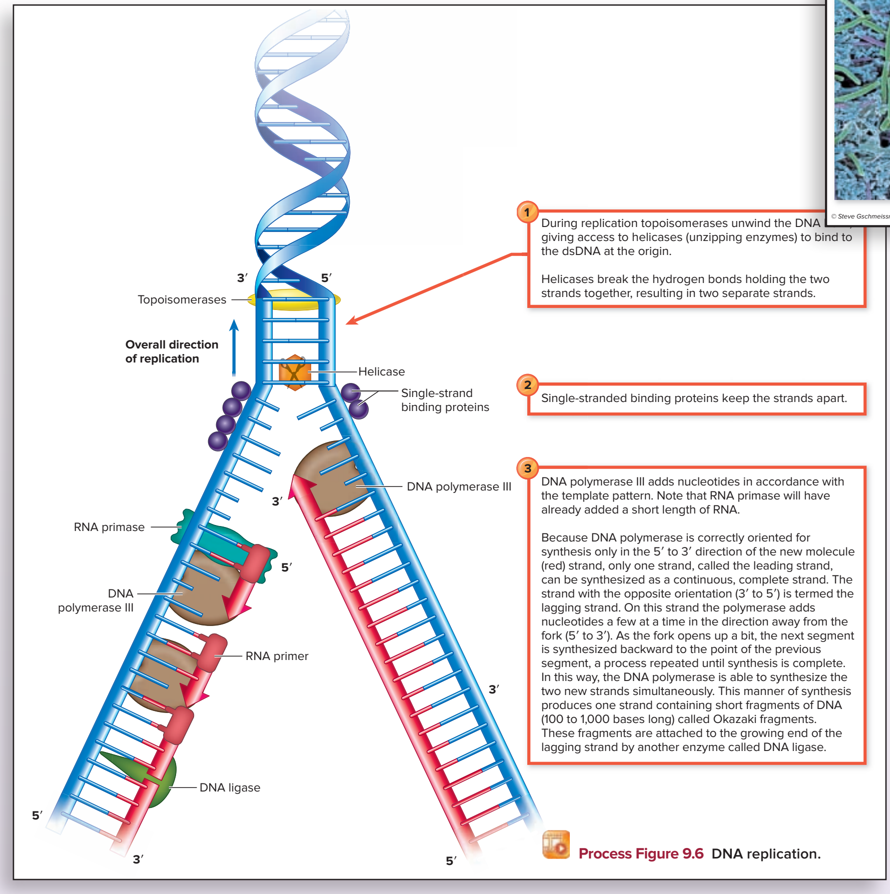


Figure 5.12 General structure of a mitochondrion. **(a)** An electron micrograph. **(b)** A three-dimensional projection. In most cells, mitochondria are elliptical or spherical, although in certain fungi, algae, and protozoa they are long and filament-like.

© CNRI/SPL/Getty Images





Process Figure 9.6 **DNA replication.**

Process Figures

Many difficult microbiological concepts are best portrayed by breaking them down into stages. These Process Figures show each step clearly marked with an orange, numbered circle and correlated to accompanying narrative to benefit all types of learners. Process Figures are clearly marked next to the figure number. The accompanying legend provides additional explanation.

Connecting Students to Their Future Careers

Many students taking this course will be entering the health care field in some way, and it is absolutely critical that they have a good background in the biology of microorganisms. Authors Kelly Cowan and Heidi Smith have made it their goal to help all students make the connections between microbiology and the world they see around them. Cowan textbooks have become known for their engaging writing style, instructional art program, and focus on active learning. The “building blocks” approach establishes the big picture first and then gradually layers concepts onto this foundation. This logical structure helps students build knowledge and ***connect*** important concepts.

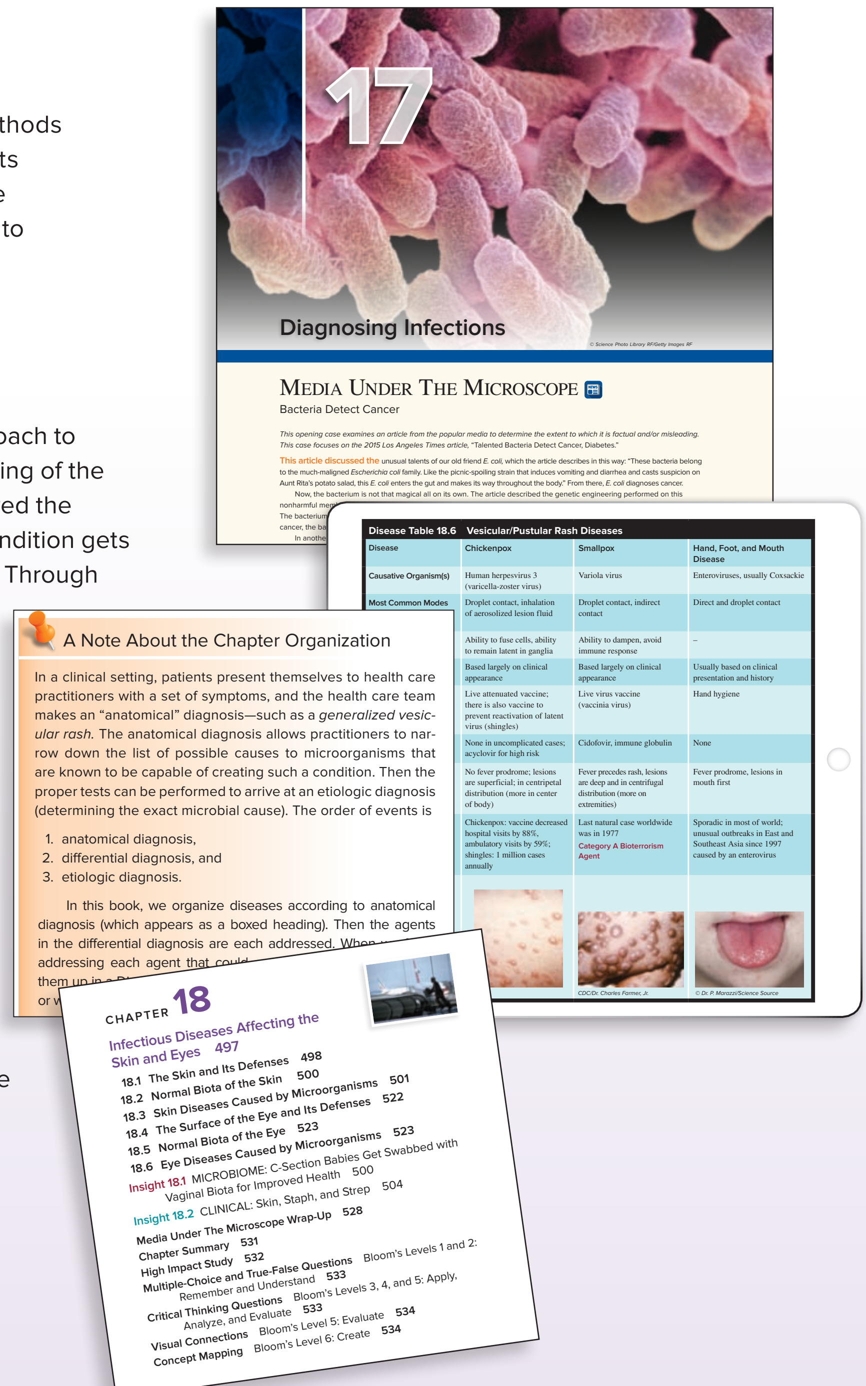
“Diagnosing Infections” Chapter

Chapter 17 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.

Systematic Presentation of Disease-Causing Organisms

Microbiology: A Systems Approach takes a unique approach to diseases by organizing microbial agents under the heading of the disease condition they cause. After all of them are covered the agents are summarized in a comparative table. Every condition gets a table, whether there is one possible cause or a dozen. Through this approach, students study how diseases affect patients—the way future health care professionals will encounter them in their jobs. A summary table follows the textual discussion of each disease and summarizes the characteristics of agents that can cause that disease. New to this edition:

Every disease table now contains national and/or worldwide epidemiological information for each causative agent.

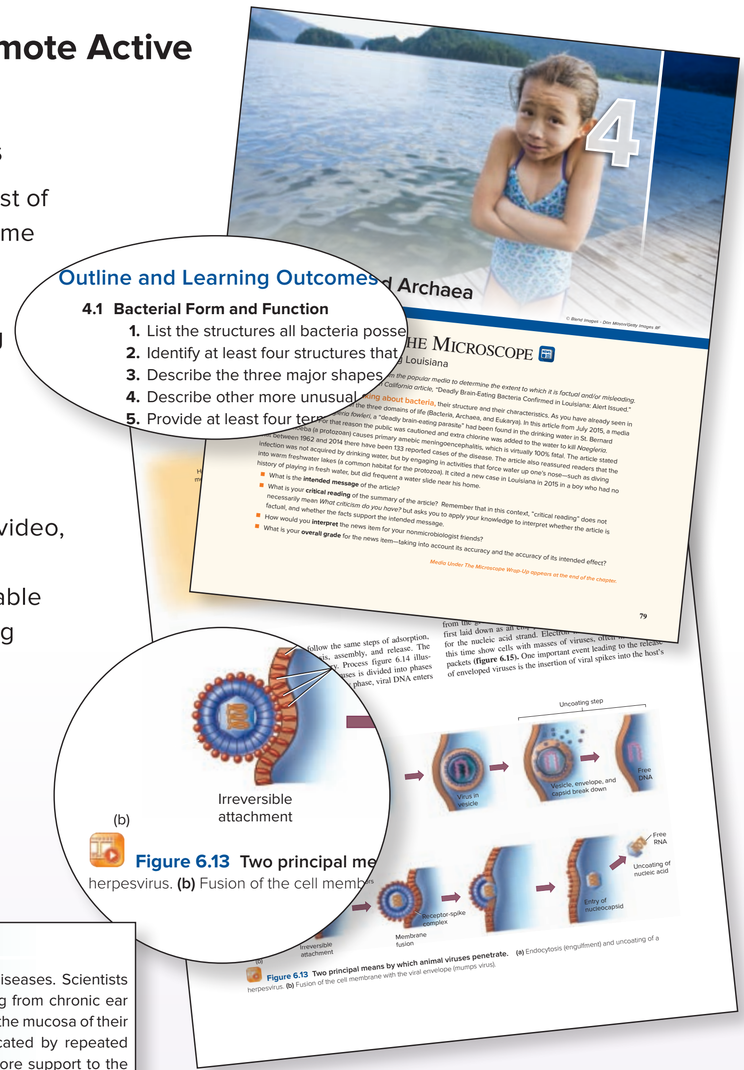


This approach is logical, systematic, and intuitive, as it encourages clinical and critical thinking in students—the type of thinking they will be using if their eventual careers are in health care. Students learn to examine multiple possibilities for a given condition and grow accustomed to looking for commonalities and differences among the various organisms that cause a given condition.

Student-Centered Pedagogy Created to Promote Active Learning

Learning Outcomes and Assess Your Progress Questions

Every chapter in the book now opens with an outline—which is a list of Learning Outcomes. Assess Your Progress with the learning outcome questions conclude each major section of the text. The Learning Outcomes are tightly correlated to digital material. Instructors can easily measure student learning in relation to the specific Learning Outcomes used in their course.



Animated Learning Modules

Certain topics need help to come to life off the page. Animations, video, audio, and text all combine to help students understand complex processes. Key topics have an Animated Learning Module assignable through Connect. An icon in the text indicates when these learning modules are available.

Disease Connection

Sometimes it is difficult for students to see the relevance of basic concepts to their chosen professions. So in this edition the basic science chapters contain Disease Connections, very short boxes that relate esoteric topics such as pH and growth phase to clinical situations (*H. pylori* and *M. tuberculosis,* for these examples).

Disease Connection

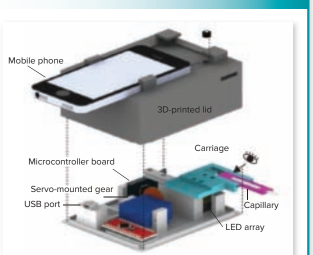
Biofilms can play a major role in infectious diseases. Scientists definitively have shown that children suffering from chronic ear infections had biofilms of bacteria growing on the mucosa of their middle ears. These biofilms were not eradicated by repeated courses of antibiotics. This discovery gave more support to the procedure of putting tubes in the ears of children with chronic or recurrent ear infections (to drain infected fluids) instead of treating with antibiotics.

Insight Readings

Each chapter includes a Microbiome Insight box and a Clinical Insight box. Research Insight boxes appear in many chapters. The Microbiome Insight boxes are a way to emphasize the important and revolutionary ways the recent findings influence almost everything we know about human health.

INSIGHT 3.1 CLINICAL: The Loa Phone

Africa has a problem with worms. Nematodes, to be exact. There are three different types of roundworms that cause human disease on that continent. One of these, known as "river blindness," is caused by the helminth *Onchocerca volvulus*, transmitted by black flies. Before widespread control efforts, an estimated 60 million people were affected. A second type is lymphatic filariasis, sometimes called elephantiasis, which is caused by ...



Courtesy Mike D'Ambrosio and Matt Bakalar, Fletcher Lab, UC Berkeley

tube) containing blood from a finger-prick. The researchers developed a program that analyzes the way in which the blood cells in the sample move around—which they will do in a very different way when there are worms moving in the blood. (The blood cells are large enough to be seen with a low-power lens.) The entire test takes only 3 minutes. And in areas where loiasis is common, it could allow MDA to move forward, saving lives without endangering those for whom it could be dangerous.

Insight 3.2 describes some other uses for smartphones in the visualization of microbes.

Source: 2015. *Science Translational Medicine.* vol. 7, p 286. DOI: 10.1126/scitranlmed.aaa3480.

INSIGHT 10.1 MICROBIOME: Host Genetics and the Microbiome

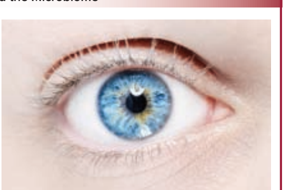
The composition of the human microbiota shows a lot of variability from person to person. Of course, we know that humans themselves show a lot of variation, which comes from their different genetic make-up. This led scientists to wonder whether the composition of the microbiota is influenced by the host's genetics.

One good way to test this is to look at two different types of pairs of people: monozygotic (identical) twins and dizygotic (fraternal) twins. Fraternal twins do not share the same genes, but identical twins do. If the microbiomes of identical twins were significantly more similar than the microbiomes of fraternal twins, it would suggest that the human genome influences what microbiome the person acquires.

To ask this question the way scientists do, you would construct a hypothesis: The degree of difference between the microbiota of fraternal twins will be no greater than the degree of difference between the microbiota of identical twins. (This is written as a null hypothesis, meaning it is a statement that there will be no difference between two groups.) Then you would set up an experiment to test the hypothesis, using a large number of pairs of both types of twins. In this study, 416 pairs of twins were examined.

In this study, the identical twins turned out to have more similar microbiomes than the fraternal twins. They had what they called "a hub of heritable taxa," chief among them a newly discovered bacterial group named *Christensenellaceae.*

So the hypothesis was disproven; there was a significant difference between the two groups. The paper's authors suggest that a person's microbiome is heritable, like, having blue eyes. Only here it is a bit more indirect—a person's genotype is heritable, which determines his or her phenotype, which may determine his or her microbiome.

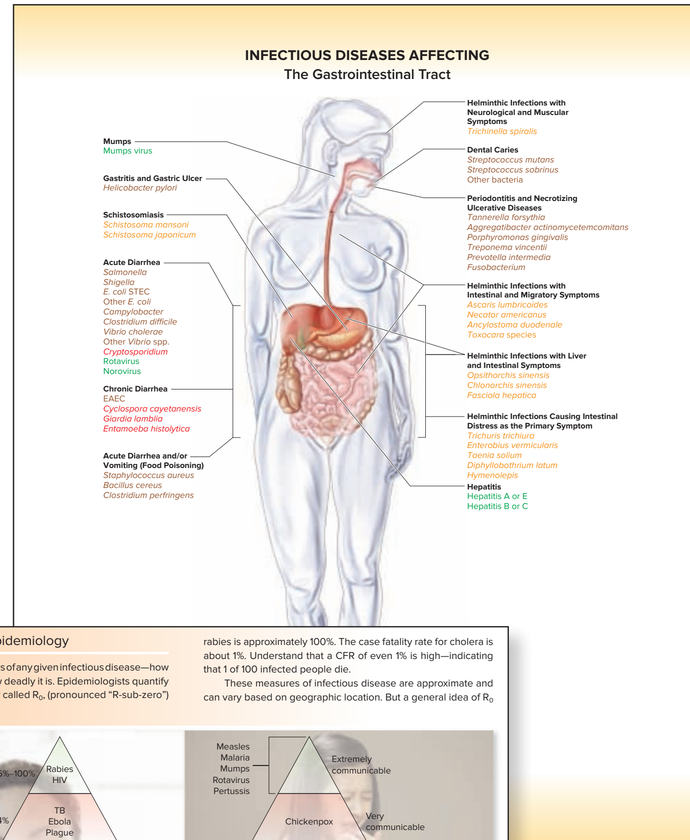


© coloroftime/Getty Images RF

There is a saying in science, "Chance favors the prepared mind." In the case of this study, the scientists found something they were not counting on: The presence of *Christensenellaceae* was associated with low body mass index (BMI). Since this was just an association and the study could not prove causation, they did another experiment in which they deliberately exposed mice to *Christensenellaceae.* Those mice had reduced weight gain compared to mice not fed *Christensenellaceae.* So the studies continue. This is what many scientists love about their jobs: discovering surprises, and finding answers to questions that practically ask themselves!

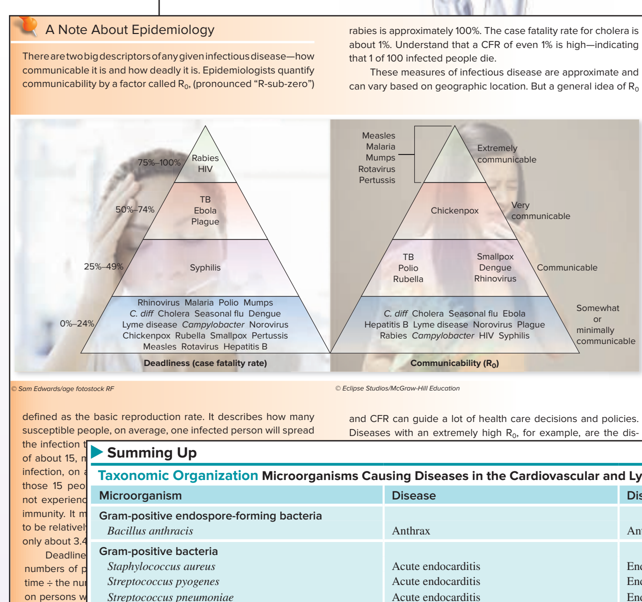
System Summary Figures

“Glass body” figures at the end of each disease chapter highlight the affected organs and list the diseases that were presented in the chapter. In addition, the microbes are color coded by type of microorganism.



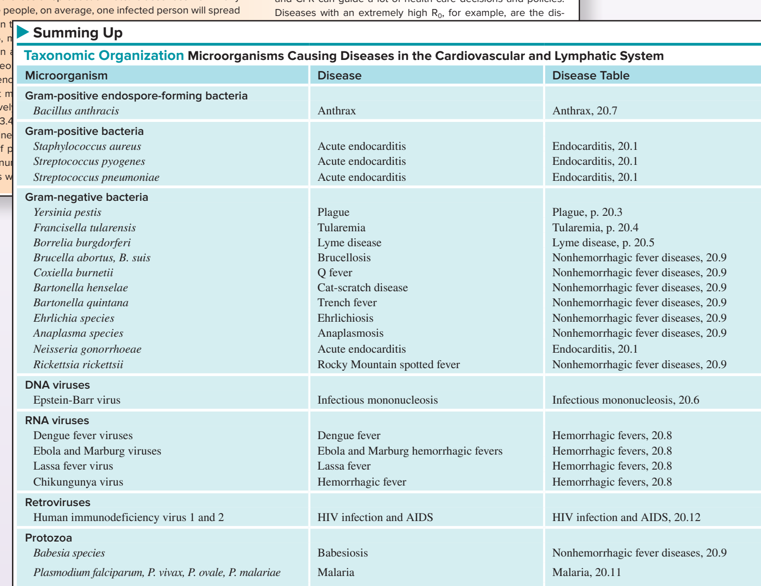
Communicability vs. Deadliness Feature

Each microbe can be characterized using two important descriptors: its relative communicability and its relative deadliness. These are important epidemiologically and clinically—and usually receive only sporadic mention in textbooks—so we have created a new visual feature that appears in each disease chapter, and in the epidemiology chapter.



Taxonomic List of Organisms

A taxonomic list of organisms is presented at the end of each disease chapter so students can see the taxonomic position of microbes causing diseases in that body system.



Summing Up

Taxonomic Organization Microorganisms Causing Diseases in the Cardiovascular and Lymphatic System

Microorganism	Disease	Disease Table
Gram-positive endospore-forming bacteria		
Bacillus anthracis	Anthrax	Anthrax, 20.7
Gram-positive bacteria		
Staphylococcus aureus	Acute endocarditis	Endocarditis, 20.1
Streptococcus pyogenes	Acute endocarditis	Endocarditis, 20.1
Streptococcus pneumoniae	Acute endocarditis	Endocarditis, 20.1
Gram-negative bacteria		
Yersinia pestis	Plague	Plague, p. 20.3
Francisella tularensis	Tularemia	Tularemia, p. 20.4
Borrelia burgdorferi	Lyme disease	Lyme disease, p. 20.5
Brucella abortus, B. suis	Brucellosis	Nonhemorrhagic fever diseases, 20.9
Coxiella burnetii	Q fever	Nonhemorrhagic fever diseases, 20.9
Bartonella henselae	Cat-scratch disease	Nonhemorrhagic fever diseases, 20.9
Bartonella quintana	Trench fever	Nonhemorrhagic fever diseases, 20.9
Ehrlichia species	Ehrlichiosis	Nonhemorrhagic fever diseases, 20.9
Anaplasma species	Anaplasmosis	Nonhemorrhagic fever diseases, 20.9
Neisseria gonorrhoeae	Acute endocarditis	Endocarditis, 20.1
Rickettsia rickettsii	Rocky Mountain spotted fever	Nonhemorrhagic fever diseases, 20.9
DNA viruses		
Epstein-Barr virus	Infectious mononucleosis	Infectious mononucleosis, 20.6
RNA viruses		
Dengue fever viruses	Dengue fever	Hemorrhagic fevers, 20.8
Ebola and Marburg viruses	Ebola and Marburg hemorrhagic fevers	Hemorrhagic fevers, 20.8
Lassa fever virus	Lassa fever	Hemorrhagic fevers, 20.8
Chikungunya virus	Hemorrhagic fever	Hemorrhagic fevers, 20.8
Retroviruses		
Human immunodeficiency virus 1 and 2	HIV infection and AIDS	HIV infection and AIDS, 20.12
Protozoa		
Babesia species	Babesiosis	Nonhemorrhagic fever diseases, 20.9
Plasmodium falciparum, P. vivax, P. ovale, P. malariae	Malaria	Malaria, 20.11
Trypanosoma cruzi	Chagas disease	Chagas disease, 20.10

Developing Critical Thinkers

The end-of-chapter material is linked to Bloom's Taxonomy. It has been carefully planned to promote active learning and provide review for different learning styles and levels of difficulty. Multiple-Choice and True-False Questions (Remember and Understand) precede the Critical Thinking, Visual Connections Questions, and Concept Mapping Exercises, which take the student through the Apply, Analyze, Evaluate, and Create levels. The consistent layout of each chapter allows students to develop a learning strategy and gain confidence in their ability to master the concepts, leading to success in the class!

Chapter Summary

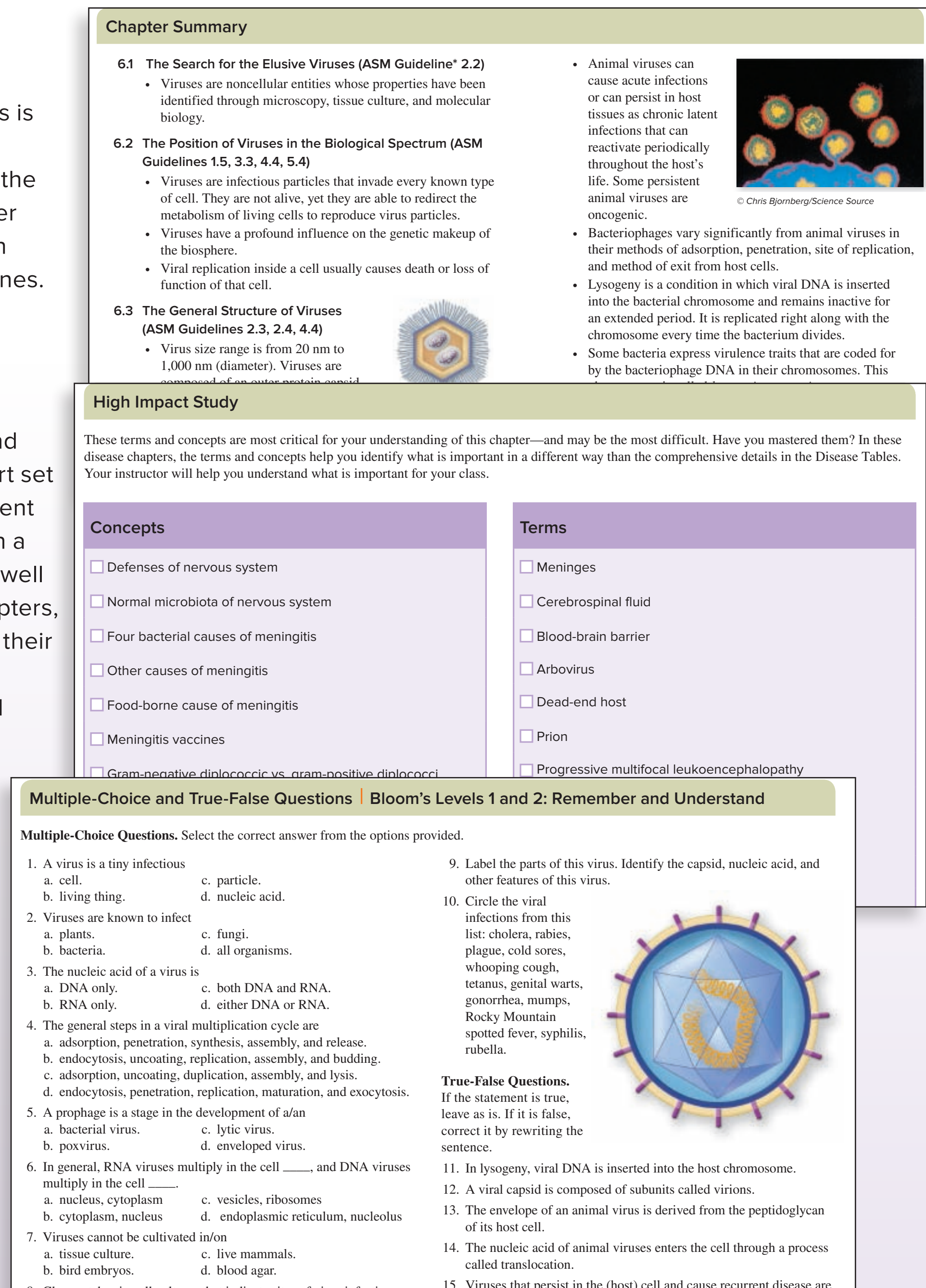
A brief outline of the main chapter concepts is provided for students with important terms highlighted. Key terms are also included in the glossary at the end of the book. The chapter summary is now tagged with new American Society for Microbiology curriculum guidelines.

New High Impact Study Feature

Students benefit most from varied study and assessment methods. We've created a short set of "Terms" and "Concepts" that help a student identify the most important 10 to 15 items in a chapter. If they understand these, they are well on their way to mastery. In the disease chapters, this gives instructors an opportunity to ask their students about the content in a way that is different from or in addition to the standard "laundry list" of diseases.

Multiple-Choice and True-False Questions

Students can assess their knowledge of basic concepts by answering these questions. Other types of questions and activities that follow build on this foundational knowledge. The Connect eBook allows students to quiz themselves interactively using these questions! Bloom's Levels for all questions are provided.



Chapter Summary

6.1 The Search for the Elusive Viruses (ASM Guideline* 2.2)
- Viruses are noncellular entities whose properties have been identified through microscopy, tissue culture, and molecular biology.

6.2 The Position of Viruses in the Biological Spectrum (ASM Guidelines 1.5, 3.3, 4.4, 5.4)
- Viruses are infectious particles that invade every known type of cell. They are not alive, yet they are able to redirect the metabolism of living cells to reproduce virus particles.
- Viruses have a profound influence on the genetic makeup of the biosphere.
- Viral replication inside a cell usually causes death or loss of function of that cell.

6.3 The General Structure of Viruses (ASM Guidelines 2.3, 2.4, 4.4)
- Virus size range is from 20 nm to 1,000 nm (diameter). Viruses are

- Animal viruses can cause acute infections or can persist in host tissues as chronic latent infections that can reactivate periodically throughout the host's life. Some persistent animal viruses are oncogenic.
- Bacteriophages vary significantly from animal viruses in their methods of adsorption, penetration, site of replication, and method of exit from host cells.
- Lysogeny is a condition in which viral DNA is inserted into the bacterial chromosome and remains inactive for an extended period. It is replicated right along with the chromosome every time the bacterium divides.
- Some bacteria express virulence traits that are coded for by the bacteriophage DNA in their chromosomes. This

© Chris Bjornberg/Science Source

High Impact Study

These terms and concepts are most critical for your understanding of this chapter—and may be the most difficult. Have you mastered them? In these disease chapters, the terms and concepts help you identify what is important in a different way than the comprehensive details in the Disease Tables. Your instructor will help you understand what is important for your class.

Concepts	Terms
☐ Defenses of nervous system	☐ Meninges
☐ Normal microbiota of nervous system	☐ Cerebrospinal fluid
☐ Four bacterial causes of meningitis	☐ Blood-brain barrier
☐ Other causes of meningitis	☐ Arbovirus
☐ Food-borne cause of meningitis	☐ Dead-end host
☐ Meningitis vaccines	☐ Prion
☐ Gram-negative diplococcic vs. gram-positive diplococci	☐ Progressive multifocal leukoencephalopathy

Multiple-Choice and True-False Questions | Bloom's Levels 1 and 2: Remember and Understand

Multiple-Choice Questions. Select the correct answer from the options provided.

1. A virus is a tiny infectious
   a. cell. c. particle.
   b. living thing. d. nucleic acid.
2. Viruses are known to infect
   a. plants. c. fungi.
   b. bacteria. d. all organisms.
3. The nucleic acid of a virus is
   a. DNA only. c. both DNA and RNA.
   b. RNA only. d. either DNA or RNA.
4. The general steps in a viral multiplication cycle are
   a. adsorption, penetration, synthesis, assembly, and release.
   b. endocytosis, uncoating, replication, assembly, and budding.
   c. adsorption, uncoating, duplication, assembly, and lysis.
   d. endocytosis, penetration, replication, maturation, and exocytosis.
5. A prophage is a stage in the development of a/an
   a. bacterial virus. c. lytic virus.
   b. poxvirus. d. enveloped virus.
6. In general, RNA viruses multiply in the cell ____, and DNA viruses multiply in the cell ____.
   a. nucleus, cytoplasm c. vesicles, ribosomes
   b. cytoplasm, nucleus d. endoplasmic reticulum, nucleolus
7. Viruses cannot be cultivated in/on
   a. tissue culture. c. live mammals.
   b. bird embryos. d. blood agar.
8. Clear patches in cell cultures that indicate sites of virus infection are
9. Label the parts of this virus. Identify the capsid, nucleic acid, and other features of this virus.
10. Circle the viral infections from this list: cholera, rabies, plague, cold sores, whooping cough, tetanus, genital warts, gonorrhea, mumps, Rocky Mountain spotted fever, syphilis, rubella.

True-False Questions. If the statement is true, leave as is. If it is false, correct it by rewriting the sentence.

11. In lysogeny, viral DNA is inserted into the host chromosome.
12. A viral capsid is composed of subunits called virions.
13. The envelope of an animal virus is derived from the peptidoglycan of its host cell.
14. The nucleic acid of animal viruses enters the cell through a process called translocation.
15. Viruses that persist in the (host) cell and cause recurrent disease are

Critical Thinking Questions

Students use higher-order Bloom's skills (Apply, Analyze, Evaluate) with these questions. There is no single correct answer; this can open doors to discussion and application. New critical thinking questions have been added for the fifth edition.

Critical Thinking Questions | Bloom's Levels 3, 4, and 5: Apply, Analyze, and Evaluate

Critical thinking is the ability to reason and solve problems using facts and concepts. These questions can be approached from a number of angles and, in most cases, they do not have a single correct answer.

1. Provide evidence in support of or refuting the following statement: Viruses are simple cellular agents of disease.
2. Summarize the unique properties of viruses and explain which of these characteristics allow them to function as "parasites."
3. Describe the nucleic acid configuration of a positive-sense RNA virus and explain why its multiplication cycle is less complex than that of a retrovirus.
4. Compare and contrast the processes of latency and lysogeny, providing examples of latent viruses and lysogenic viruses.
5. Use the Internet to search prion diseases, and identify three major differences between a viral disease and a prion disease.

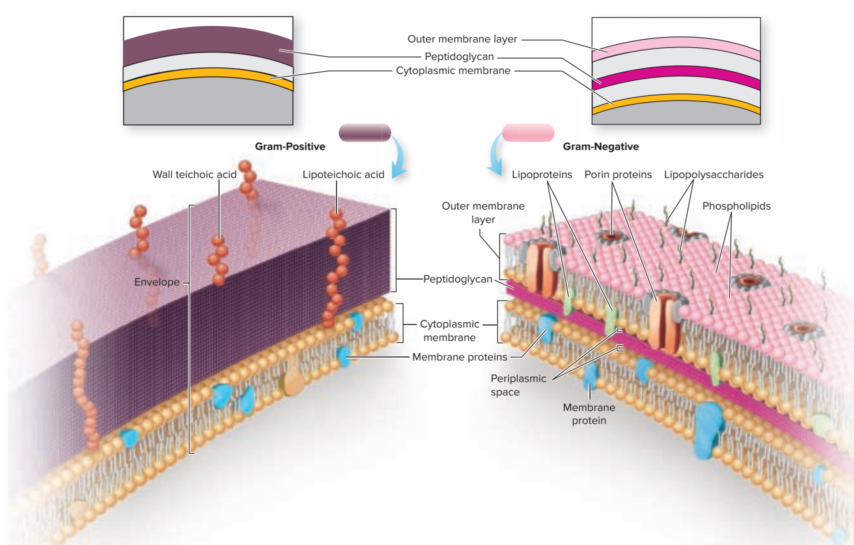
Visual Connections

Visual Connections questions take images and concepts learned in previous chapters and ask students to apply that knowledge to concepts newly learned in the current chapter. This helps students evaluate information in new contexts and enhances learning.

Visual Connections | Bloom's Level 5: Evaluate

This question uses visual images or previous content to make connections to this chapter's concepts.

1. **From chapter 4, figure 4.16.**
   a. In both cell types shown, sketch where the membrane attack complex (MAC) would form.
   b. Speculate on whether gram-positive or gram-negative bacterial cells are more resistant to the formation of a membrane attack complex.



Concept Mapping

Every chapter contains a list of terms from which students are asked to construct (Create) a concept map. Connect expands this activity with interactive concept maps.

Concept Mapping | Bloom's Level 6: Create

Appendix D provides guidance for working with concept maps.

1. Using the words that follow, please create a concept map illustrating the relationships among these key terms from chapter 7.

symbiosis	parasitism	disease
protection	commensalism	pathogens
mutualism	nonsymbiosis	normal biota

Changes to the Fifth Edition

New to *Microbiology, A Systems Approach*

GLOBAL CHANGES THROUGHOUT THE FIFTH EDITION

- Twenty-five opening case studies, "Media Under The Microscope," that help students critically examine journalistic accounts of microbiology topics
- Language is simplified throughout book. Sentences are shortened and general vocabulary is updated.
- Twenty-five new Microbiome Insight boxes; 25 new Clinical Insight boxes (one per chapter)
- Many new photographs and drawn illustrations
- CDC antibiotic resistance threat level indicated in disease tables
- "Category A" bioterror threat organisms indicated in disease tables
- A new end-of-chapter feature, "High Impact Study," that identifies the 10 to 15 most important terms *and* concepts in the chapter
- A new visual feature in each disease chapter (chapters 18 through 23) that places the microbes from that chapter in context with respect to *communicability* and *deadliness*

Major chapter changes

Chapter 1: The Main Themes of Microbiology

- LUCA information updated
- Taxonomy and classification discussions clarified and simplified

Chapter 2: The Chemistry of Biology

- How the microbiome of sponges may have created oxygen on our planet

Chapter 3: Tools of the Laboratory

- Many new photos of laboratory media

Chapter 4: Bacteria and Archaea

- Update on archaea flagella

Chapter 5: Eukaryotic Cells and Microorganisms

- Chapter made more concise
- New: eukaryotes as members of the microbiome
- New: neglected parasitic infections (NPIs)

Chapter 6: An Introduction to the Viruses

- New: discussion of viruses in the microbiome
- Updated viral taxonomy
- New diseases caused by prions

Chapter 7: Microbial Nutrition, Ecology, and Growth

- Shifts discussion around "commensals," with respect to microbiome
- Simplifies the discussion around diffusion

Chapter 8: Microbial Metabolism

- Introduces electricity-eating bacteria

Chapter 9: Microbial Genetics

- Language greatly simplified

Chapter 10: Genetic Engineering and Recombinant DNA

- SNP discussion expanded
- New: high-throughput sequencing, CRISPR and gene drives discussed

Chapter 11: Physical and Chemical Control of Microbes

- New: UV and hydrogen peroxide disinfection of hospital rooms

Chapter 12: Antimicrobial Treatment

- Most art changed and updated
- New: epimutation mechanism of antibiotic resistance
- New: CRISPR approach to overcome antibiotic resistance
- New: role of persisters in antibiotic resistance
- New: information about CDC Threat appraisal

Chapter 13: Microbe-Human Interactions: Health and Disease

- Vastly rewritten to reflect new microbiome findings plus host-parasite findings
- New: role of epigenetic factors in host defense and in microbial pathogenesis
- New: concept of a holobiont
- More emphasis on polymicrobial infections
- Reflects decreased emphasis on "pathogen/nonpathogen" designation
- Expanded epidemiology section

Chapter 14: Host Defenses I: Overview and Nonspecific Defenses

- New: findings about existence of lymphatic system in CNS
- New: disrupted microbiome as possible cause of some autoimmune diseases

Chapter 15: Host Defenses II: Specific Immunity and Immunization

- New: added IRA-B cells, gamma-delta T cells
- New: microbiome can influence T cell activity in autoimmune diseases

Chapter 16: Disorders in Immunity

- New approach to allergy treatment and prevention
- New: role of the gut microbiome in asthma, etc.
- New: autoimmunity and the microbiome

Chapter 17: Diagnosing Infections

- New: point-of-care diagnostics

Chapter 18: Infectious Diseases Affecting the Skin and Eyes

- New: MRSA soft tissue infections as a separate condition
- An Insight box about measles transmission in an airport

Chapter 19: Infectious Diseases Affecting the Nervous System

- New: *N. meningitidis* serotype B vaccine recommendations
- Rewritten arbovirus/encephalitis section to reflect current epidemiology

Chapter 20: Infectious Diseases Affecting the Cardiovascular and Lymphatic Systems

- New: epidemic of endocarditis and epidural abscesses accompanying heroin epidemic
- New: findings about low percentages of Lyme disease displaying bull's-eye lesion; also Lyme disease–like illnesses caused by other *Borrelia* species
- HGA and HGE changed to anaplasmosis and ehrlichiosis
- Babesiosis added
- New: malaria vaccine for children
- New HIV diagnosis technique

Chapter 21: Infectious Diseases Affecting the Respiratory System

- New: microbiome findings that lungs are not sterile

Chapter 22: Infectious Diseases Affecting the Gastrointestinal Tract

- More emphasis on food-borne diseases
- New: Crohn's disease and the gut microbiome

Chapter 23: Infectious Diseases Affecting the Genitourinary System

- More discussion of catheter-associated urinary tract infections
- New: role of vaginal microbiome in high infant mortality rates

Chapter 24: Microbes and the Environment

- Added large section on the "One Health" movement, pointing out the relationship between warming climate and emerging diseases
- New: metagenome studies using high throughput sequencing
- New: concept of the plastisphere introduced
- New: ocean virome

Chapter 25: Applied Microbiology and Food and Water Safety

- New: biologics (drugs) added under biotechnology section

Acknowledgments

We are most grateful to our students who have tried to teach us how to more effectively communicate this subject. All the professors who reviewed manuscript or sent e-mails with feedback were our close allies as well, especially when they were liberal in their criticism. We would like to thank Dorothy Wood, Kaethe Sandman, and Connie Fisk for their contributions to the digital offerings. Our minders at McGraw-Hill Education are paragons of patience and professionalism: Darlene Schueller is the best editor in the business, which makes it all the more surprising that she continues to work with us on book after book. Other members of our McGraw-Hill Education team upon whom we lean heavily are Marija Magner, Kristine Rellihan, Jessica Portz, Brent dela Cruz, Lori Hancock, Lorraine Buczek, Debra DeBord, Dorothy Wendel, and Gina Delaney.

—Kelly Cowan
—Heidi Smith

Review Process, Including Heat Maps

In the preparation of each edition, we have been guided by the collective wisdom of reviewers who are expert microbiologists and excellent teachers. They represent experience in community colleges, liberal arts colleges, comprehensive institutions, and research universities. We have followed their recommendations, while remaining true to our overriding goal of writing a readable, student-centered text. This edition has also been designed to be amenable to a variety of teaching styles. Each feature incorporated into this edition has been carefully considered in how it may be used to support student learning in both the traditional classroom and the flipped learning environment.

Also in this edition, we are very pleased to have been able to incorporate real student data points and input, derived from thousands of our LearnSmart users, to help guide our revision. LearnSmart Heat Maps provided a quick visual snapshot of usage of portions of the text and the relative difficulty students experienced in mastering the content. With these data, we were able to hone not only our text content but also the LearnSmart questions.

- If the data indicated that the subject covered was more difficult than other parts of the book, as evidenced by a high proportion of students responding incorrectly, we substantively revised or reorganized the content to be as clear and illustrative as possible.
- In some sections, the data showed that a smaller percentage of the students had difficulty learning the material. In those cases, we revised the *text* to provide a clearer presentation by rewriting the section, providing additional examples to strengthen student problem-solving skills, designing new text art or figures to assist visual learners, and so on.
- In other cases, one or more of the LearnSmart questions for a section were not as clear or did not appropriately reflect the content. In these cases, the *question,* rather than the text, was edited.

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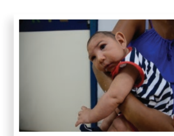
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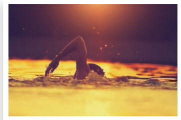

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CHAPTER 25

Applied Microbiology and Food and Water Safety 752

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The Main Themes of Microbiology

MEDIA UNDER THE MICROSCOPE

Filthy Coffee Machine?

This opening case examines an article from the popular media to determine the extent to which it is factual and/or misleading. This case focuses on the 2015 Huffington Post article, "Your Keurig Machine May Be Covered in Bacteria And Mold."

The popular single-serve coffee machines are certainly handy. Everyone in the house or the office can have his or her own flavor of coffee! And you don't get that overcooked coffee taste that leaving a pot of coffee on the burner produces. This online news article told a darker story, however. CBS stations in Pittsburgh, Dallas, and Chicago swabbed 29 of their coffeemakers and sent the swabs to a laboratory to be cultured. The report said that "More than half of the machines came back with bacterial counts in the millions." One machine from Dallas was positive for *Escherichia coli.* A woman who owned one of the sampled Keurigs was interviewed and said, "It makes me want to cry."

- What is the **intended message** of the article?
- What is your **critical reading** of the summary of the article? Remember that in this context, "critical reading" does not necessarily mean *What criticism do you have?* but asks you to apply your knowledge to interpret whether the article is factual, and whether the facts support the intended message.
- How would you **interpret** the news item for your nonmicrobiologist friends?
- What is your **overall grade** for the news item—taking into account its accuracy and the accuracy of its intended effect?

Media Under The Microscope Wrap-Up appears at the end of the chapter.

Outline and Learning Outcomes

1.1 The Scope of Microbiology

1. List the various types of microorganisms.
2. Identify multiple professions using microbiology.

1.2 The Impact of Microbes on Earth: Small Organisms with a Giant Effect

3. Describe the role and impact of microbes on the earth.
4. Explain the theory of evolution and why it is called a theory.

1.3 Human Use of Microorganisms

5. Explain one old way and one new way that humans manipulate organisms for their own uses.

1.4 Infectious Diseases and the Human Condition

6. Summarize the relative burden of human disease caused by microbes, emphasizing the differences between developed countries and developing countries.

1.5 The General Characteristics of Microorganisms

7. Differentiate among bacteria, archaea, and eukaryotic microorganisms.
8. Identify a fourth type of microorganism.
9. Compare and contrast the relative sizes of the different microbes.

1.6 The Historical Foundations of Microbiology

10. Make a time line of the development of microbiology from the 1600s to today.
11. List some recent microbiological discoveries of great impact.
12. Explain what is important about the scientific method.

1.7 Naming, Classifying, and Identifying Microorganisms

13. Differentiate among the terms *nomenclature, taxonomy,* and *classification.*
14. Create a mnemonic device for remembering the taxonomic categories.
15. Correctly write the binomial name for a microorganism.
16. Draw a diagram of the three major domains.
17. Explain the difference between traditional and molecular approaches to taxonomy.

1.1 The Scope of Microbiology

Microbiology is a specialized area of biology that deals with living things ordinarily too small to be seen without magnification. Such **microscopic** organisms are collectively referred to as **microorganisms** (my″-kroh-or′-gun-izms), **microbes,** or other terms depending on the kind of microbe or the purpose. In the context of infection and disease, some people call them germs, viruses, or agents; others even call them "bugs"; but none of these terms are clear. In addition, some of these terms place undue emphasis on the disagreeable reputation of microorganisms. But, as we will learn throughout the course of this book, only a small minority of microorganisms are implicated in causing harm to other living beings. There are several major groups of microorganisms that we'll be studying. They are **bacteria, viruses, protozoa, helminths** (parasitic invertebrate animals such as worms), and **fungi.** All of these are cellular organisms, except for the viruses. Viruses infect each of the cellular organisms, and are noncellular, parasitic, protein-coated genetic elements that can cause harm to the host cell they infect. Their evolutionary history and impact are intimately connected with the evolution of microbes and with all living organisms, including humans. As we will see in subsequent chapters, each group of microbes exhibits a distinct collection of biological characteristics.

The nature of microorganisms makes them both very easy and very difficult to study—easy because they reproduce so rapidly and we can quickly grow large populations in the laboratory and difficult because we usually can't see them directly. We rely on a variety of indirect means of analyzing them in addition to using microscopes.

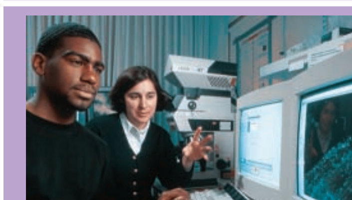
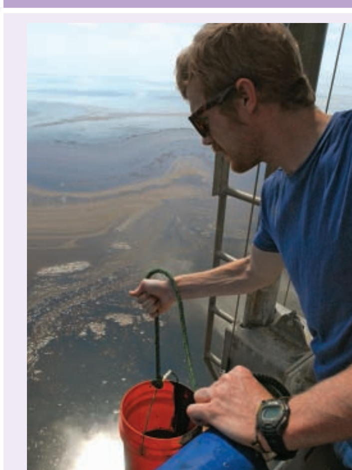
Microbiologists study every aspect of microbes—their cell structure and function, their growth and physiology, their genetics, their taxonomy and evolutionary history, and their interactions with the living and nonliving environment. The last aspect includes their uses in industry and agriculture and the way they interact with mammalian hosts, in particular, their properties that may cause disease or lead to benefits.

Some descriptions of different branches of study appear in **table 1.1.** Studies in microbiology have led to greater understanding of many general biological principles. For example, the study of microorganisms established universal concepts concerning the chemistry of life; systems of inheritance; and the global cycles of nutrients, minerals, and gases.

1.1 Learning Outcomes—Assess Your Progress

1. List the various types of microorganisms.
2. Identify multiple professions using microbiology.

Table 1.1 Microbiology—A Sampler

A. Medical Microbiology This branch deals with microbes that cause diseases in humans and animals. Researchers examine factors that make the microbes virulent and mechanisms for inhibiting them.		**Figure A.** A staff microbiologist at the Centers for Disease Control and Prevention (CDC) examines a culture of influenza virus identical to one that circulated in 1918. The lab is researching why this form of the virus was so deadly and how to develop vaccines and other treatments. Handling such deadly pathogens requires a high level of protection with special headgear and hoods. *CDC/James Gathany*
B. Public Health Microbiology and Epidemiology These branches monitor and control the spread of diseases in communities. Institutions involved in this work are the U.S. Public Health Service (USPHS) with its main agency, the Centers for Disease Control and Prevention (CDC) located in Atlanta, Georgia, and the World Health Organization (WHO), the medical limb of the United Nations.		**Figure B.** Two epidemiologists conducting interviews as part of the effort to curb the cholera epidemic in Haiti. Photograph taken in 2013. *CDC/Preetha Iyengar, M.D.*
C. Immunology This branch studies the complex web of protective substances and cells produced in response to infection. It includes such diverse areas as vaccination, blood testing, and allergy. Immunologists also investigate the role of the immune system in cancer and autoimmune diseases.		**Figure C.** An immunologist and students freeze dry samples. *© Ariel Skelley/Blend Images LLC RF*
D. Industrial Microbiology This branch safeguards our food and water, and also includes biotechnology, the use of microbial metabolism to arrive at a desired product, ranging from bread making to gene therapy. Microbes can be used to create large quantities of substances such as amino acids, beer, drugs, enzymes, and vitamins.		**Figure D.** Scientists use a multispectral imaging system for inspection of chickens. *USDA-ARS/tephen R Ausmus*
E. Agricultural Microbiology This branch is concerned with the relationships between microbes and domesticated plants and animals. Plant specialists focus on plant diseases, soil fertility, and nutritional interactions. Animal specialists work with infectious diseases and other associations animals have with microorganisms.		**Figure E.** Plant microbiologists examine images of alfalfa sprouts to see how microbial growth affects plant roots. *USDA/Scott Bauer*
F. Environmental Microbiology These microbiologists study the effect of microbes on the earth's diverse habitats. Whether the microbes are in freshwater or saltwater, topsoil or the earth's crust, they have profound effects on our planet. Subdisciplines of environmental microbiology are Aquatic microbiology—the study of microbes in the earth's surface water; Soil microbiology—the study of microbes in terrestrial parts of the planet; Geomicrobiology—the study of microbes in the earth's crust; and Astrobiology (also known as exobiology)—the search for/study of microbial and other life in places off of our planet.		**Figure F.** Researchers collect samples and data in Lake Erie. *© Christopher Berkey/epa/Corbis*

1.2 The Impact of Microbes on Earth: Small Organisms with a Giant Effect

The most important realization you should have in a microbiology course is the profound influence microorganisms have on all aspects of the earth and its residents. For billions of years, microbes have extensively shaped the development of the earth's habitats and the evolution of other life forms. It is understandable that scientists searching for life on other planets first look for signs of microorganisms.

Cellular organisms that preceded our current cell types arose on this planet about 3.5 billion years ago, according to the fossil record. It appears that they were the only living inhabitants until about 2.9 billion years ago. At that time, a cell called the last universal common ancestor, or LUCA, seems to have given rise to three types of cells. Two of these were bacteria and archaea, and the third was a more complex type of single-celled organism, the **eukaryote** (yoo″-kar-ee-ote). Eukary means *true nucleus,* because these were the only cells containing a nucleus. Bacteria and archaea have no true nucleus. For that reason, they have traditionally been called **prokaryotes** (meaning *prenucleus*). But researchers are suggesting we no longer use the term *prokaryote* because archaea and bacteria are so distant genetically.

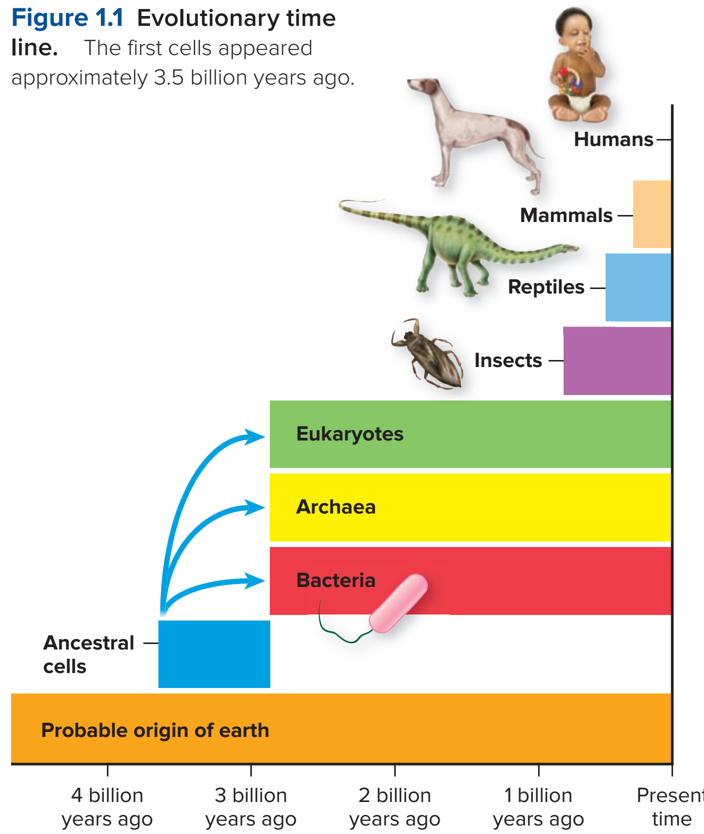


Figure 1.1 **Evolutionary time line.** The first cells appeared approximately 3.5 billion years ago.

A Note About Bacteria and Archaea

Microbiologists used to have it so easy, in the sense that we could use two terms to define all cell types: **prokaryote** and **eukaryote.** Prokaryotes referred to bacteria and archaea, that is, until genetic studies showed us that they are not closely related so we couldn't group them into a single category. Archaea seem to be genetically more related to eukaryotes, although structurally they resemble bacteria, thus, the source of the prior confusion. So now we have three cell types: eukaryotes, bacteria, and archaea. In this book, we are going to focus on bacteria and the eukaryotes, because as far as we know these groups are responsible for the majority of human disease. We will address archaea in various sections of the book where the distinction is useful, but mainly we will refer to bacteria, even when the description might also refer to archaea. It just might get confusing if we continue to say "bacteria and archaea" when the information you need is about bacteria.

Figure 1.1 illustrates the history of life on earth. On the scale pictured in the figure, humans seem to have just appeared. Bacteria preceded even the earliest animals by more than 2 billion years. This is a good indication that humans are not likely to—nor should we try to—eliminate bacteria from our environment. They've survived and adapted to many catastrophic changes over the course of their geologic history.

Another indication of the huge influence bacteria exert is how **ubiqitous** they are. Microbes can be found nearly everywhere, from deep in the earth's crust to the polar ice caps and oceans to inside the bodies of plants and animals. Being mostly invisible, the actions of microorganisms are usually not as obvious or familiar as those of larger plants and animals. They make up for their small size by occurring in large numbers and living in places where many other organisms cannot survive. Above all, they play central roles that are essential to life in the earth's landscape.

A Note About "Karyote" Versus "Caryote"

You will see the terms *prokaryote* and *eukaryote* spelled with *c* (*procaryote* and *eucaryote*) as well as *k*. Both spellings are accurate. This book uses the modern *k* spelling.

When we point out that single-celled organisms have adapted to a wide range of conditions over the 2.9 billion years of their presence on this planet, we are talking about **evolution.** Life in its present form would not be possible if the earliest life forms had not changed constantly, adapting to their environment and circumstances. Getting from the far left in figure 1.1 to the far right where humans appeared involved billions and billions of tiny changes, starting with the first cell that appeared about a billion years after the planet itself was formed.

You have no doubt heard this concept described as the "theory of evolution." Let's clarify some terms. **Evolution** is the accumulation of changes that occur in organisms as they adapt to their environments. It is documented every day in all corners of the planet, an observable phenomenon testable by science. Referring to it as the **theory of evolution** has led to great confusion among the public. As we will explain in section 1.6, scientists use the term "theory" in a different way than the general public does. By the time a principle has been labeled a theory in science, it has undergone years and years of testing and not been disproven. This is much different than the common usage, as in "My theory is that he overslept and that's why he was late." The theory of evolution, like the germ theory and many other scientific theories, are labels for well-studied and well-established natural phenomena.

Microbial Involvement in Shaping Our Planet

Microbes are deeply involved in the flow of energy and food through the earth's ecosystems.[1] Most people are aware that plants carry out **photosynthesis,** which is the light-fueled conversion of carbon dioxide to organic material, accompanied by the formation of oxygen (called oxygenic photosynthesis). However, bacteria invented photosynthesis long before first plants appeared, first as a process that did not produce oxygen (*anoxygenic photosynthesis*). This anoxygenic photosynthesis later evolved into oxygenic photosynthesis, which not only produced oxygen but also was much more efficient in extracting energy from sunlight. Hence, bacteria were responsible for changing the atmosphere of the earth from one without oxygen to one with oxygen. The production of oxygen also led to the use of oxygen for aerobic respiration and the formation of ozone, both of which set off an explosion in species diversification. Today, photosynthetic microorganisms (bacteria and algae) account for more than 70% of the earth's photosynthesis, contributing the majority of the oxygen to the atmosphere **(figure 1.2*a*).**

Another process that helps keep the earth in balance is the process of biological **decomposition** and nutrient recycling. Decomposition involves the breakdown of dead matter and wastes into simple compounds that can be directed back into the natural cycles of living things **(figure 1.2*b*).** When death occurs, the body immediately begins to decompose. Bacteria play a major role in decomposition of the body. The action of bacteria causes the conversion of soft tissues within the body to liquids and gases. The chemicals released as a result of decomposition, including hydrogen sulfide, are responsible for the pungent (and immediately identifiable to anyone who has smelled it before) smell of death. If it were not for multitudes of bacteria and fungi, many chemical elements would become locked up and unavailable to organisms; we humans would drown in our own industrial and personal wastes! In the long-term scheme of things, microorganisms are the main forces that drive the structure and content of the soil, water, and atmosphere. For example:

- The very temperature of the earth is regulated by gases, such as carbon dioxide, nitrous oxide, and methane, which create an insulation layer in the atmosphere and help retain heat. Many of these gases are produced by microbes living in the environment and in the digestive tracts of animals.

1. Ecosystems are communities of living organisms and their surrounding environment.

(a)

(b)

Figure 1.2 Examples of microbial habitats. (a) Summer pond with a thick mat of algae—a rich photosynthetic community. **(b)** Microbes play a large role in decomposing dead animal and plant matter.

(a) ©Jerome Wexler/Science Source; (b) © Michel & Christine Denis-Huot/Science Source

- Recent studies have found that large numbers of organisms exist within and beneath the earth's crust in sediments, rocks, and even volcanoes. It is increasingly evident that this enormous underground community of microbes is a significant influence on weathering, mineral extraction, and soil formation.
- Bacteria and fungi live in complex associations with plants that assist the plants in obtaining nutrients and water and may protect them against disease. Microbes form similar interrelationships with animals, notably, in the stomach of cattle, where a rich assortment of bacteria digest the complex carbohydrates of the animals' diets and cause the release of methane into the atmosphere.

1.2 Learning Outcomes—Assess Your Progress

3. Describe the role and impact of microbes on the earth.
4. Explain the theory of evolution and why it is called a theory.

1.3 Human Use of Microorganisms

Microorganisms clearly have monumental importance to the earth's operation. Their diversity and versatility make them excellent candidates for solving human problems. By accident or choice, humans have been using microorganisms for thousands of years to improve life and even to shape civilizations. Baker's and brewer's yeast, types of single-celled fungi, cause bread to rise and ferment sugar into alcohol to make wine and beers. Other fungi are used to make special cheeses such as Roquefort or Camembert. These and other "home" uses of microbes have been in use for thousands of years. For example, historical records show that households in ancient Egypt kept moldy loaves of bread to apply directly to wounds and lesions. When humans manipulate microorganisms to make products in an industrial setting, it is called biotechnology. For example, some specialized bacteria have unique capacities to mine precious metals or to create energy **(figure 1.3).**

Genetic engineering is an area of biotechnology that manipulates the genetics of microbes, plants, and animals for the purpose of creating new products and genetically modified organisms (GMOs). The powerful technique for designing GMOs is termed **recombinant DNA technology.** This technology makes it possible to transfer genetic material from one organism to another and to deliberately alter DNA.[2] Bacteria and yeasts were some of the first organisms to be genetically engineered. Even though many citizens are very uncomfortable with GMO processes, it is also true that many people are already benefiting from their medical, industrial, and agricultural uses. Microbes can be engineered to synthesize many indispensable products such as drugs, hormones, and enzymes.

Among the genetically unique organisms that have been designed by bioengineers are bacteria that mass produce antibiotic-like substances, yeasts that produce human insulin, pigs that

(a) (b) (c)

Figure 1.3 Microbes at work. **(a)** Test tubes of yellow and green algae being grown as a possible energy source. **(b)** Microbes as synthesizers. Fermenting tanks at a winery. **(c)** Workers spray nutrients on the shore of Prince William Sound in Alaska after the Exxon *Valdez* oil tanker spill in an attempt to enrich oil-degrading microbes.

2. DNA, or deoxyribonucleic acid, is the chemical substance that comprises the genetic material of organisms.

produce human hemoglobin, and plants that contain natural pesticides or fruits that do not ripen too rapidly. Genetic engineering has also provided important human vaccines and therapies.

Another way of tapping into the unlimited potential of microorganisms is the science of **bioremediation** (by′-oh-ree-mee-dee-ay″-shun). This process involves the introduction of microbes into the environment to restore stability or to clean up toxic pollutants. Microbes have a surprising capacity to break down chemicals that would be harmful to other organisms. This includes even human-made chemicals that scientists have developed and for which there are no natural counterparts.

Agencies and companies have developed microbes to handle oil spills and detoxify sites contaminated with heavy metals, pesticides, and other chemical wastes **(figure 1.3*c*).** One form of bioremediation that has been in use for some time is the treatment of water and sewage. Because clean freshwater supplies are dwindling worldwide, it will become even more important to find ways to reclaim polluted water.

1.3 Learning Outcome—Assess Your Progress

5. Explain one old way and one new way that humans manipulate organisms for their own uses.

1.4 Infectious Diseases and the Human Condition

One of the most fascinating aspects of the microorganisms with which we share the earth is that, despite all of the benefits they provide, they also contribute significantly to human misery as **pathogens** (path′-oh-jenz). You must understand: The vast majority of microorganisms that associate with humans cause no harm. In fact, they provide many benefits to their human hosts. It is important to note that a diverse microbial biota living in and on humans is an important part of human well-being. However, humankind is also plagued by more than 2,000 different microbes that can cause various types of disease. Infectious diseases still devastate human populations worldwide, despite significant strides in understanding and treating them. The World Health Organization (WHO) estimates there are a total of 10 billion new infections across the world every year. Infectious diseases are also among the most common causes of death in much of humankind, and they still kill a significant percentage of the U.S. population. **Table 1.2** depicts the 10 top causes of death per year (by all causes, infectious and noninfectious) in the United States and also worldwide. The worldwide death toll from infections is about 13 million people per year. For example, the World Health Organization reports that every 30 seconds a child dies from malaria.

Disease Connection

The most deadly lower respiratory tract infections are influenza and pneumonia. Seasonal influenza is generally hardest on the very young and very old, although during years when pandemic strains of the influenza virus are circulating, young, healthy adults can be severely affected. Influenza infections put you at risk for developing pneumonia, caused either by the influenza virus itself or by secondary viruses or bacteria. Of course, you can also develop pneumonia without first being infected by the influenza virus.

In **figure 1.4** you see that noncommunicable diseases are much more frequent in both the United States and the world. You will also note that the United States experiences relatively few—*relatively* few—communicable diseases compared to the number of noncommunicable diseases.

Malaria, which kills between 440,000 and 700,000 people every year worldwide, is caused by a microorganism transmitted by mosquitoes. Currently, the most effective way for citizens of

Table 1.2 Top Causes of Death—All Diseases

United States	No. of Deaths	Worldwide	No. of Deaths
1. Heart disease	611,105	1. Heart disease	7.3 million
2. Cancer	584,881	2. Stroke	6.7 million
3. Chronic lower respiratory diseases	149,205	3. Lower-respiratory infections (influenza and pneumonia)*	3.1 million
4. Accidents (unintentional injuries)	130,557	4. Chronic obstructive pulmonary disease	3.1 million
5. Stroke (cerebrovascular diseases)	128,978	5. Trachea, bronchus, lung cancers	1.6 million
6. Alzheimer's disease	84,767	6. HIV/AIDS	1.5 million
7. Diabetes	75,578	7. Diarrheal diseases	1.5 million
8. Influenza and pneumonia	56,979	8. Diabetes	1.5 million
9. Nephritis, nephrotic syndrome, and nephrosis	47,112	9. Road injury	1.3 million
10. Intentional self-harm (suicide)	41,149	10. Hypertensive heart disease	1.1 million

*Diseases in red are those most clearly caused by microorganisms.

Source: CDC data published in 2015 for year 2013. Data from the World Health Organization and the Centers for Disease Control and Prevention. WHO data published in 2015 representing final figures for the year 2012.

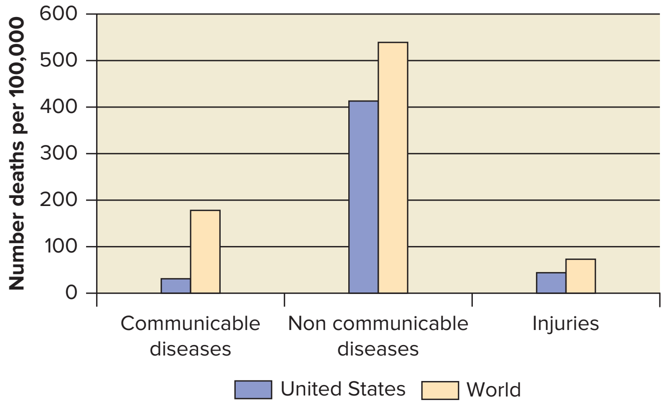


Figure 1.4 **Causes of death in the United States and the world.**

Source: Data from the World Health Organization for 2012.

developing countries to avoid infection with the causal agent of malaria is to sleep under a bed net, because the mosquitoes are most active in the evening. Yet even this inexpensive solution is beyond the reach of many. Mothers in Southeast Asia and elsewhere have to make nightly decisions about which of their children will sleep under the single family bed net, because a second one, priced at about $10, is too expensive for them.

Adding to the overload of infectious diseases, we are also witnessing an increase in the number of new (emerging) and older (reemerging) diseases. Ebola, AIDS, hepatitis C, and viral encephalitis are examples of diseases that cause severe mortality and morbidity. To somewhat balance this trend, there have also been some advances in eradication of diseases such as polio and leprosy and diseases caused by certain parasitic worms.

One of the most eye-opening discoveries in recent years is that many diseases that used to be considered noninfectious probably do involve microbial infection. The most famous of these is gastric ulcers, now known to be caused by a bacterium called *Helicobacter*. But there are more. An association has been established between certain cancers and bacteria and viruses, between diabetes and the coxsackievirus, and between schizophrenia and the coxsackievirus. Diseases as different as multiple sclerosis, obsessive compulsive disorder, coronary artery disease, and even obesity have been linked to chronic infections with microbes. It seems that the golden age of microbiological discovery, during which all of the "obvious" diseases were characterized and cures or preventions were devised for them, should more accurately be referred to as the *first* golden age. We're now discovering the subtler side of microorganisms. Their roles in quiet but slowly destructive diseases are now well known. These include female infertility, caused by *Chlamydia* infection, and malignancies such as liver cancer (hepatitis viruses) and cervical cancer (human papillomavirus).

As mentioned in section 1.5, another important development in infectious disease trends is the increasing number of patients with weakened defenses that are kept alive for extended periods. They are subject to infections by common microbes that are not pathogenic to healthy people. There is also an increase in microbes that are resistant to drugs. It appears that even with the most modern technology available to us, microbes still have the "last word," as the great French scientist Louis Pasteur observed.

1.4 Learning Outcome—Assess Your Progress

6. Summarize the relative burden of human disease caused by microbes, emphasizing the differences between developed countries and developing countries.

1.5 The General Characteristics of Microorganisms

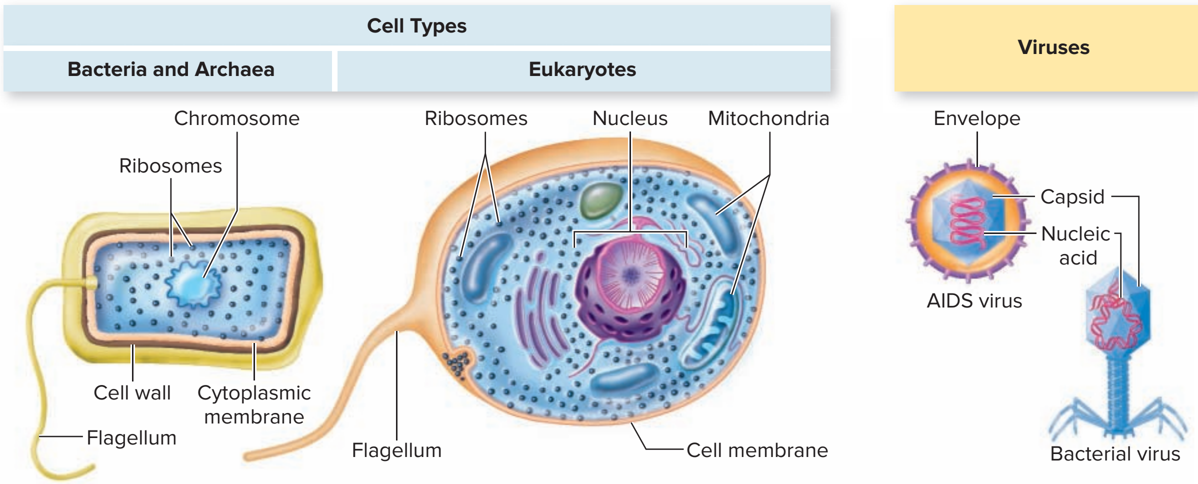
Cellular Organization

As discussed in section 1.1, three basic cell lines appeared during evolutionary history. These lines—**Archaea, Eukarya,** and **Bacteria**—differ not only in the complexity of their cell structure **(figure 1.5*a*)** but also in contents and function.

A Note About Viruses

Viruses are subject to intense study by microbiologists. As mentioned before, they are not independently living, cellular organisms. Instead, they are small particles that exist at the level of complexity somewhere between large molecules and cells **(figure 1.5*b*).** Viruses are much simpler than cells; outside their host, they are composed essentially of a small amount of hereditary material (either DNA or RNA but never both) wrapped up in a protein covering that is sometimes enveloped by a protein-containing lipid membrane. In this extracellular state, they are individually referred to as **a virus particle** or **virion.** When inside their host organism, in the intracellular state, viruses usually exist only in the form of genetic material that confers a partial genetic program on the host organisms. That is why many microbiologists refer to viruses as parasitic particles; however, a few consider them to be very primitive organisms. Nevertheless, all biologists agree that viruses are completely dependent on an infected host cell's machinery for their multiplication and dispersal.

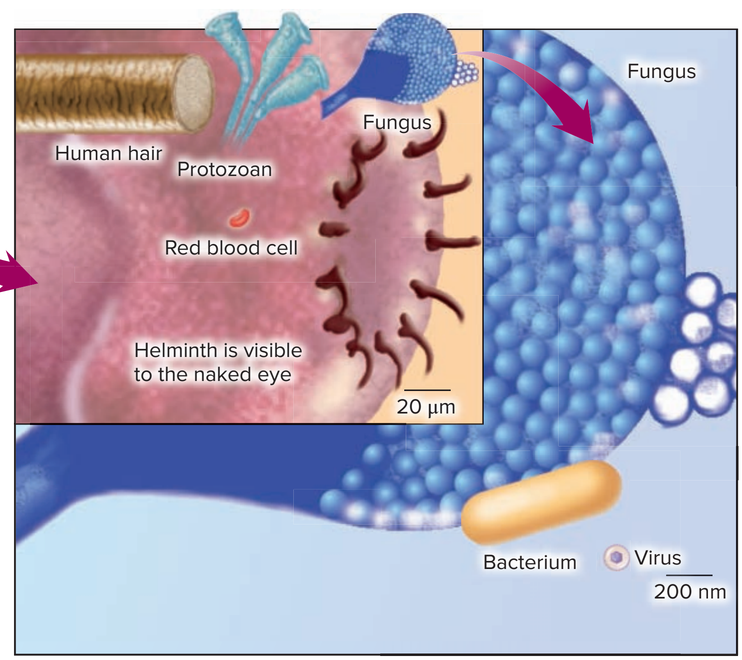
To make a broad generalization, bacterial and archaeal cells are about 10 times smaller than eukaryotic cells. They generally lack many of the eukaryotic cell structures such as **organelles.** Organelles are small, double-membrane-bound structures in the eukaryotic cell that perform specific functions; they include the nucleus, mitochondria, and chloroplasts. All bacteria and archaea are microorganisms, but only some eukaryotes are microorganisms. The majority of microorganisms are single-celled (all bacteria and archaea and some eukaryotes), but some consist of a few cells **(figure 1.6).** Certain invertebrate animals—such as helminths (worms), many of which can be seen with the naked eye—are also included in the study of infectious diseases because of the way they are transmitted and the way the body responds to them, though they are not microorganisms.

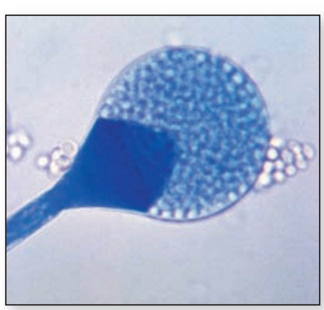


(a) (b)

Figure 1.5 Cell structure. **(a)** Comparison of a bacterial/archaeal cell and a eukaryotic cell (not to scale). **(b)** Two examples of viruses.

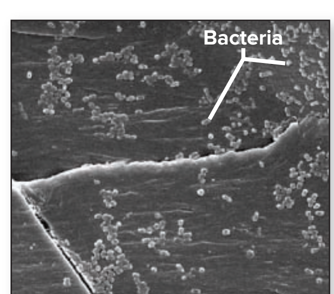
Helminth: Head (scolex) of *Taenia solium*



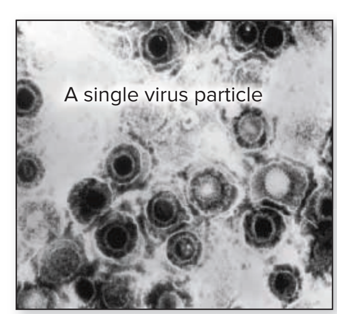


Fungus: *Mucor*

Protozoan: *Vorticella*



Bacterium: *E. coli*



Virus: Herpes simplex

Figure 1.6 Five types of microorganisms. The drawing at top right shows relative size differences. The photos of organisms around the drawing are pictured at different magnifications in order to show their details.

(Top Left) CDC; (Middle Left) CDC/Dr. Lucille K. Georg; (Bottom Left) © Nancy Nehring/E+/Getty Images RF; (Bottom Center) CDC/Janice Carr; (Bottom Right) CDC