FOURTH EDITION

Microbiology
A Systems Approach

Marjorie Kelly Cowan
Miami University

McGraw Hill Education

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MICROBIOLOGY: A SYSTEMS APPROACH, FOURTH EDITION

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 DOW/DOW 1 0 9 8 7 6 5 4

ISBN 978–0–07–340243–7
MHID 0–07–340243–5

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Senior Content Licensing Specialist: *John Leland*
Art Studio and Compositor: *Electronic Publishing Services Inc., NYC*
Typeface: *10/12 Palatino LT Std*
Printer: *R. R. Donnelley*

Library of Congress Cataloging-in-Publication Data

Cowan, M. Kelly, author.
Microbiology : a systems approach. – Fourth edition / Marjorie Kelly Cowan, Miami University–Middletown.
pages cm
Includes index.
ISBN 978–0–07–340243–7 — ISBN 0–07–340243–5 (hard copy : alk. paper) 1. Microbiology–Textbooks. I. Title.
QR41.2.C69 2015
579–dc23
2013039844

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Brief Contents

About the Authors

Kelly Cowan just celebrated her 20th anniversary at Miami University Middletown, an open admissions campus in Ohio. She received her Ph.D. at the University of Louisville, and later worked at the University of Maryland and the University of Groningen in the Netherlands. She specializes in teaching microbiology to nonmajors, and especially to pre-nursing and allied health students. She herself fell in love with microbiology while pursuing an undergraduate degree in dental hygiene. She has made it her personal mission to hear nurses and dental hygienists she encounters in everyday situations exclaim, "I *loved* my microbiology class!"

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

With this fourth edition, we are pleased to continue to have Jennifer Herzog on the team. Jen works hand-in-hand with the textbook author, creating online tools that truly complement and enhance the book's content. Because of Jen we now 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.

Jennifer Herzog, M.S., M. Phil., is an assistant professor of biology at Herkimer County Community College, Herkimer, New York, where she regularly teaches biology and microbiology to nonmajors and allied health students. She has been an active member of the American Society for Microbiology for nearly 20 years, most recently serving as Chair of the ASM Conference for Undergraduate Education and serving as Chair-Elect for the ASM's Education Division. In addition, she currently authors the "Journal Watch" section of the ASM's *Journal of Microbiology & Biology Education* and serves on the ASM's Microbe Library Editorial Review Board.

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.

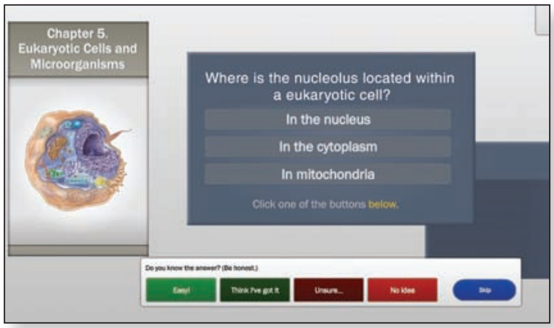
—Kelly Cowan

I dedicate this book to all public health workers who devote their lives to bringing the advances and medicines enjoyed by the industrialized world to *all* humans.

LEARNSMART™ ADVANTAGE

LearnSmart® is one of the most effective and successful adaptive learning resources available on the market today. More than 2 million students have answered more than 1.3 billion questions in LearnSmart since 2009, making it the most widely used and intelligent adaptive study tool that's proven to strengthen memory recall, keep students in class, and boost grades. Students using LearnSmart are 13% more likely to pass their classes, and 35% less likely to drop out.

LearnSmart continuously adapts to each student's needs by building an individual learning path so students study smarter and retain more knowledge. Turnkey reports provide valuable insight to instructors, so precious class time can be spent on higher-level concepts and discussion.

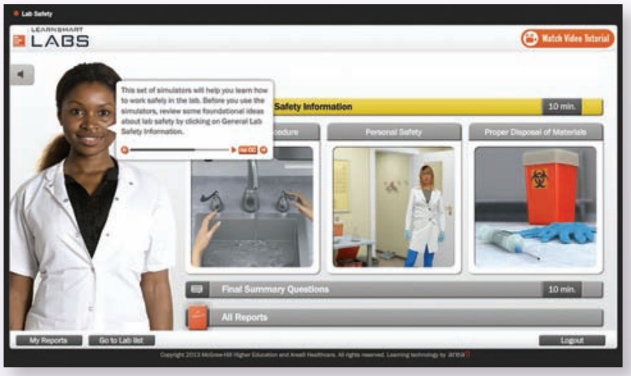


Fueled by LearnSmart—the most widely used and intelligent adaptive learning resource—**SmartBook™** is the first and only adaptive reading experience available today.

Distinguishing what a student knows from what they don't, and honing in on concepts they are most likely to forget, SmartBook personalizes content for each student in a continuously adapting reading experience. Reading is no longer a passive and linear experience, but an engaging and dynamic one where students are more likely to master and retain important concepts, coming to class better prepared.

As a result of the adaptive reading experience found in SmartBook, students are more likely to retain knowledge, stay in class, and get better grades.

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, they engage in a highly realistic simulated lab experience that allows for mistakes and the execution of the scientific method.



LearnSmart Prep™ The primary goal of LearnSmart Prep is to help students who are unprepared to take college-level courses. Using super-adaptive technology, the program identifies what a student doesn't know, and then provides "teachable moments" designed to mimic the office hour experience. When combined with a personalized learning plan, an unprepared or struggling student has all the tools they need to quickly and effectively learn the foundational knowledge and skills necessary to be successful in a college-level course.

www.learnsmartadvantage.com

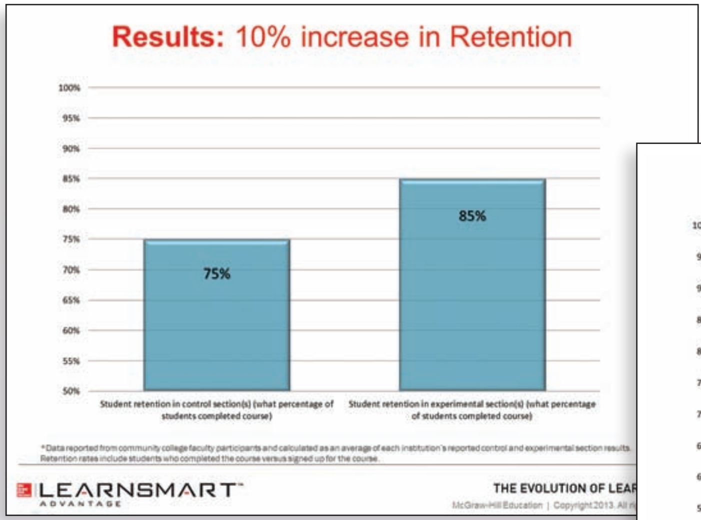
Digital efficacy study shows results!

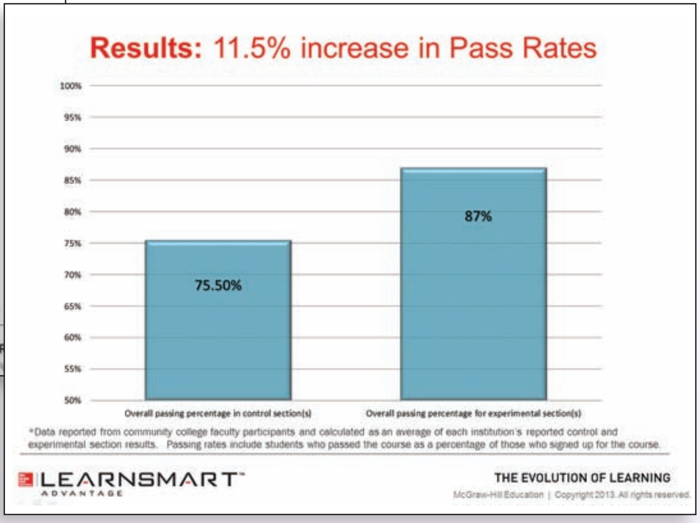
Digital efficacy study final analysis shows students experience higher success rates when required to use LearnSmart.

- Passing rates increased by an average of **11.5%** across the schools and by a weighted average of **7%** across all students.
- Retention rates increased an average of **10%** across the schools and by a weighted average of **8%** across all students.

Study details:

- Included two state universities and four community colleges.
- Control sections assigned chapter assignments consisting of testbank questions and the experimental sections assigned LearnSmart, both through McGraw-Hill Connect®.
- Both types of assignments were counted as a portion of the grade, and all other course materials and assessments were consistent.
- 358 students opted into the LearnSmart sections and 332 into the sections where testbank questions were assigned.





"LearnSmart has helped me to understand exactly what concepts I do not yet understand. I feel like after I complete a module I have a deeper understanding of the material and a stronger base to then build on to apply the material to more challenging concepts."

—Student

"LearnSmart is intuitive and analyzes where the students' strengths and weaknesses are and develops a strategy to properly tutor the student. Connect Microbiology gives the students examples of test questions in several different formats and provides other materials to help them study and review the chapters."

—Stephen Wagner, Stephen F. Austin State University

"After collecting data for five semesters, including two 8-week intensive courses, the trend was very clear: students who used LearnSmart scored higher on exams and tended to achieve a letter grade higher than those who did not."

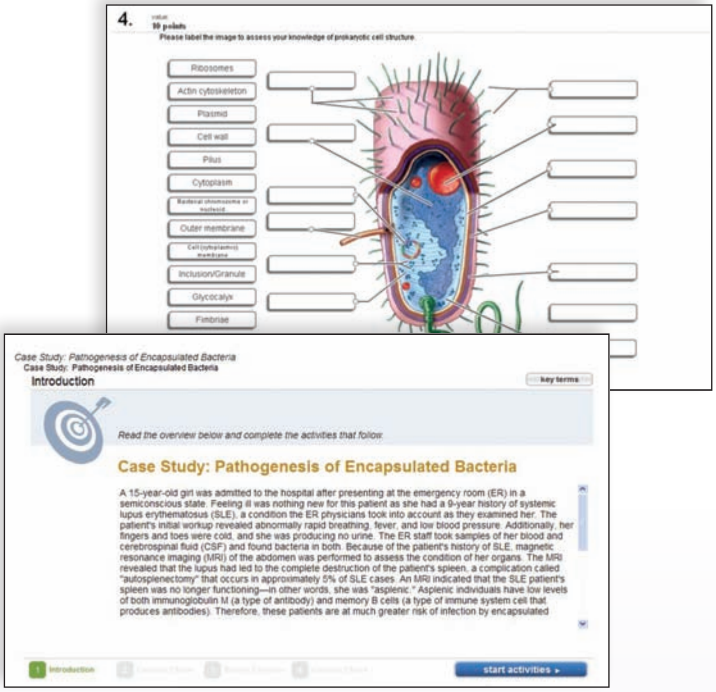
—Gabriel Guzman, Triton College

Connecting to Core Concepts

McGraw-Hill ConnectPlus® Microbiology

McGraw-Hill Connect Microbiology is a digital teaching and learning environment that saves students and instructors time while improving performance over a variety of critical outcomes.

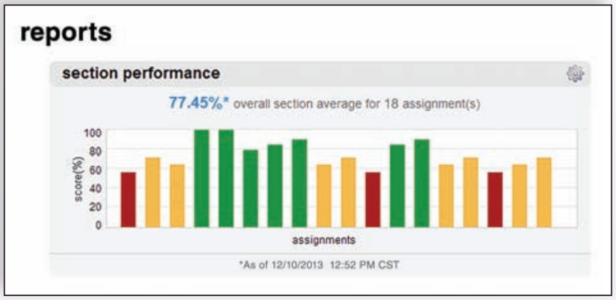
- From in-site tutorials to tips and best practices, to live help from colleagues and specialists—you're never left alone to maximize Connect's potential.
- Instructors have access to a variety of resources including assignable and gradable interactive questions based on textbook images, case study activities, tutorial videos, and more.
- Digital images, PowerPoint slides, and instructor resources are also available through Connect.
- Digital Lecture Capture: Get Connected. Get McGraw-Hill Tegrity Campus™. Capture your lectures for students. Easy access outside of class anytime, anywhere, on just about any device.



Gather assessment information

Generate powerful data related to student performance against Learning Outcomes, specific topics, level of difficulty, and more.

Visit www.mcgrawhillconnect.com.



Connect seamlessly integrates with every learning management system out there through McGraw-Hill Campus, so you can easily combine your course resources into a single platform. Instructors and students benefit from universal single sign-on, automatic registration, and gradebook synchronization.

"The clear explanation of complex topics with adequate graphic resources (in text and online) are its greatest strength. This is really enhanced with the Connect and LearnSmart materials. The online materials are the best available."

—Clifton Franklund, Ferris State University

Self-study resources are also available at **www.mhhe.com/cowan4e.**

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

1. **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. Pre- and post-testing allow instructors and students to assess their overall comprehension of the activity.
2. **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.
3. **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.
4. **Animations:** Animation quizzes pair our high-quality animations with questions designed to probe student understanding of the illustrated concepts.
5. **Tutorial Animation Learning Modules:** Making use of McGraw-Hill's collection of videos and animations, this question type presents an interactive, self-grading, and assessable activity. Pre- and post-testing is used to assess shifts in student comprehension. Integrated questions force students to stop, think, and evaluate their understanding of the process being presented. These tutorials take a stand-alone, static animation and turn it into an interactive learning experience for your students with real-time remediation.
6. **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!
7. **Classification:** Ask students to organize concepts or structures into categories by placing them in the correct "bucket."
8. **Sequencing:** Challenge students to place the steps of a complex process in the correct order.
9. **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 ConnectPlus 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.

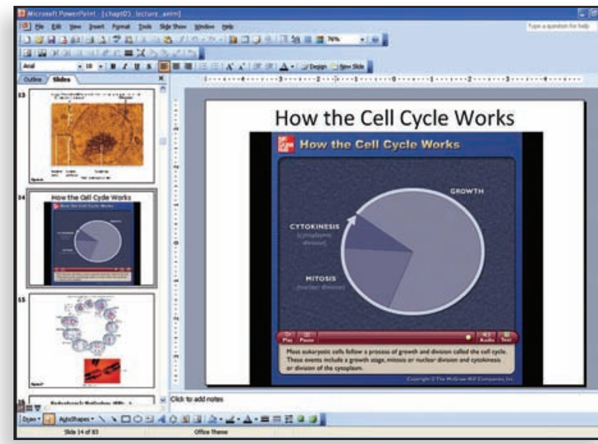
INSTRUCTORS
Presentation and Lecture Capture Tools

Presentation Tools Allow You to Customize Your Lectures

Enhanced Lecture Presentations contain lecture outlines, art, photos, tables, and animations embedded where appropriate. Fully customizable, but complete and ready to use, these presentations will enable you to spend less time preparing for lecture!

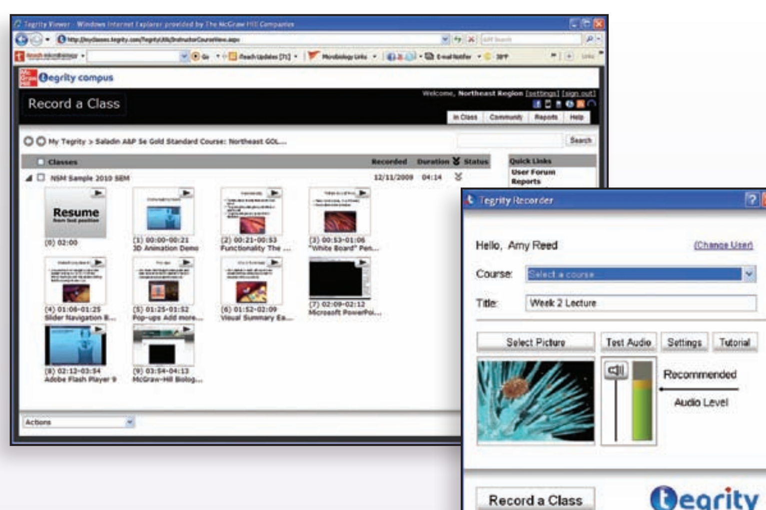
Animations Over 100 animations bring key concepts to life, available for instructors and students.

Animation PPTs Animations are truly embedded in PowerPoint® for ultimate ease of use! Just copy and paste into your custom slide show and you're done!



Take your course online—easily—with one-click Digital Lecture Capture

McGraw-Hill Tegrity Campus™ records and distributes your lectures with just a click of a button. Students can view them anytime/anywhere via computer, iPod, or mobile device. Tegrity Campus indexes as it records your slideshow presentations and anything shown on your computer so **students can use keywords to find exactly what they want to study.**



"This text is the complete package. It is well written and is supplemented with superior digital content."

—Nahel W. Awadallah, Johnston Community College

Be sure to visit Kelly's blog, www.microbiologymaven.com, where she and her guest bloggers tackle science and science teaching, as well as the occasional off-the-wall topic. If you subscribe (for free) you'll get emails once or twice a week with new entries: just enough to relieve stress and renew your sense of camaraderie with fellow instructors around the country.

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Introducing **McGraw-Hill Create™**—a new, self-service website that allows you to create custom course materials—print and eBooks—by drawing upon McGraw-Hill's comprehensive, cross-disciplinary content. Add your own content quickly and easily. Tap into other rights-secured third-party sources as well. Then, arrange the content in a way that makes the most sense for your course. Even personalize your book with your course name and information! Choose the best format for your course: color print, black and white print, or eBook. The eBook is now even viewable on an iPad! And, when you are done you will receive a free PDF review copy in just minutes!

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

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

Brown/Smith: *Benson's Microbiological Applications: Laboratory Manual in General Microbiology,* 13th edition
Short Version (978-0-07-340241-3)
Complete Version (978-0-07-766802-0)

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)

Harley: *Laboratory Exercises in Microbiology,* 9th edition (978-0-07-751055-8)

Kleyn et al.: *Microbiology Experiments*: *A Health Science Perspective,* 7th edition (978-0-07-731554-2)

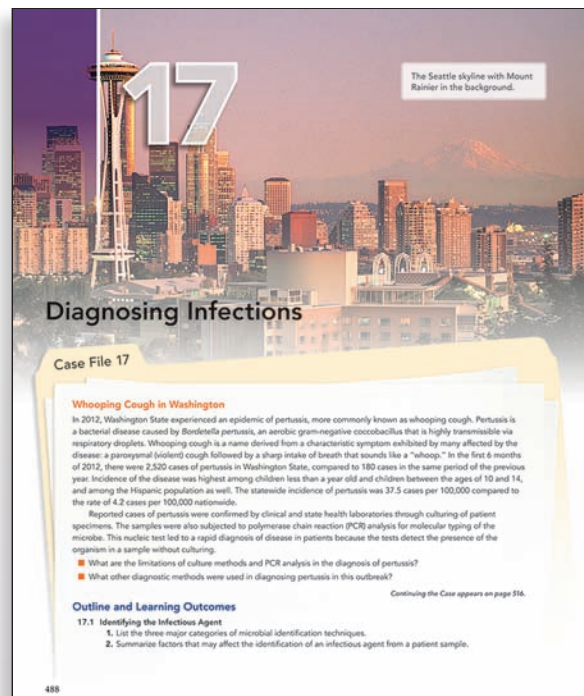
Morello: *Laboratory Manual and Workbook in Microbiology: Applications to Patient Care,* 11th edition (978-0-07-340239-0)

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. Author Kelly Cowan has made it her goal to help all students make the connections between microbiology and the world they see around them. Her 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

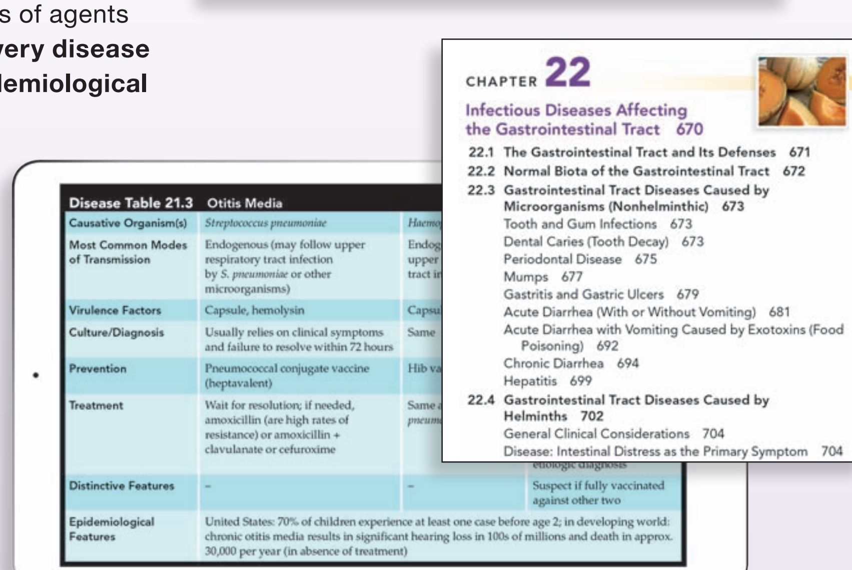
Chapter 17 brings together in one place the current methods used to diagnose infectious diseases. The chapter starts with collecting samples from the patient and details the biochemical, serological, and molecular methods used to identify causative microbes.



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 worldwide epidemiological information for each causative agent.**

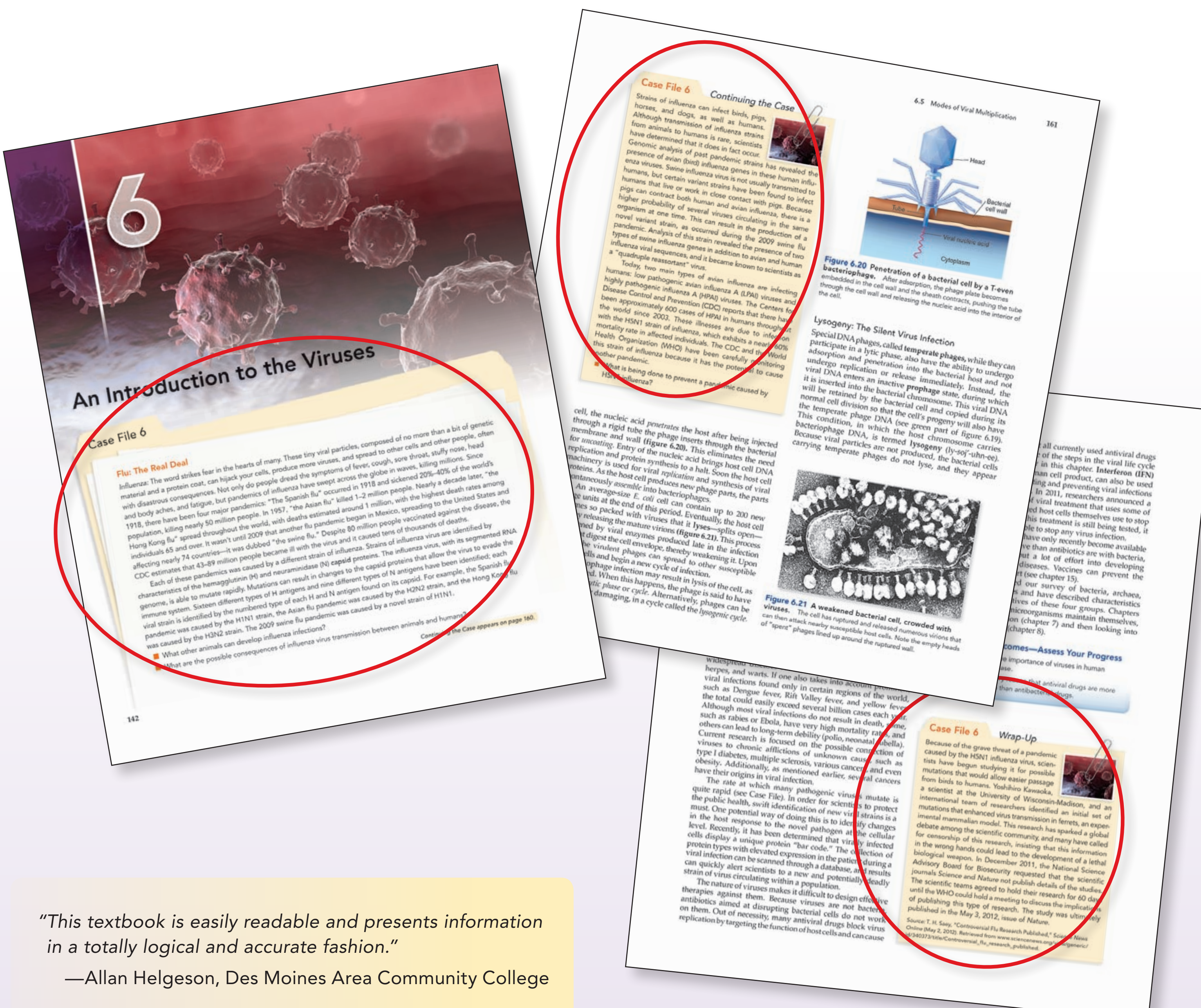
This approach is logical, systematic, and intuitive, as it encourages clinical and critical thinking in students—the type of thinking they will be using if their eventual careers are in health care. Students learn to examine multiple possibilities for a given condition and grow accustomed to looking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



CHAPTER 22

Chapter Opening Case Files!

Each chapter opens with a Case File, which helps students grasp the relevance of the material they're about to learn. The questions that directly follow the Case File challenge students to begin to think critically about what they are going to read, expecting that they'll be able to answer them once they've worked through the chapter. The Continuing the Case feature appears within the chapter where relevant, to help students follow the real-world application of the case. The Case File Wrap-Up summarizes the case at the end of the chapter, pulling together the applicable content and the chapter's topics. All of the case files are new in the fourth edition, including hot microbiological topics that are making news headlines today.



"This textbook is easily readable and presents information in a totally logical and accurate fashion."

—Allan Helgeson, Des Moines Area Community College

Connecting Students to the Content with Truly Instructional Art

Effective science illustrations not only look pretty, but help students visualize complex concepts and processes and paints a conceptual picture for them. The art combines vivid colors, multi-dimensionality, 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.

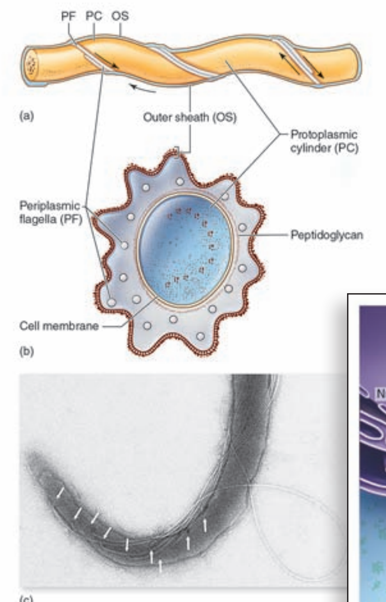


Figure 4.10 The orientation of periplasmic flagella o spirochete cell. **(a)** Longitudinal section. **(b)** Cross section (e view). Contraction of the filaments imparts a spinning and undul pattern of locomotion. **(c)** Electron micrograph captures the deta of periplasmic flagella and their insertion points (arrows) in *Borre burgdorferi*, the cause of Lyme disease. One flagellum has escap outer sheath, probably during preparation for EM. (Bar = 0.2 mi

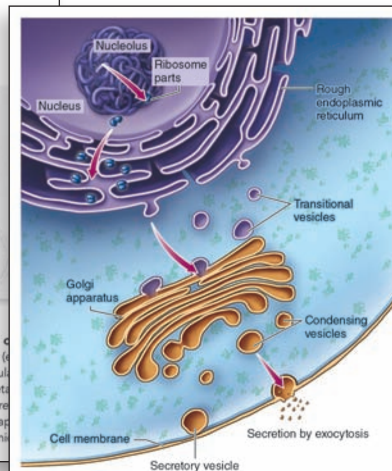
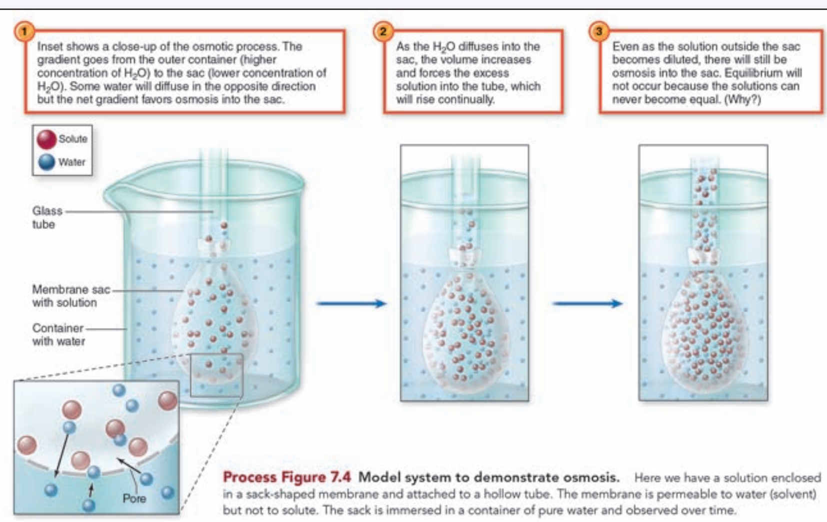


Figure 5.10 The transport process. The cooperation of organelles in protein synthesis and transport: nucleus ⟶ RER ⟶ Golgi apparatus ⟶ vesicles ⟶ secretion.

> *"The readabililty makes this text a winner. Excellent text!"*
>
> —Kimberly Harding, Colorado Mountain College



Process Figure 7.4 Model system to demonstrate osmosis. Here we have a solution enclosed in a sack-shaped membrane and attached to a hollow tube. The membrane is permeable to water (solvent) but not to solute. The sack is immersed in a container of pure water and observed over time.

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 Microbiology with Relevant Examples

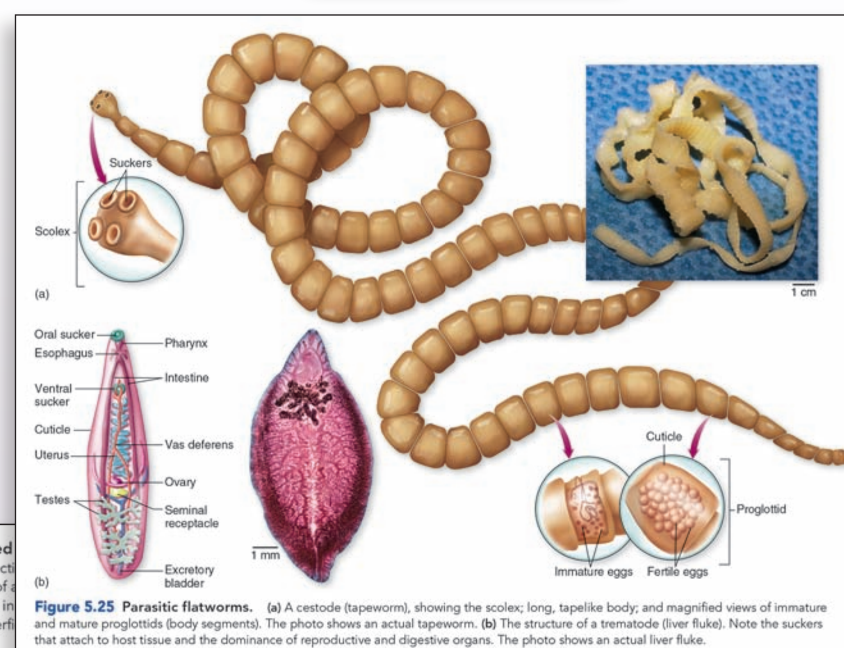
Real Clinical Photos Help Students Visualize Diseases

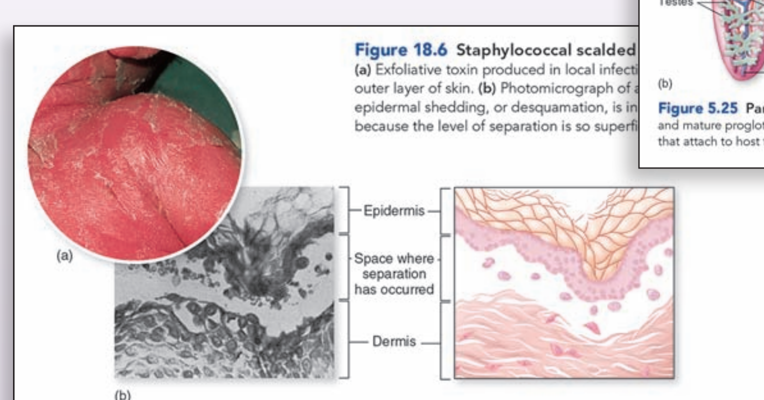
Clinical Photos

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

Combination Figures

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



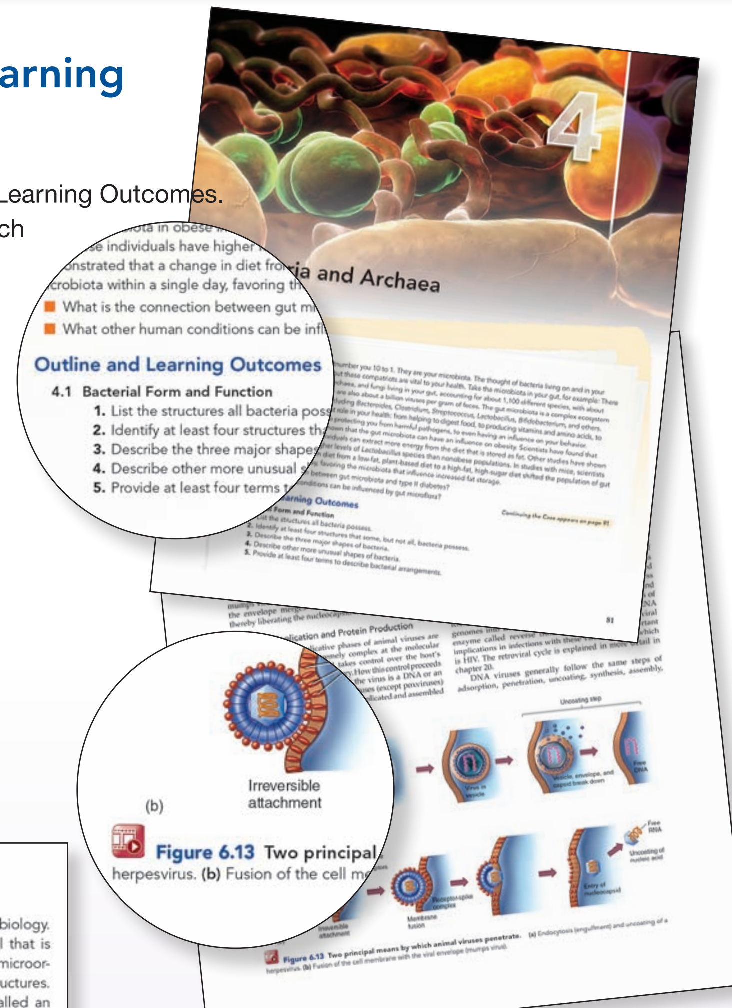


Connecting Students to Microbiology Through Student-Centered Pedagogy

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.

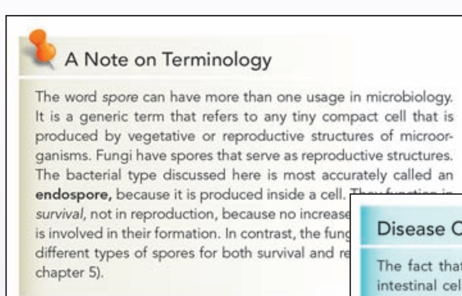


Animated Learning Modules

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.

Notes

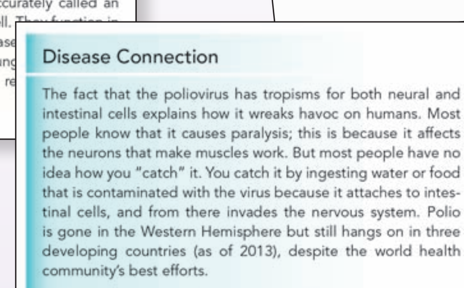
Notes appear, where appropriate, throughout the text. They give students helpful information about various terminologies, exceptions to the rule, or important clarifications.


A Note on Terminology

The word *spore* can have more than one usage in microbiology. It is a generic term that refers to any tiny compact cell that is produced by vegetative or reproductive structures of microorganisms. Fungi have spores that serve as reproductive structures. The bacterial type discussed here is most accurately called an **endospore,** because it is produced inside a cell. The function in *survival,* not in reproduction, because no increase is involved in their formation. In contrast, the fung different types of spores for both survival and re chapter 5).

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

The fact that the poliovirus has tropisms for both neural and intestinal cells explains how it wreaks havoc on humans. Most people know that it causes paralysis; this is because it affects the neurons that make muscles work. But most people have no idea how you "catch" it. You catch it by ingesting water or food that is contaminated with the virus because it attaches to intestinal cells, and from there invades the nervous system. Polio is gone in the Western Hemisphere but still hangs on in three developing countries (as of 2013), despite the world health community's best efforts.

Tables

This edition contains numerous illustrated tables. Horizontal contrasting lines set off each entry, making it easy to read.

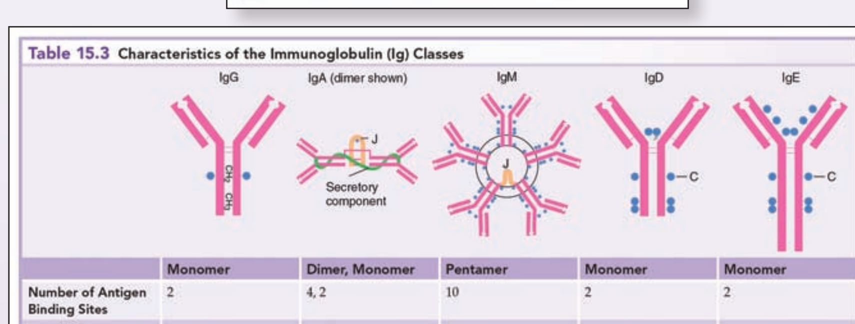
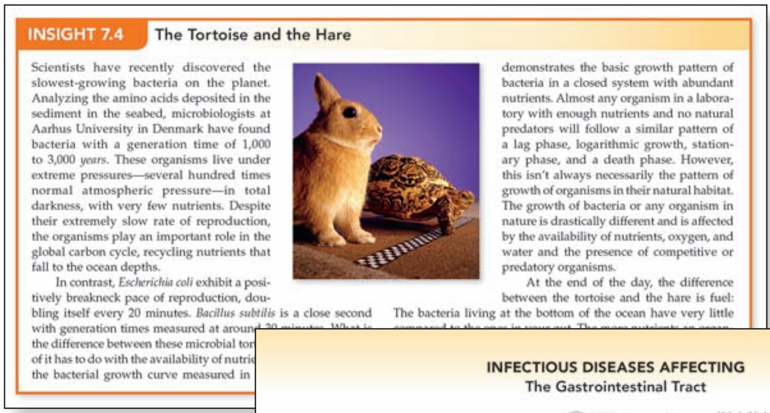


Table 15.3 Characteristics of the Immunoglobulin (Ig) Classes

	IgG	IgA	IgM	IgD	IgE
	Monomer	Dimer, Monomer	Pentamer	Monomer	Monomer
Number of Antigen Binding Sites	2	4, 2	10	2	2
Molecular Weight	150,000	170,000-385,000	900,000	180,000	200,000



INSIGHT 7.4 The Tortoise and the Hare

Scientists have recently discovered the slowest-growing bacteria on the planet. Analyzing the amino acids deposited in the sediment in the seabed, microbiologists at Aarhus University in Denmark have found bacteria with a generation time of 1,000 to 3,000 *years*. These organisms live under extreme pressures—several hundred times normal atmospheric pressure—in total darkness, with very few nutrients. Despite their extremely slow rate of reproduction, the organisms play an important role in the global carbon cycle, recycling nutrients that fall to the ocean depths.

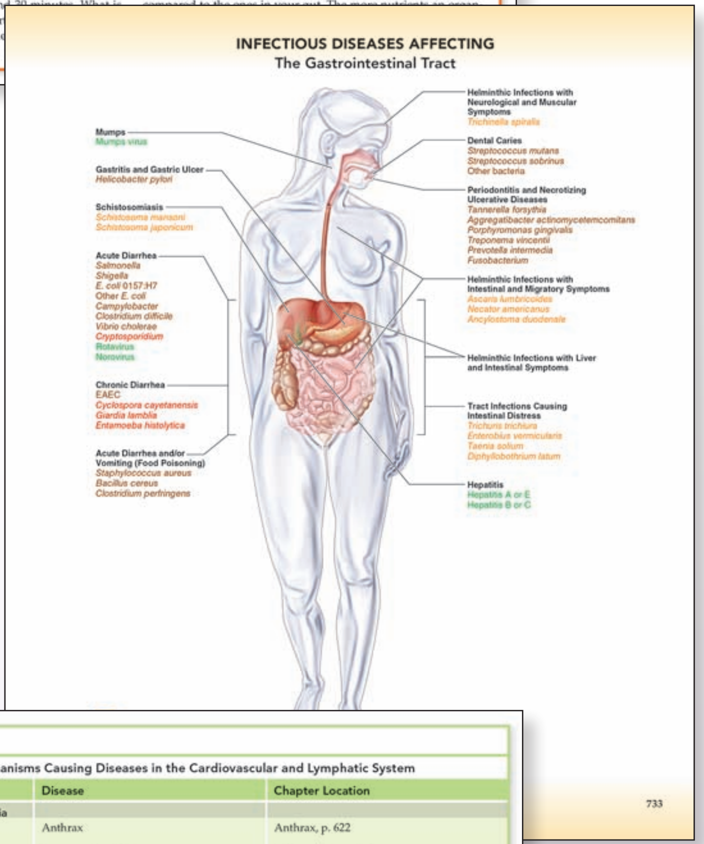
In contrast, *Escherichia coli* exhibit a positively breakneck pace of reproduction, doubling itself every 20 minutes. *Bacillus subtilis* is a close second with generation times measured at aroun… the difference between these microbial tor… of it has to do with the availability of nutri… the bacterial growth curve measured in …

demonstrates the basic growth pattern of bacteria in a closed system with abundant nutrients. Almost any organism in a laboratory with enough nutrients and no natural predators will follow a similar pattern of a lag phase, logarithmic growth, stationary phase, and a death phase. However, this isn't always necessarily the pattern of growth of organisms in their natural habitat. The growth of bacteria or any organism in nature is drastically different and is affected by the availability of nutrients, oxygen, and water and the presence of competitive or predatory organisms.

At the end of the day, the difference between the tortoise and the hare is fuel: The bacteria living at the bottom of the ocean have very little …

Insight Readings

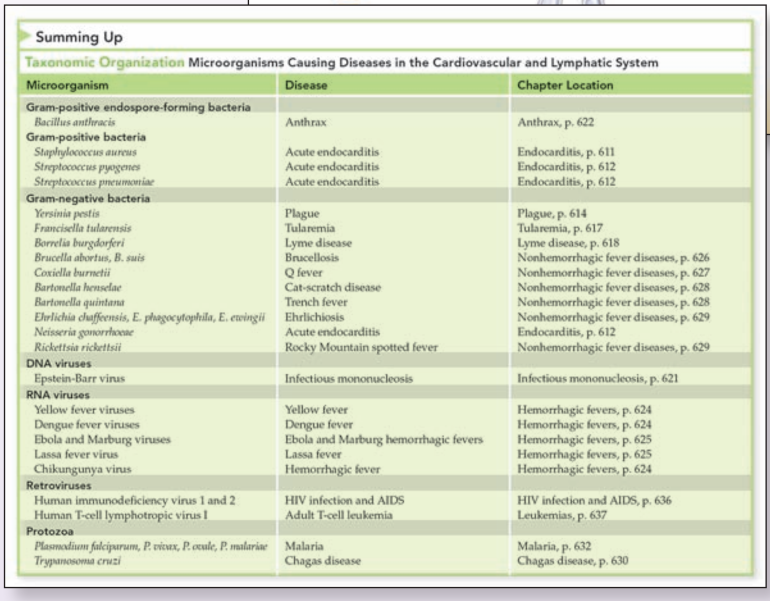
Found throughout each chapter, current, real-world readings allow students to see an interesting application of the concepts they're studying.



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.

> *"I appreciate the organization in the way the topics are broken up so students can easily maintain their focus while reading. The Disease Tables, Insight Readings, and System Summary Figures are a great way for them to review and apply what they have learned."*
>
> —Alicia D. Carley, Northwest Technical College



Summing Up

Taxonomic Organization Microorganisms Causing Diseases in the Cardiovascular and Lymphatic System

Microorganism	Disease	Chapter Location
Gram-positive endospore-forming bacteria		
Bacillus anthracis	Anthrax	Anthrax, p. 622
Gram-positive bacteria		
Staphylococcus aureus	Acute endocarditis	Endocarditis, p. 611
Streptococcus pyogenes	Acute endocarditis	Endocarditis, p. 612
Streptococcus pneumoniae	Acute endocarditis	Endocarditis, p. 612
Gram-negative bacteria		
Yersinia pestis	Plague	Plague, p. 614
Francisella tularensis	Tularemia	Tularemia, p. 617
Borrelia burgdorferi	Lyme disease	Lyme disease, p. 618
Brucella abortus, B. suis	Brucellosis	Nonhemorrhagic fever diseases, p. 626
Coxiella burnetii	Q fever	Nonhemorrhagic fever diseases, p. 627
Bartonella henselae	Cat-scratch disease	Nonhemorrhagic fever diseases, p. 628
Bartonella quintana	Trench fever	Nonhemorrhagic fever diseases, p. 628
Ehrlichia chaffeensis, E. phagocytophila, E. ewingii	Ehrlichiosis	Nonhemorrhagic fever diseases, p. 629
Neisseria gonorrhoeae	Acute endocarditis	Endocarditis, p. 612
Rickettsia rickettsii	Rocky Mountain spotted fever	Nonhemorrhagic fever diseases, p. 629
DNA viruses		
Epstein-Barr virus	Infectious mononucleosis	Infectious mononucleosis, p. 621
RNA viruses		
Yellow fever viruses	Yellow fever	Hemorrhagic fevers, p. 624
Dengue fever viruses	Dengue fever	Hemorrhagic fevers, p. 624
Ebola and Marburg viruses	Ebola and Marburg hemorrhagic fevers	Hemorrhagic fevers, p. 625
Lassa fever virus	Lassa fever	Hemorrhagic fevers, p. 625
Chikungunya virus	Hemorrhagic fever	Hemorrhagic fevers, p. 624
Retroviruses		
Human immunodeficiency virus 1 and 2	HIV infection and AIDS	HIV infection and AIDS, p. 636
Human T-cell lymphotropic virus I	Adult T-cell leukemia	Leukemias, p. 637
Protozoa		
Plasmodium falciparum, P. vivax, P. ovale, P. malariae	Malaria	Malaria, p. 632
Trypanosoma cruzi	Chagas disease	Chagas disease, p. 630

Taxonomic List of Organisms

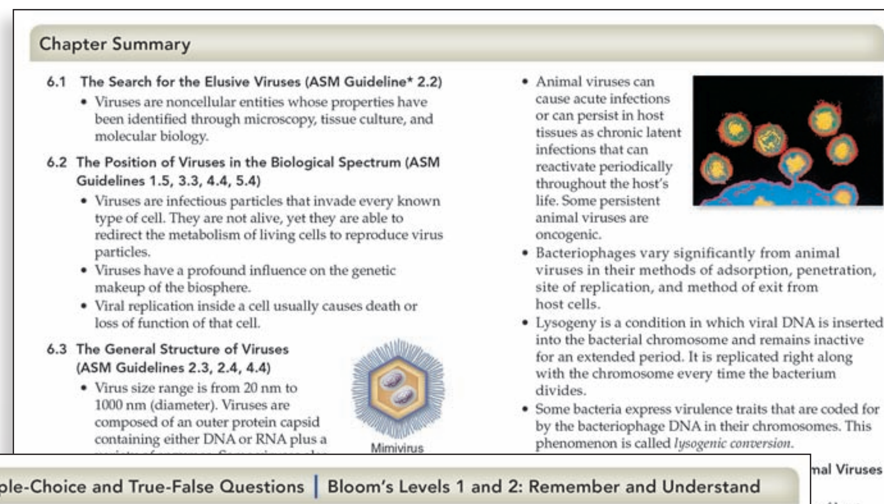
A taxonomic list of organisms is presented at the end of each disease chapter so students can see the taxonomic position of microbes causing diseases in that body system.

Connecting Learning to Bloom's Taxonomy

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, Concept Connections, 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 curricular guidelines.



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.

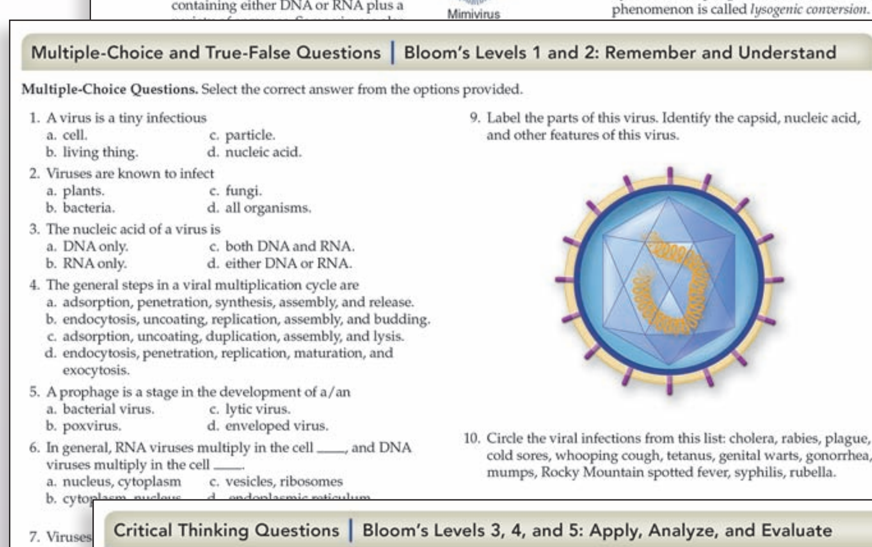
6.3 The General Structure of Viruses (ASM Guidelines 2.3, 2.4, 4.4)
- Virus size range is from 20 nm to 1000 nm (diameter). Viruses are composed of an outer protein capsid containing either DNA or RNA plus a

Mimivirus

- 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 phenomenon is called *lysogenic conversion*.

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 ConnectPlus eBook allows students to quiz themselves interactively using these questions! Bloom's Levels for all questions are provided.



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.

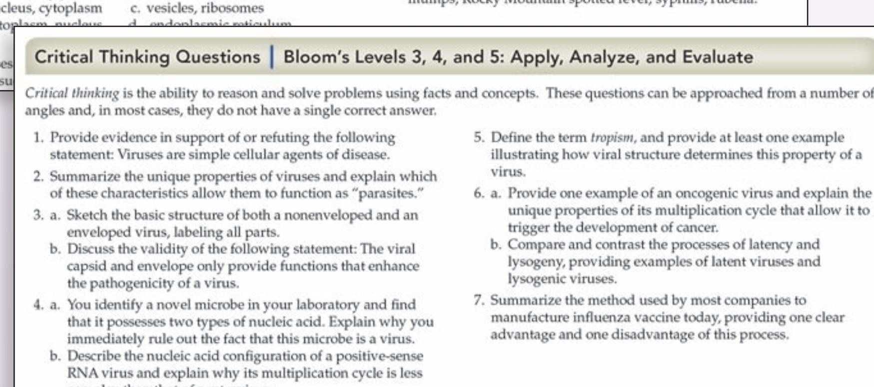
1. A virus is a tiny infectious
 a. cell. c. particle.
 b. living thing. d. nucleic acid.
2. Viruses are known to infect
 a. plants. c. fungi.
 b. bacteria. d. all organisms.
3. The nucleic acid of a virus is
 a. DNA only. c. both DNA and RNA.
 b. RNA only. d. either DNA or RNA.
4. The general steps 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

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.

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 fourth edition.



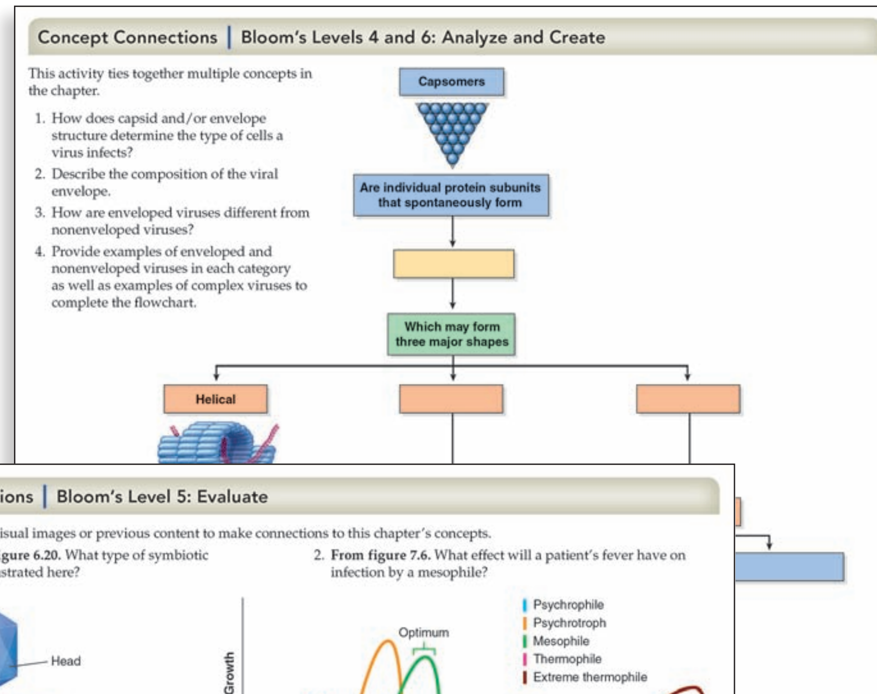
Critical Thinking Questions | Bloom's Levels 3, 4, and 5: Apply, Analyze, and Evaluate

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. a. Sketch the basic structure of both a nonenveloped and an enveloped virus, labeling all parts.
 b. Discuss the validity of the following statement: The viral capsid and envelope only provide functions that enhance the pathogenicity of a virus.
4. a. You identify a novel microbe in your laboratory and find that it possesses two types of nucleic acid. Explain why you immediately rule out the fact that this microbe is a virus.
 b. 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.
5. Define the term *tropism*, and provide at least one example illustrating how viral structure determines this property of a virus.
6. a. Provide one example of an oncogenic virus and explain the unique properties of its multiplication cycle that allow it to trigger the development of cancer.
 b. Compare and contrast the processes of latency and lysogeny, providing examples of latent viruses and lysogenic viruses.
7. Summarize the method used by most companies to manufacture influenza vaccine today, providing one clear advantage and one disadvantage of this process.

Concept Connections

A new feature that ties together topics in a visual manner, and calls on students' ability to Analyze and Create while connecting material from the chapter.



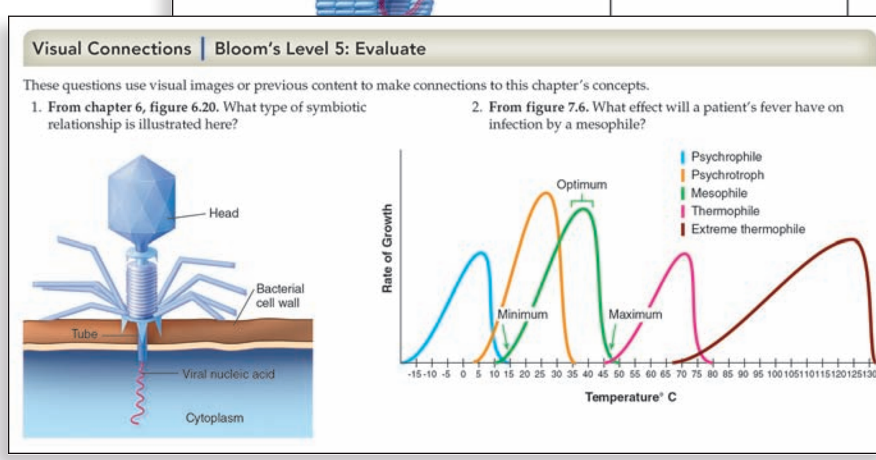
Concept Connections | Bloom's Levels 4 and 6: Analyze and Create

This activity ties together multiple concepts in the chapter.

1. How does capsid and/or envelope structure determine the type of cells a virus infects?
2. Describe the composition of the viral envelope.
3. How are enveloped viruses different from nonenveloped viruses?
4. Provide examples of enveloped and nonenveloped viruses in each category as well as examples of complex viruses to complete the flowchart.

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.



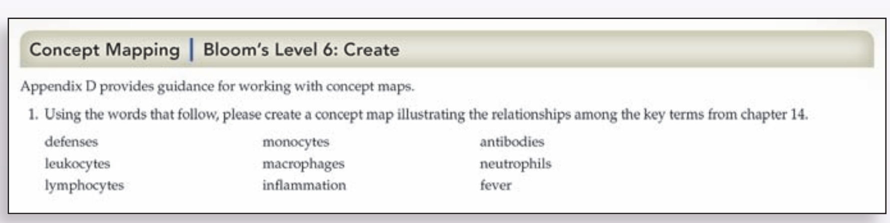
Visual Connections | Bloom's Level 5: Evaluate

These questions use visual images or previous content to make connections to this chapter's concepts.

1. **From chapter 6, figure 6.20.** What type of symbiotic relationship is illustrated here?
2. **From figure 7.6.** What effect will a patient's fever have on infection by a mesophile?

Concept Mapping

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

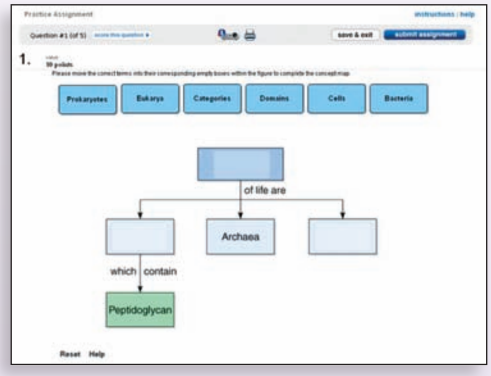


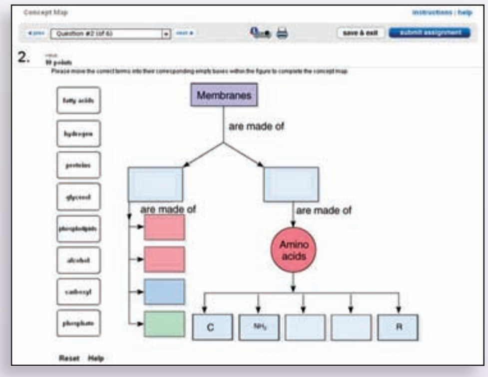
Concept Mapping | Bloom's Level 6: Create

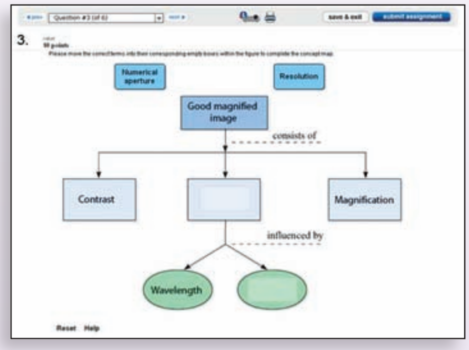
Appendix D provides guidance for working with concept maps.

1. Using the words that follow, please create a concept map illustrating the relationships among the key terms from chapter 14.

defenses	monocytes	antibodies
leukocytes	macrophages	neutrophils
lymphocytes	inflammation	fever







Changes to the Fourth Edition

New to *Microbiology, A Systems Approach*

Brand new

- **Every disease table now contains national and worldwide epidemiological information for each causative agent**

Global changes throughout the fourth edition

- Disease Connections have been added to nondisease chapters
- Learning Outcomes have been class tested and improved
- All new case studies
- 75% of the Insight boxes are new

In end-of-chapter section:

- Chapter summary is tagged with new American Society for Microbiology curricular guidelines
- All questions are labeled with Bloom's levels
- New feature: Concept Connections in each chapter
- All new Critical Thinking Questions

Major chapter changes

Chapter 1

- Revised discussion of history of cellular life on earth and the three domains

Chapter 3

- Simplified and clarified discussion of resolution; added a figure showing wavelengths

Chapter 4

- New information added on microcompartments and S layers

Chapter 5

- Updated protist classification
- Added O & P testing

Chapter 6

- Discussion of the new proposed viral domain
- Virus phage introduced
- DRACO broad-spectrum antiviral treatment described

Chapter 7

- Improved presentation of molecular transport
- Additional information on biofilms

Chapter 8

- Explanations of metabolic processes written in simpler language
- Illustrations greatly improved

Chapter 9

- Streamlined discussions of replication and translation by putting text right next to visuals and highlighting important terms in text
- Added proteomics
- Added figure on transformation so that there are three figures for three processes of horizontal gene transfer

Chapter 10

- Chapter almost completely new! Topics rewritten/updated/added
- Cloning, synthetic biology, miRNA strategies, sequencing and proteomics
- Many new figures

Chapter 11

- New figures and tables to make content more manageable
- Description of critical, semicritical, and noncritical medical devices
- Added discussion of disinfecting biofilms

Chapter 12

- Discussion of how new drugs may target host cell factors and still be selectively toxic
- More discussion of treating biofilm bacteria
- Changed the order of discussion to reflect clinical sequence
- Role of smartphone apps in selecting drugs
- New drugs added
- New tables for better organization
- Fecal therapy described

Chapter 13

- All new human microbiome section added
- Lots of information on gut microbiome
- New figure and information on newborn colonization
- More information of quorum sensing
- Added “the built environment” to reservoirs
- Updated section on healthcare-associated infection
- Added molecular Koch’s postulates
- Added use of technology and social media in disease tracking
- Improved section on emerging diseases

Chapter 14

- Discussion of microbiome’s role as first line of defense
- New research on platelets being involved in immunity
- Added information on collectins

Chapter 15

- Changed order of presentation: T cells first
- Much updated art
- Added information on CD80/CD28
- More emphasis on adult vaccines

Chapter 16

- More emphasis on hygiene hypothesis
- New research on autoimmunity

Chapter 17

- New section: “Breakthrough Methodologies” (deep sequencing, imaging, etc.)

Chapter 18

- MRSA, VRSA updated
- Vaccine information (i.e., MMRV) updated
- Leishmaniasis’ creep into the United States discussed

Chapter 19

- Information on gut-brain axis added

Chapter 20

- Chagas disease added

Chapter 21

- Normal biota radically updated due to Human Microbiome Project
- Whooping cough epidemic addressed
- Much new information on both influenza and TB
- Causes of community-acquired pneumonia ranked as to frequency

Chapter 22

- Added information on 2010 mumps outbreak
- New information on non-O157:H7 STECs
- Added figure on most common causes of food-borne disease

Chapter 23

- Normal biota radically updated due to Human Microbiome Project
- Added information about head and neck cancers in males from HPV
- Added a figure summarizing incidence of *all* STIs

Chapter 24

- More bioremediation information
- More information on extreme environments
- Named *Prochlorococcus* as responsible for massive amounts of photosynthesis
- Two new figures: distribution of water on earth’s surface and CO_2 levels over time

Chapter 25

- More emphasis on the transition from early biotech to genetically engineered organisms
- More detail about how coliform tests are not optimal
- More detail on HACCP, and new information about the Food Safety Modernization Act
- Updates on biofuels

Acknowledgments

I am most grateful to my students who have tried to teach me how to more effectively communicate this subject. All the professors (listed below) who reviewed manuscript for me were my close allies as well, especially when they were liberal in their criticism. Thanks to my co-author Jen Herzog for her great work on the digital side of things, and to Andrea Rediske for her writing assistance. Jill Kolodsick provided detailed reviews and I sincerely appreciated this feedback. My minders at McGraw-Hill are paragons of patience and professionalism: Darlene Schueller, Amy Reed, and Sherry Kane especially. Jeanne Patterson is the best copy editor west of the Mississippi. (Are you east of the Mississippi? Well, in the vicinity of the Mississippi….) Lastly, thanks to the thick-and-thin crew, my family: Taylor, Sam, Suzanne, Aaron, and Ted.

—Kelly Cowan

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Table of Contents

1

The Main Themes of Microbiology

Case File 1

It's Raining Bacteria

Bacteria are ubiquitous on the planet, but how profound is their impact on our lives? In addition to their impact on the earth's temperature, weathering, mineral extraction, and soil formation, recent studies have shown that bacteria have a major influence over another aspect of the earth's ecosystem: the weather. For years, scientists have believed that dust particles or minerals in clouds caused water droplets to coalesce into larger droplets and form rain, snow, or hail. However, recent research shows that bacteria are the predominant particles that induce the formation of precipitation.

After a hailstorm hit the Montana State University campus in Bozeman, Montana, Alexander Michaud and his collaborators gathered hailstones larger than 5 cm in diameter, separated them into four layers, and analyzed them as they melted. They were surprised to find that *Pseudomonas syringae*, a species of bacteria that is commonly implicated in infections of plants and as the cause of postharvest rots, grew from the water in the hailstones.

Michaud explains that bacteria found in the embryo—the first part of the hailstone to develop—initiate the growth of a hailstone. "In order for precipitation to occur, a nucleating particle must be present to allow for aggregation of water molecules," he states. "There is growing evidence that these nuclei can be bacteria or other biological particles."

- Why do you think that climate scientists never realized that microbes actually caused nucleation of water droplets in clouds?
- How does *P. syringae* make it rain at warm temperatures?

Continuing the Case appears on page 14.

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 several 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, algae, protozoa, helminths** (parasitic invertebrate animals such as worms), and **fungi.** All of these microbes—just like plants and animals—can be infected by **viruses,** which are noncellular, **parasitic,** protein-coated genetic elements, dependent on their infected host. They can cause harm to the host 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.

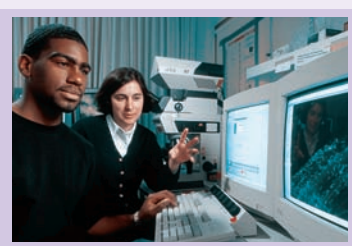
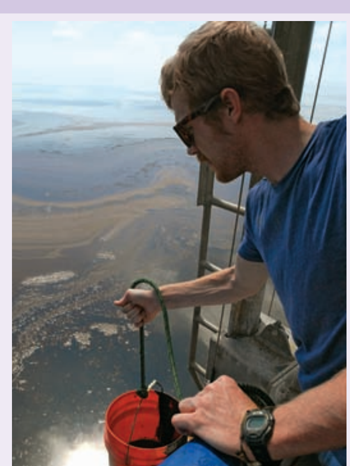
Microbiologists study every aspect of microbes—their cell structure and function, their growth and physiology, their genetics, their taxonomy and evolutionary history, and their interactions with the living and nonliving environment. The latter includes their uses in industry and agriculture and the 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 (see chapters 2 and 8); systems of inheritance (see chapter 9); and the global cycles of nutrients, minerals, and gases (see chapter 24).

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.
B. Public Health Microbiology and Epidemiology These branches monitor and control the spread of diseases in communities. Institutions involved in this concern 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.** Epidemiologists from the CDC employ an unusual method for microbial sampling. They are collecting grass clippings to find the source of an outbreak of tularemia in Massachusetts.
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 (see chapters 15, 16, and 17).		**Figure C.** An immunologist harvests chicken antibodies from egg yolks.
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.** Food inspectors sample a beef carcass for potential infectious agents. The safety of the food supply has wide-ranging importance.
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.
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.

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

The most important knowledge that should emerge from 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.

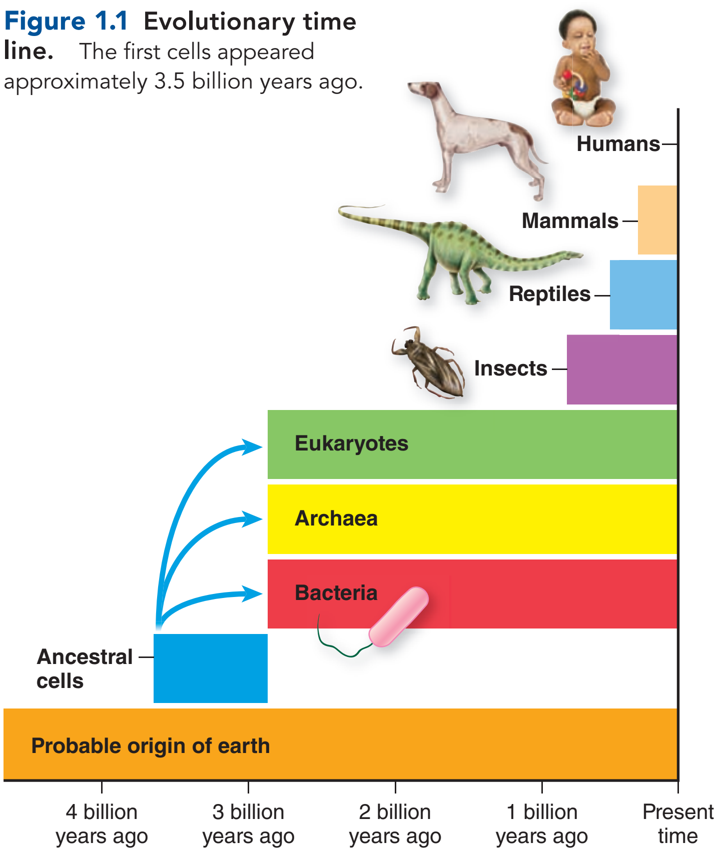
Single-celled organisms that preceded our current cell types arose on this planet about 3.5 billion years ago, according to the fossil record. It appears that they were the only living inhabitants until about 2.9 billion years ago. At that time, three types of cells arose from that original cell type: two were bacteria and archaea, and a more complex type of single-celled organism arose, the **eukaryote** (yoo"-kar-ee-ote). Eu-kary 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.

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 (for example, in this chapter), 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.

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



Another indication of the huge influence bacteria exert is how **ubiquitous** 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 that 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 *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. It is often referred to as the **theory of evolution.** This 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*).**

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

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*).** 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 the digestive tracts of animals.

(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.

- Recent estimates propose 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 clean up human-created contamination **(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). One 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 fungi were some of the first organisms to be genetically engineered. This was possible because they are single-celled organisms and they are so adaptable to changes in their genetic makeup. Recombinant DNA technology has unlimited potential in terms of

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

(a) (b) (c)

Figure 1.3 Microbes at work. **(a)** An aerial view of a copper mine looks like a giant quilt pattern. The colored patches are bacteria in various stages of extracting metals from the ore. **(b)** Microbes as synthesizers. Fermenting tanks at a winery. **(c)** Members of a biohazard team from the National Oceanic and Atmospheric Agency (NOAA) participate in the removal and detoxification of 63,000 tons of crude oil released by a wrecked oil tanker on the coast of Spain. The bioremediation of this massive spill made use of naturally occurring soil and water microbes as well as commercially prepared oil-eating species of bacteria and fungi.

medical, industrial, and agricultural uses. Microbes can be engineered to synthesize desirable 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 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 Outcomes—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). 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 nearly 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 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. Both of these diseases are thoroughly discussed in chapter 21.

Table 1.2 Top Causes of Death—All Diseases

United States	No. of Deaths	Worldwide	No. of Deaths
1. Heart disease	617,000	1. Heart disease	7.3 million
2. Cancer	565,000	2. Stroke	6.2 million
3. Chronic lower-respiratory disease	141,000	3. Lower-respiratory infections (influenza and pneumonia)*	3.5 million
4. Cerebrovascular disease	134,000	4. Chronic obstructive pulmonary disease	3.3 million
5. Accidents (unintentional injuries)	122,000	5. Diarrheal diseases	2.5 million
6. Alzheimer's disease	82,000	6. HIV/AIDS	1.8 million
7. Diabetes	71,000	7. Trachea, bronchus, lung cancers	1.4 million
8. Influenza and pneumonia	56,000	8. Tuberculosis	1.3 million
9. Kidney disease	48,000	9. Diabetes	1.3 million
10. Suicide	36,000	10. Road traffic accidents	1.2 million

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

Source: Data from the World Health Organization and the Centers for Disease Control and Prevention. Data published in 2011 representing final figures for the year 2008.

In **figure 1.4,** you can see that high-income countries like ours see many more deaths caused by chronic, noninfectious diseases (heart disease, cancer, stroke) than those caused by infections. Low-income countries (on the left on the graph) suffer high rates of death from these diseases but even higher rates of deaths from infections. Economics is closely tied to survival in these countries.

Malaria, which kills between 700,000 and 1.2 million people every year worldwide, is caused by a microorganism transmitted by mosquitoes (see chapter 20). Currently, the most effective way for citizens of 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 $5, 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. AIDS, hepatitis C, and

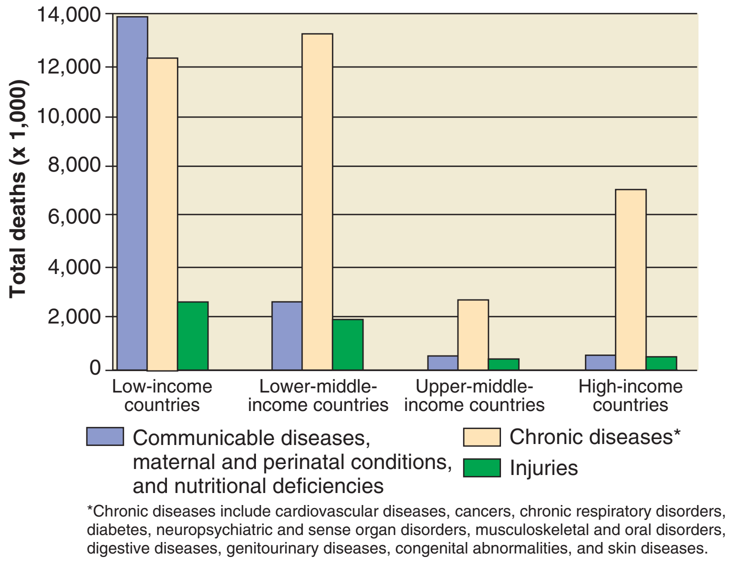


Figure 1.4 The role of infectious diseases versus other causes of death in countries of varying income.

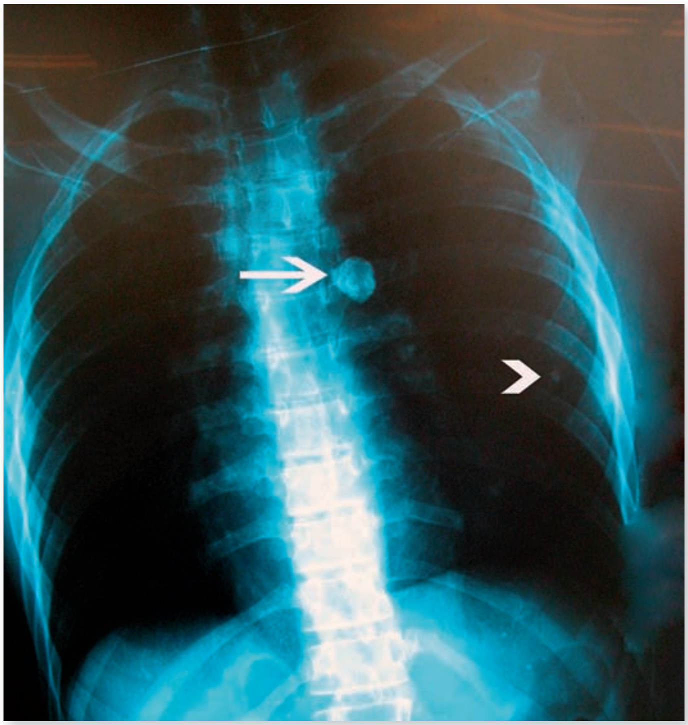
INSIGHT 1.1 The War Is Far from Over

In 1964, the surgeon general of the United States told Congress, "It is time to close the book on infectious diseases. The war against pestilence is over." Recently discovered antibiotics and newly introduced vaccines were extremely effective against diseases that had haunted humankind for centuries. It was easy to think that humans had won the war over the microbes. What the surgeon general didn't realize was that the microbes that have inhabited this planet for millennia were slowly and quietly evolving to address the new threat.

Research on novel antibiotics slowed in the 1960s and 1970s, due in part to the sentiment among scientists and the medical community that once dangerous microbes were no longer a threat. Doctors regularly prescribed antibiotics for infections that were viral in origin, sometimes due to patient demand. Patients were careless in taking antibiotics, often not finishing a full prescription. Suddenly, drug-resistant strains such as methicillin-resistant *Staphylococcus aureus* (MRSA) and multidrug-resistant *Mycobacterium tuberculosis* (MDR-TB) began appearing worldwide.

In 2007, American Andrew Speaker left the country for his wedding. He had been previously diagnosed with MDR-TB, but preliminary tests showed that he was not a threat to others and had been cleared to travel by his doctors. *Mycobacterium tuberculosis* is a notoriously slow-growing organism, and after he left the country, further tests revealed that he harbored a strain of extensively drug-resistant tuberculosis (XDR-TB). During his travels throughout Europe and the Mediterranean, along with connecting flights in Canada and the United States, he unwittingly exposed thousands of fellow travelers to XDR-TB. Once he returned, Speaker submitted to voluntary quarantine for treatment, but the incident sparked an international firestorm.

This is only one example of the ability of microbes to adapt to the ever-changing world in which we live. Increased globalization and travel, growing populations of susceptible and immune-suppressed individuals, emerging infectious diseases from previously unexplored areas of the world, and reemerging infectious diseases like tuberculosis show that not only is the war against pestilence not over, it's only just beginning.



X ray showing a tubercle in a tuberculosis patient.

Source: 2007. *J. Am. Med. Assoc.* vol. 298, no. 1, p. 83.

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 a virus called the Borna agent. 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). Here, again, low-income countries differ from high-income countries. It seems that up to 26% of cancers in low-income countries are caused by viruses or bacteria, while less than 7% of malignancies in the developed world are microbially induced.

As mentioned earlier, 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 **(Insight 1.1).** 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 Outcomes—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 earlier, 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.

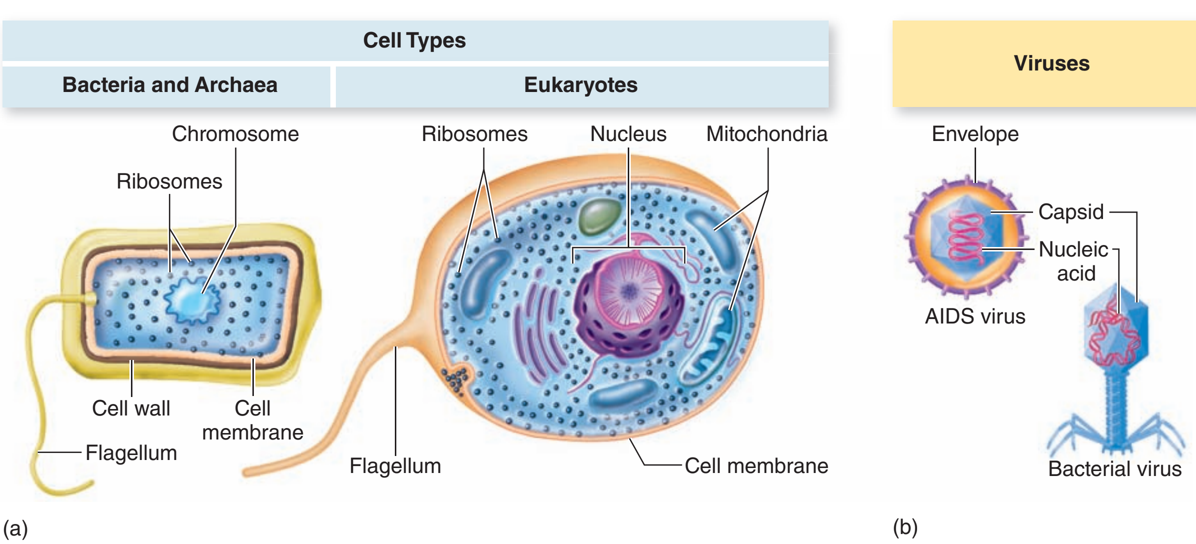


Figure 1.5
Cell structure. **(a)** Comparison of a bacterial/archaeal cell and a eukaryotic cell (not to scale). **(b)** Two examples of viruses. These cell types and viruses are discussed in more detail in chapters 4, 5, and 6.