Marjorie Kelly Cowan
Heidi Smith
with Jennifer Lusk
BSN RN CCRN

Third Edition

Microbiology FUNDAMENTALS

A Clinical Approach

Meet The Microbiome
What you need to know about the microbiome as it relates to each chapter.

Epidemiology
Disease tables have epidemiology statistics for every organism.

NCLEX®-Style Questions
Inside and Online!

Mc Graw Hill Education

Third Edition

Microbiology FUNDAMENTALS

A Clinical Approach

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Marjorie Kelly Cowan
Miami University Middletown

Heidi Smith
Front Range Community College

Jennifer Lusk
BSN RN CCRN, Clinical Advisor

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MICROBIOLOGY FUNDAMENTALS: A CLINICAL APPROACH, THIRD EDITION

This book is printed on acid-free paper.

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Brief Contents

With contributions from Ronald M. Atlas and Marjorie Kelly Cowan

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About the Authors

Courtesy Kelly Cowan

Kelly Cowan, PhD, started teaching microbiology at Miami University in 1993. Her specialty is teaching microbiology for pre-nursing/allied health students at the university's Middletown campus, a regional open-admissions campus. She started life as a dental hygienist. She then went on to attain her PhD at the University of Louisville, and later worked at the University of Maryland's Center of Marine Biotechnology and the University of Groningen in The Netherlands. Kelly has published (with her students) 24 research articles stemming from her work on bacterial adhesion mechanisms and plant-derived antimicrobial compounds. But her first love is teaching—both doing it and studying how to do it better. She is past chair of the Undergraduate Education Committee of the American Society for Microbiology (ASM). Her current research focuses on the student achievement gap associated with economic disparities, as well as literacy in the science classroom. In her spare time, Kelly hikes, reads, and still tries to (s)mother her three grown kids.

Heidi Smith leads the microbiology discipline at Front Range Community College, 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 her face-to-face and online teaching approaches and student performance in her classes. Outside of the classroom, Heidi oversees a federal grant program designed to train and support underrepresented students for undergraduate research and transfer into four-year STEM degree programs. She is also 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. Off campus, Heidi enjoys the beautiful Colorado outdoors with her husband and three young children.

©Heidi Smith

Jennifer Lusk, BSN, RN, CCRN, is a registered nurse at a large academic children's hospital in Denver, Colorado. She has practiced in pediatric intensive care for 10 years in large inner-city pediatric hospitals. Jennifer has spent her nursing career caring for critically ill children as a bedside nurse, charge nurse, and Continuous Renal Replacement Therapy (CRRT) specialist. She is the CRRT Clinical Program Coordinator, providing oversight and program development for the critical care dialysis therapy. She enjoys her diverse clinical role, which involves educating nurses and physicians, mentoring, researching, writing policies, and quality improvement work. In her time away from work, Jennifer enjoys spending time outdoors with her husband and dog, especially hiking and exploring national parks.

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Preface

Students:

Welcome! I am so glad you are here. I am very excited for you to try this book. I wrote it after years of frustration, teaching from books that didn't focus on the right things that my students needed. My students (and, I think, you) need a solid but not overwhelming introduction to microbiology and infectious diseases. I asked myself: What are the major concepts I want my students to remember five years from now? And then I worked backward from there, making sure everything pointed to the big picture.

While this book has enough detail to give you context, there is not so much detail that you will lose sight of the major principles. Biological processes are described right next to the illustrations that illustrate them. The format is easier to read than most books, because there is only one column of text on a page and wider margins. The margins gave me space to add interesting illustrations and clinical content. A working nurse, Jennifer Lusk, brings her experience to life on the pages and shows you how this information will matter to you when you are working as a health care provider. We have interesting and up-to-the-moment Case Files, Medical Moments, Microbiome selections, and NCLEX® questions in every chapter. My coauthor, Heidi Smith, has brought so much to the book and online material. I don't think you'll find a better online set of learning tools anywhere.

I really wanted this to be a different kind of book. I've started using it in my own classes and my students love it! Well, maybe they have to say that, but I hope you truly do enjoy it and find it to be a refreshing kind of science book.

—Kelly Cowan

I dedicate this book to every hard-working student studying in a health care field.–Kelly

I dedicate this book to my favorite people, Ryan, Noah, Ryleigh, and Jake.–Heidi

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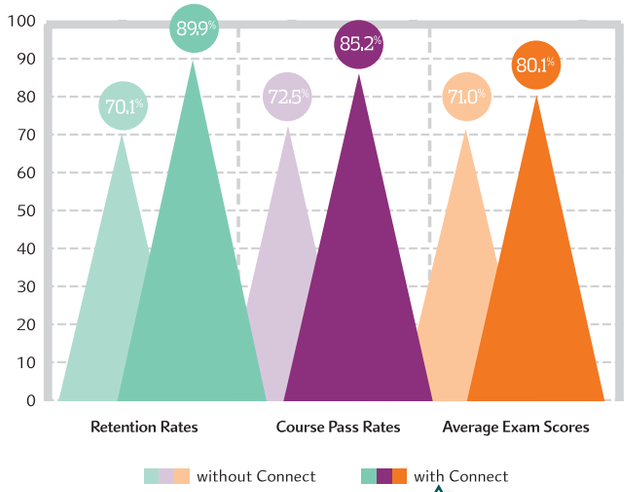

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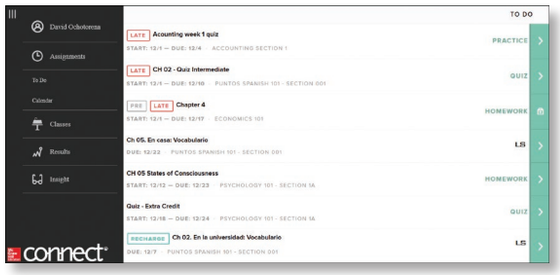
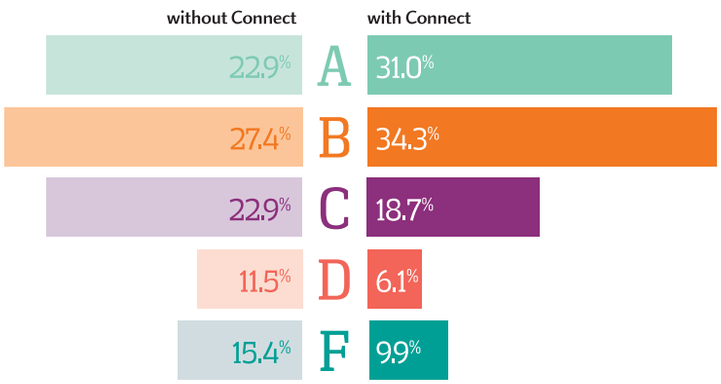


Impact on Final Course Grade Distribution



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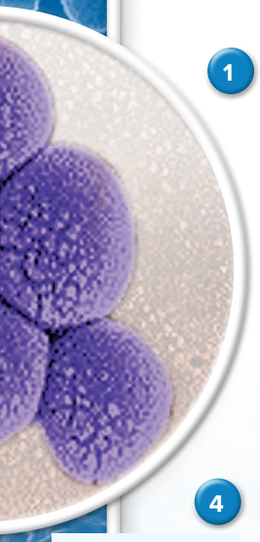
UNIQUE INTERACTIVE QUESTION TYPES

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



Source: CDC/Janice Haney Carr

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. **SmartGrid Questions:** New to this edition, SmartGrid questions replace the traditional end-of-chapter questions, and all of these questions are available for assignment in Connect. These questions were carefully constructed to assess chapter material as it relates to all six concepts outlined in the American Society of Microbiology curriculum guidelines plus the competency of "Scientific Thinking." The questions are cross-referenced with Bloom's taxonomy of learning level. Seven concepts/competencies x three increasing Bloom's levels = a robust assessment tool.
5. **Animations:** Animation quizzes pair our high-quality animations with questions designed to probe student understanding of the illustrated concepts.
6. **Animation Learning Modules:** Animations, videos, audio, and text all combine to help students understand complex processes. These tutorials take a stand-alone, static animation and turn it into an interactive learning experience for your students with real-time remediation. Key topics have an Animated Learning Module assignable through Connect.
7. **Labeling:** Using the high-quality art from the textbook, check your students' visual understanding as they practice interpreting figures and learning structures and relationships.
8. **Classification:** Ask students to organize concepts or structures into categories by placing them in the correct "bucket."
9. **Sequencing:** Challenge students to place the steps of a complex process in the correct order.
10. **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, ASM topic, 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.

NCLEX®

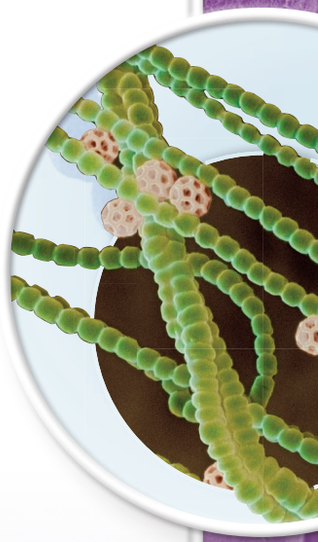
NCLEX® Prep Questions: Sample questions are available in Connect to assign to students, and there are questions throughout the book as well.

Source: CDC/Janice Haney Carr (*S. aureus* and *Legionella*); Source: CDC/Dr. Erskine Palmer & Byron Skinner (Rotavirus); Source: CDC/Dr. Stan Erlandsen (*Giardia* cyst); ©Science Photo Library/ Getty Images (white blood cells); ©Steve Gschmeissner/ Science Source (fallopian tube surface); NIAID, NIH/Rocky Mountain Laboratories (*Salmonella typhimurium*)

ADDITIONAL RESOURCES

Create what you've only imagined.

McGraw-Hill Create is a self-service website that allows you to create custom course materials using McGraw-Hill Education's comprehensive, cross-disciplinary content and digital products.



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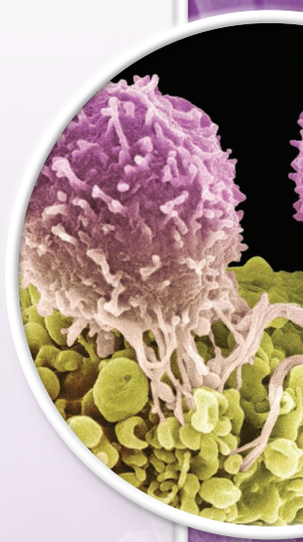
McGraw-Hill Campus® is a groundbreaking service that puts world-class digital learning resources just a click away for all your faculty and students. All your faculty—whether or not they use a McGraw-Hill Education title—can instantly browse, search, and access the entire library of McGraw-Hill Education instructional resources and services including eBooks, test banks, PowerPoint slides, animations, and learning objects—from any Learning Management System (LMS), at no additional cost to your institution. Users also have single sign-on access to McGraw-Hill Education digital platforms, including Connect, ALEKS®, Create, and Tegrity.

LearnSmart® Prep is designed to get students ready for a forthcoming course by quickly and effectively addressing prerequisite knowledge gaps that may cause problems down the road. LearnSmart Prep maintains a continuously adapting learning path individualized for each student, and tailors content to focus on what the student needs to master in order to have a successful start in the new class.



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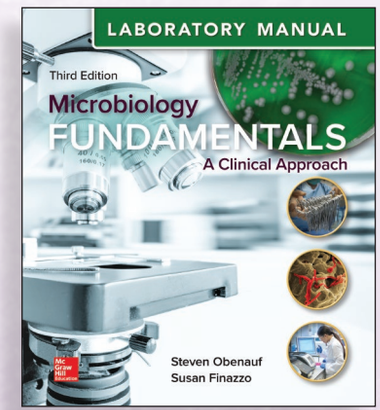
Microbiology Fundamentals Laboratory Manual, Third Edition

Steven Obenauf, Broward College
Susan Finazzo, Perimeter College, Georgia State University

Written specifically for pre-nursing and allied health microbiology students, this manual features brief, visual exercises with a clinical emphasis.

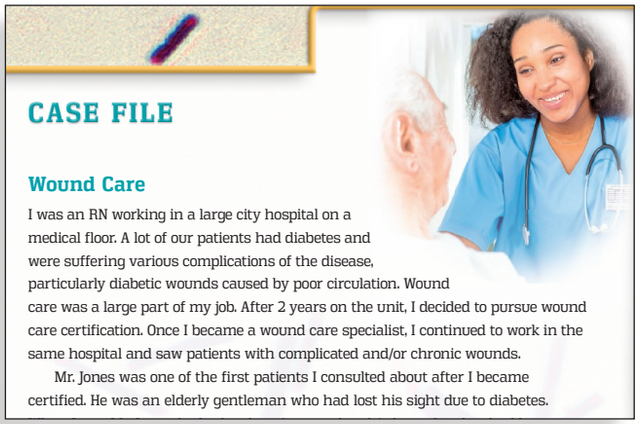


CLINICAL

Clinical applications help students see the relevance of microbiology.

Case File Each chapter begins with a case written from the perspective of a former microbiology student.

These high-interest introductions provide a specific example of how the chapter content is relevant to real life and future health care careers.



CASE FILE

Wound Care

I was an RN working in a large city hospital on a medical floor. A lot of our patients had diabetes and were suffering various complications of the disease, particularly diabetic wounds caused by poor circulation. Wound care was a large part of my job. After 2 years on the unit, I decided to pursue wound care certification. Once I became a wound care specialist, I continued to work in the same hospital and saw patients with complicated and/or chronic wounds.

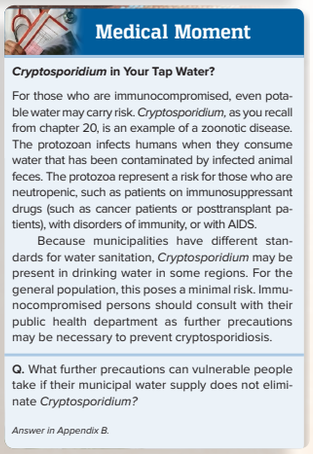
Mr. Jones was one of the first patients I consulted about after I became certified. He was an elderly gentleman who had lost his sight due to diabetes.

SmartGrid: From Knowledge to Critical Thinking

SmartGrid

In place of traditional end-of-chapter questions, Kelly Cowan has created a grid made up of three columns and seven rows, for a total of 21 questions. The rows contain the six major curricular guidelines (and the competency of *scientific thinking*) from the American Society for Microbiology. The columns represent increasing levels of Bloom's taxonomy of learning. Each question is carefully constructed of material from the chapter that meets both the ASM guideline and the Bloom's level indicated. Instructors can assign a row (to emphasize a curriculum guideline) or a column (asking a variety of questions at a particular Bloom's level). The questions in column 3 (Bloom's level 5 and 6) can easily be used for group problem solving and other higher-order learning activities.

Medical Moment These boxes give students a more detailed clinical application of a nearby concept in the chapter. New in this edition: Each Medical Moment ends with a question. Answers appear in Appendix B.



Medical Moment

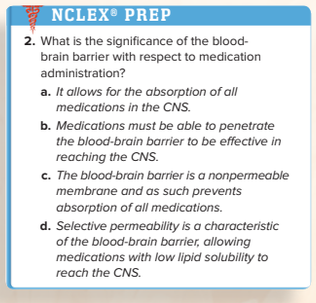
***Cryptosporidium* in Your Tap Water?**

For those who are immunocompromised, even potable water may carry risk. *Cryptosporidium*, as you recall from chapter 20, is an example of a zoonotic disease. The protozoan infects humans when they consume water that has been contaminated by infected animal feces. The protozoa represent a risk for those who are neutropenic, such as patients on immunosuppressant drugs (such as cancer patients or posttransplant patients), with disorders of immunity, or with AIDS.

Because municipalities have different standards for water sanitation, *Cryptosporidium* may be present in drinking water in some regions. For the general population, this poses a minimal risk. Immunocompromised persons should consult with their public health department as further precautions may be necessary to prevent cryptosporidiosis.

Q. What further precautions can vulnerable people take if their municipal water supply does not eliminate *Cryptosporidium*?

Answer in Appendix B.



NCLEX® PREP

2. What is the significance of the blood-brain barrier with respect to medication administration?

a. *It allows for the absorption of all medications in the CNS.*

b. *Medications must be able to penetrate the blood-brain barrier to be effective in reaching the CNS.*

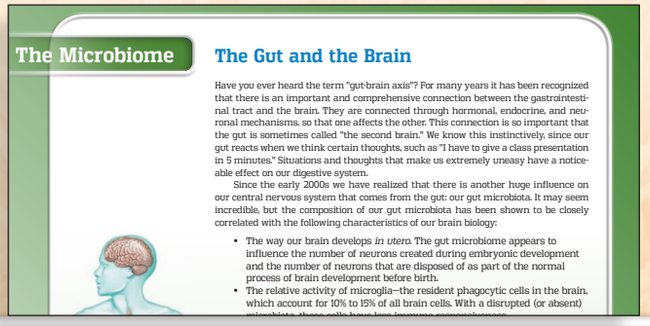
c. *The blood-brain barrier is a nonpermeable membrane and as such prevents absorption of all medications.*

d. *Selective permeability is a characteristic of the blood-brain barrier, allowing medications with low lipid solubility to reach the CNS.*

NCLEX® Prep Questions Found throughout the chapter, these multiple-choice questions are application-oriented and designed to help students learn the microbiology information they will eventually need to pass the NCLEX® examination. Students will begin learning to think critically, apply information, and over time, prep themselves for the examination.

Additional questions are available in Connect for homework and assessment.

The Microbiome Each chapter ends with a reading about a microbiome discovery or story that is relevant to that chapter.



The Microbiome

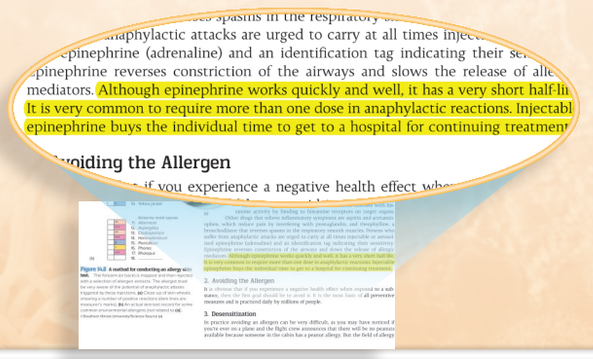
The Gut and the Brain

Have you ever heard the term "gut-brain axis"? For many years it has been recognized that there is an important and comprehensive connection between the gastrointestinal tract and the brain. They are connected through hormonal, endocrine, and neuronal mechanisms, so that one affects the other. This connection is so important that the gut is sometimes called "the second brain." We know this instinctively, since our gut reacts when we think certain thoughts, such as "I have to give a class presentation in 5 minutes." Situations and thoughts that make us extremely uneasy have a noticeable effect on our digestive system.

Since the early 2000s we have realized that there is another huge influence on our central nervous system that comes from the gut: our gut microbiota. It may seem incredible, but the composition of our gut microbiota has been shown to be closely correlated with the following characteristics of our brain biology:

- The way our brain develops *in utero*. The gut microbiome appears to influence the number of neurons created during embryonic development and the number of neurons that are disposed of as part of the normal process of brain development before birth.
- The relative activity of microglia—the resident phagocytic cells in the brain, which account for 10% to 15% of all brain cells. With a disrupted (or absent)

Clinical Examples Throughout Clinical insights and examples are woven throughout the chapter—not just in boxed elements.

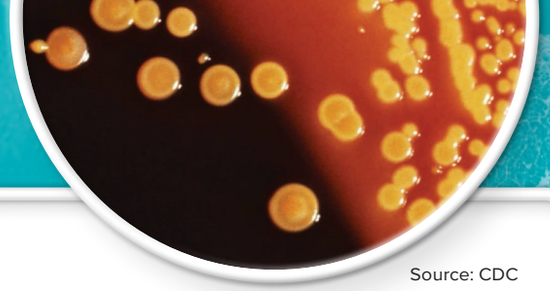


...spasms in the respiratory...
...naphylactic attacks are urged to carry at all times inject...
...epinephrine (adrenaline) and an identification tag indicating their se...
...epinephrine reverses constriction of the airways and slows the release of alle...
mediators. Although epinephrine works quickly and well, it has a very short half-li...
It is very common to require more than one dose in anaphylactic reactions. Injectabl...
epinephrine buys the individual time to get to a hospital for continuing treatmen...

...oiding the Allergen

...if you experience a negative health effect wh...

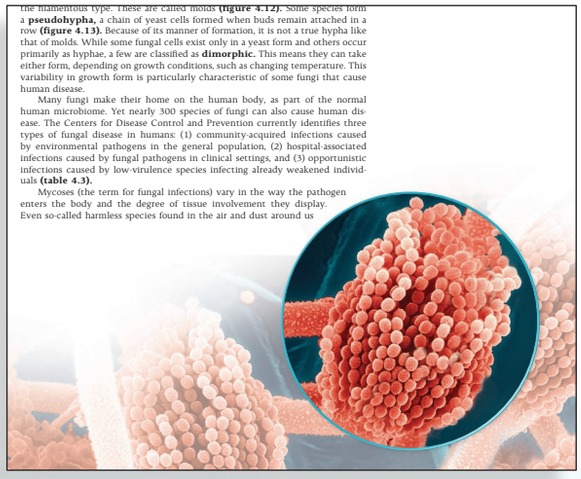
VISUAL



Source: CDC

Visually appealing layouts and vivid art closely linked to narrative for easier comprehension.

Engaging, Accurate, and Educational Art Single column of text is easier to read and leaves space for eye-catching art to keep students engaged.

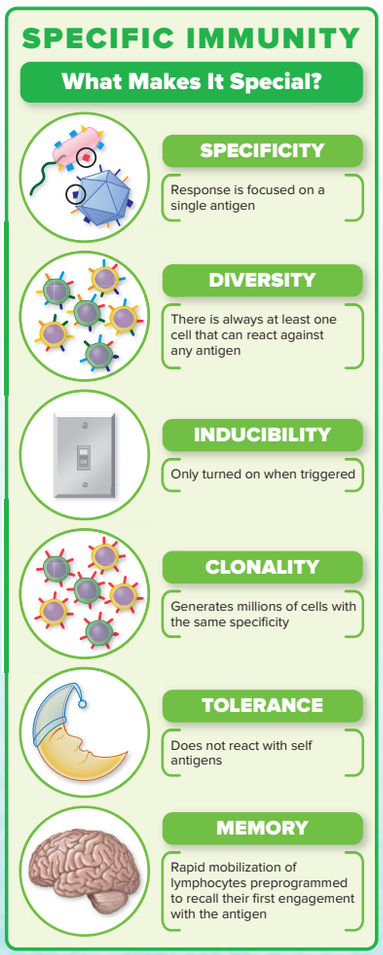


the filamentous type. These are called molds **(figure 4.12)**. Some species form a **pseudohypha,** a chain of yeast cells formed when buds remain attached in a row **(figure 4.13)**. Because of its manner of formation, it is not a true hypha like that of molds. While some fungal cells exist only in a yeast form and others occur primarily as hyphae, a few are classified as **dimorphic.** This means they can take either form, depending on growth conditions, such as changing temperature. This variability in growth form is particularly characteristic of some fungi that cause human disease.

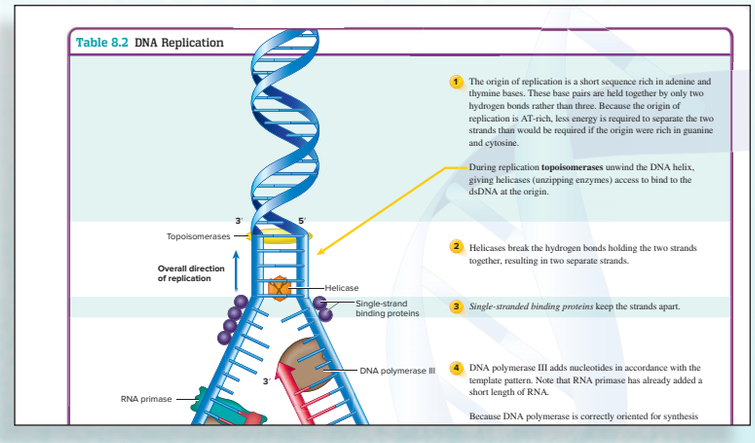
Many fungi make their home on the human body, as part of the normal human microbiome. Yet nearly 300 species of fungi can also cause human disease. The Centers for Disease Control and Prevention currently identifies three types of fungal disease in humans: (1) community-acquired infections caused by environmental pathogens in the general population, (2) hospital-associated infections caused by fungal pathogens in clinical settings, and (3) opportunistic infections caused by low-virulence species infecting already weakened individuals **(table 4.3)**.

Mycoses (the term for fungal infections) vary in the way the pathogen enters the body and the degree of tissue involvement they display. Even so-called harmless species found in the air and dust around us

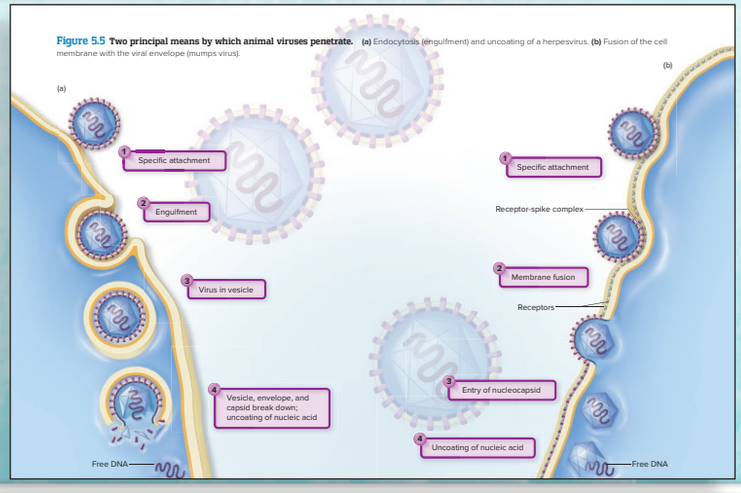
Infographics New infographic-style visual summaries that students can relate to.



Visual Tables The most important points explaining a concept are distilled into table format and paired with explanatory art.



Process Figures Complex processes are broken into easy-to-follow steps. Numbered steps in the art coordinate with numbered text boxes to walk students through the figure.



BRIEF

Streamlined coverage of core concepts help students retain the information they will need for advanced courses.

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Chemistry topics required for understanding microbiology are combined with the foundation content found in chapter 1.

Genetics content is synthesized into one chapter covering the concepts that are key to microbiology students.

A chapter in microbiology textbooks that is often not used in health-related classes becomes relevant because it presents the 21st-century idea of "One Health"—that the environment and animals influence human health and infections.

Brief Contents

With contributions from Ronald M. Atlas and Marjorie Kelly Cowan

Duplication Eliminated Detail is incorporated into figures so students can learn in context with the art. This allows a more concise narrative flow while still retaining core information.

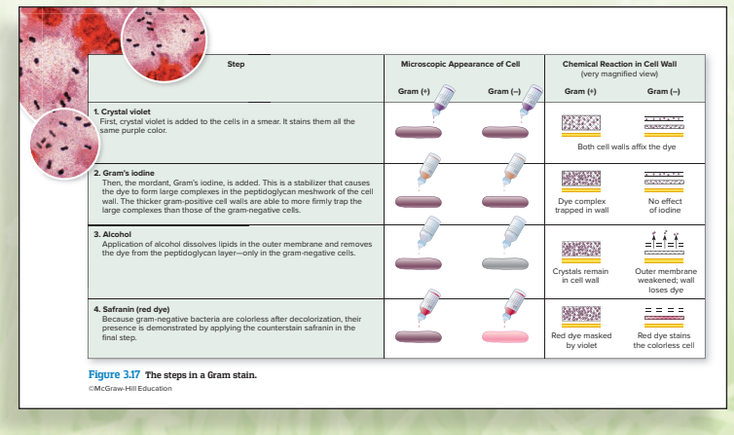

Figure 3.17 The steps in a Gram stain.

Changes to the Third Edition

Significant Changes

New end-of-chapter feature organizes 21 questions in a grid. The rows contain the six major curricular guidelines (and the competency of *scientific thinking*) from the American Society for Microbiology. The columns represent increasing levels of Bloom's Taxonomy of learning. Each question is carefully constructed of material from the chapter that meets both the ASM guideline and the Bloom's level indicated. Instructors can assign a row (to emphasize a curriculum guideline) or a column (asking a variety of questions at a particular Bloom's level). The questions in column three (Bloom's level 5 and 6) can easily be used for group problem solving and other higher-order learning activities.

Microbiome information in every chapter and also as a separate boxed feature at the end of the chapter. These features also walk students through how to critically analyze the onslaught of studies and findings.

Infographic-style tables present material in a way that students can connect with.

The Medical Moments now each end with an open-ended question. Answers to the questions are in Appendix B.

Chapter 12 (Host Defenses I: Overview and Nonspecific Defenses) is almost completely reorganized and rewritten based on feedback from reviewers and students.

Category A bioterror threat organisms are indicated in disease tables.

Disease chapter feature A new visual feature in each disease chapter (chapters 16 through 21) places the microbes from that chapter in context with respect to ***communicability*** and ***deadliness.***

Organisms denoted In all disease tables, each organism is denoted as "B, V, F, P, or H"—indicating bacterium, virus, etc. When bacterial, the table also shows G+ or G−.

Chapter Highlights

Chapter 1 More explicit explanation of the scientific method.

Chapter 2 Illustrations made simpler and clearer.

Chapter 3 Addition of nanotube/nanowires as bacterial appendages; additional discussion of bacterial cytoskeletal proteins.

Chapter 4 Added endosymbiotic theory (incorporating last common ancestor and role of DNA viruses); neglected parasitic infections in the United States; and a table with examples of community-acquired, hospital-acquired, and opportunistic infections.

Chapter 5 New prion disease (MSA).

Chapter 6 Expansion of the binary "saprobe" and "parasite"—so that nonsaprobes can be seen as normal biota as well as parasites. Changes to discussion of "commensal" versus "mutualistic" in light of importance of microbiome to human health.

Chapter 7 Simplified the language and added discussion of "rock-eating" bacteria.

Chapter 8 Added single-nucleotide polymorphisms, deep DNA sequencing, synthetic biology, gene therapy, and CRISPR.

Chapter 9 Added new FDA ban on triclosan and other chemicals.

Chapter 10 Comprehensive updates of currently used antibiotics; new antibiotic strategies from noncultivable microorganisms, peptides, RNA interference, CRISPR; new discussion of allylamine class of antifungals; and of colistin-resistant bacteria.

Chapter 11 Extensively rewritten to include newest understanding of human microbiome, epigenetic host changes that microbes cause, big data in epidemiology, more emphasis on polymicrobial infections, new epidemiological feature.

Chapter 12 Changed overall organization for greater understanding; simplified cytokine section, added role of microbiome in nonspecific immunity, rewrote antimicrobial products section and added host restriction factors; simplified the figure showing origins of blood cells; added diagram of lymph node.

Chapter 13 Enhanced emphasis on clonal deletion; changed T-cell terminology to include T follicular helper cells; added infographic on how vaccines are prepared, tested, and come to market.

Chapter 14 Cancer's ability to dampen immune response; new ways to desensitize against allergens, role of the gut microbiome in hypersensitivities and in autoimmune disease.

Chapter 15 Decreased immunology section to accommodate more genetic testing; included MGIT testing, more point-of-care diagnostics, PCR, qPCR, pan bacterial qPCR, new strategies in development such as identifying all the viruses a person has ever encountered in a single drop of blood; new infographics summarize the testing procedures for phenotypic, genotypic, and immunological methods in a visually consistent manner.

Chapter 16 Updated normal biota sections.

Chapter 17 Zika added as highlight disease; another opportunity (in Microbiome feature) to discuss difference between correlation and causation and how media report it.

Chapter 18 Information on new children's malaria vaccine; updates on Ebola epidemic and lessons learned; added *Ehrlichia, Anaplasma,* and *Babesia* to nonhemorrhagic diseases.

Chapter 19 Added human metapneumovirus as agent of pneumonia.

Chapter 20 More information about other Shiga-toxin-producing *E. coli* (in addition to O157:H7); non-cholera *Vibrio* species.

Chapter 21 Carbapenem-resistance in UTIs; the significant increase in STIs in the United States (2015 CDC report). All updated statistics; table clearly outlining who should get HPV vaccine.

Chapter 22 New list of emerging and reemerging diseases; new infographic of WHO predictions about health effects of climate change.

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I am always most grateful to my students in my classes. They teach me every darned day how to do a better job helping them understand these concepts that are familiar to me but new to them. All the instructors who reviewed the manuscript were also great allies. I thank them for lending me some of their microbiological excellence. I had several contributors to the book and digital offerings—Jennifer Smith, Ronald Atlas, Kathleen Sandman, Dorothy Wood, Nicole Frank, and Connie Fisk chief among them. Heidi Smith improves everything she touches, especially this book. Jennifer Lusk added very meaningful medical insights and clinical content. My handlers at McGraw-Hill Education make the wheels go around. They include Marija Magner, Valerie Kramer, Jessica Portz, Matt Backhaus, Christina Nelson, and Lori Hancock. Darlene Schueller, my day-to-day editor, is a wonderful human being and taskmaster, in that order. In short, I'm just a lucky girl surrounded by talented people.

—Kelly Cowan

I, too, am thankful for the many students that enter my classroom every year. My work was greatly inspired by their questions, their ideas, and their unique way of looking at complex things. I am filled with gratitude to Kelly Cowan for her willingness to partner with me; I constantly learn from her about better ways to reach all students. Writing a solid digital package requires more than just one mind; for this work, Dorothy Wood brought her expertise and creativity in writing critical thinking questions for every chapter. Finally, I appreciate the entire microbiology team at McGraw-Hill Education who truly believes in producing materials that lead to student success.

—Heidi Smith

Reviewers

Tara Allison
Gannon University

Gary Armour
Lincoln Land Community College

Jennifer Bess
Hillsborough Community College

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Brigham Young University—Idaho

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Lori A. Smith
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Wendy J. Wilson
Las Positas College

We are very pleased to have been able to incorporate real student data points and input, derived from thousands of our SmartBook users, to help guide our revision. SmartBook 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 SmartBook questions.

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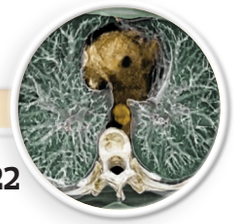

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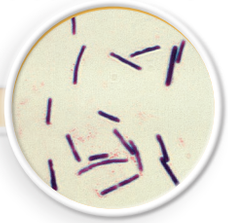

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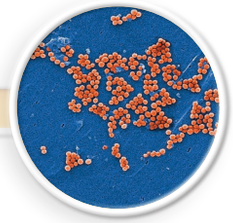

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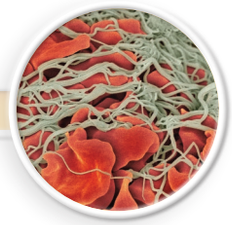

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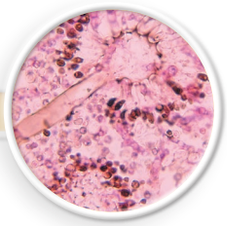

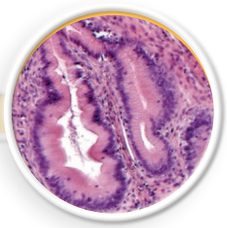

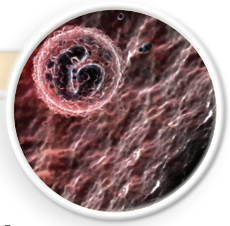

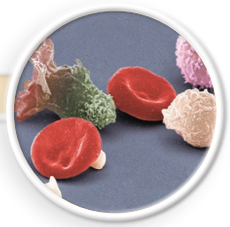

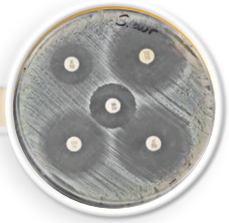

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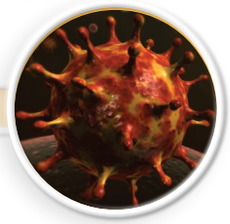

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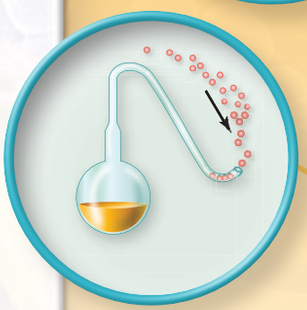
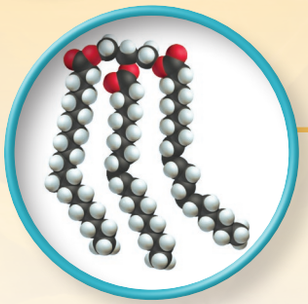
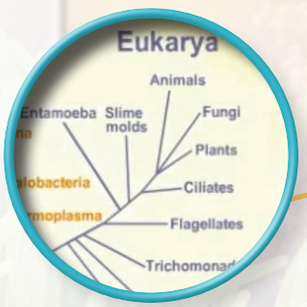
1 Introduction to Microbes and Their Building Blocks







IN THIS CHAPTER...

1.1 Microbes: Tiny but Mighty

1. List the various types of microorganisms that can colonize humans.
2. Describe the role and impact of microbes on the earth.
3. Explain the theory of evolution and why it is called a theory.
4. Explain the ways that humans manipulate organisms for their own uses.
5. Summarize the relative burden of human disease caused by microbes.
6. Differentiate among bacteria, archaea, and eukaryotic microorganisms.
7. Identify an acellular infectious agent that is studied in microbiology.
8. Compare and contrast the relative sizes of the different microbes.

1.2 Microbes in History

9. Make a time line of the development of microbiology from the 1600s to today.
10. List some recent microbiology discoveries of great impact.
11. Identify the important features of the scientific method.

1.3 Macromolecules: Superstructures of Life

12. Name the four main families of biochemicals.
13. Provide examples of cell components made from each of the families of biochemicals.
14. Differentiate among primary, secondary, tertiary, and quaternary levels of protein structure.
15. List the three components of a nucleotide.
16. Name the nitrogen bases of DNA and RNA.
17. List the three components of ATP.
18. Recall three characteristics common to all cells.

1.4 Naming, Classifying, and Identifying Microorganisms

19. Differentiate among the terms *nomenclature*, *taxonomy*, and *classification*.
20. Create a mnemonic device for remembering the taxonomic categories.
21. Correctly write the binomial name for a microorganism.
22. Draw a diagram of the three major domains.
23. Explain the difference between traditional and molecular approaches to taxonomy.

CASE FILE

The Subject Is You!

At the beginning of every chapter in this book a different health care worker will tell you a story about something "microbiological" that happened to him or her in the line of duty. For this first chapter, though, I am claiming "dibs" as author and am going to introduce myself to you by telling you about the first day of class in my course.

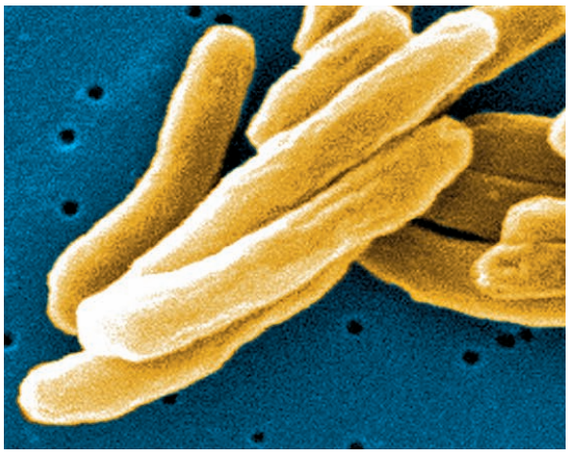
Long ago I noticed that students have a lot of anxiety about their microbiology course. I know that starts you out with one strike against you, as attitudes are such powerful determinants of our success. So on the first day of class I often spend some time talking with students about how much they already know about microbiology.

Sometimes I start with "How many of you have taken your kids for vaccinations?" since in the classes I teach very many students are parents. Right away students will tell me why they or friends they know have not vaccinated their children and I can tell them there's a sophisticated microbiological concept they are referencing, even if they aren't naming it: *herd immunity,* discussed in chapter 11 of this book.

My favorite question (now that we're all warmed up) is "Who knows someone—whom you don't have to identify—who has had a really unusual or scary infection?" A surprising number of people have known someone who has had malaria, or leptospirosis, or endocarditis, or encephalitis. Then the conversation gets interesting as students begin to understand how much they already know about microbiology, and the class is not going to be as intimidating as they thought.

- Think about how many times you have taken antibiotics in the past few years. What is special about antibiotics that they are only given to treat infections?
- What is the most unusual infection you have ever encountered among family or friends or patients you have cared for?

Case File Wrap-Up appears at the end of the chapter.



Mycobacterium tuberculosis bacteria
Source: CDC/Janice Carr

Important Note to Students!

This is your author here. I wanted to alert you right up front that you should look at the figures and read the tables in the chapters. I know that it is human nature to skip these, when you see the reference in the main text (like "**figure 1.4**") and just move on with the next sentence. But in this book I made a real point to put a lot of information in the figures and tables, because it is easier to digest things such as processes and categories when they are presented in a more visual format. And there are a lot of "processes" and "categories" in biology! So I opted for a bit less text, and a bit more pictures and tables. So be sure to make it a point to stop by and examine these visual features. Thanks! Kelly

1.1 Microbes: Tiny but Mighty

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. There are several major groups of microorganisms that we'll be studying. They are **bacteria, archaea, protozoa, fungi, helminths,** and **viruses.** There is another very important group of organisms called **algae.** They are critical to the health of the biosphere but do not directly infect humans, so we will not consider them in this book. Each of the other six groups contains members that colonize humans, so we will focus on them.

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.

Microbes and the Planet

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 appeared on this planet about 3.8 billion years ago according to the fossil record. One of these organisms–referred to as LCA, or the Last Common Ancestor–eventually led to the appearance of two newer single cell types, called bacteria and archaea. A little bit later this single-celled ancestor gave rise to **eukaryotic** (yoo-kar′-ee-ot-ic) cells. The type of cell known as LCA no longer exists. Only its "offspring"–bacteria, archaea, and eukaryotes–remain. *Eu-kary* means "true nucleus," and these were the only cells containing a nucleus. Bacteria and archaea have no true nucleus. For that reason, they have traditionally been called **prokaryotes** (pro-kar′-ee-otes), meaning "prenucleus." But researchers are suggesting we no longer use the term *prokaryote* to lump them together because archaea and bacteria are so distinct genetically. If you consider the six types of microorganisms we will be dealing with in this book, you will recognize bacteria and archaea as each having their own domain. The protozoa, fungi, and helminths are all in the domain Eukarya. Viruses do not appear on the tree of life since they are not cells, and not considered living. That sounds strange, but we will delve into that in the virus chapter, which comes later.

Figure 1.1 depicts the resulting tree of life–a diagram of all organisms on the planet. There are two important things to note about this figure. First, all of biologic life falls into these three categories, known as domains. Most of the organisms you are familiar with (animals, plants, etc.) are in one category, Eukarya. Second, these three domains all emerged from a single common cell type (the "stem" at the bottom).

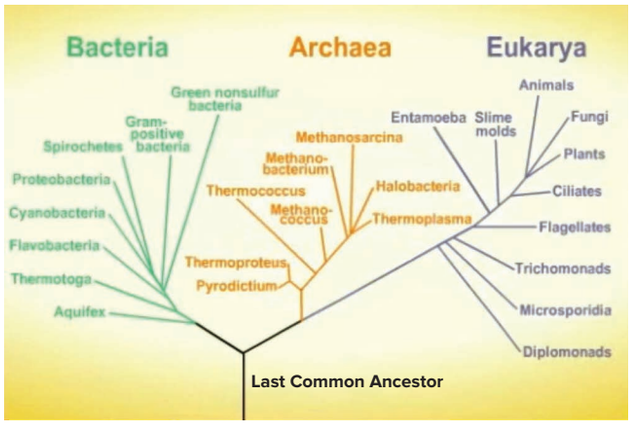


Figure 1.1 **Current view of evolutionary relatedness of all organisms.**

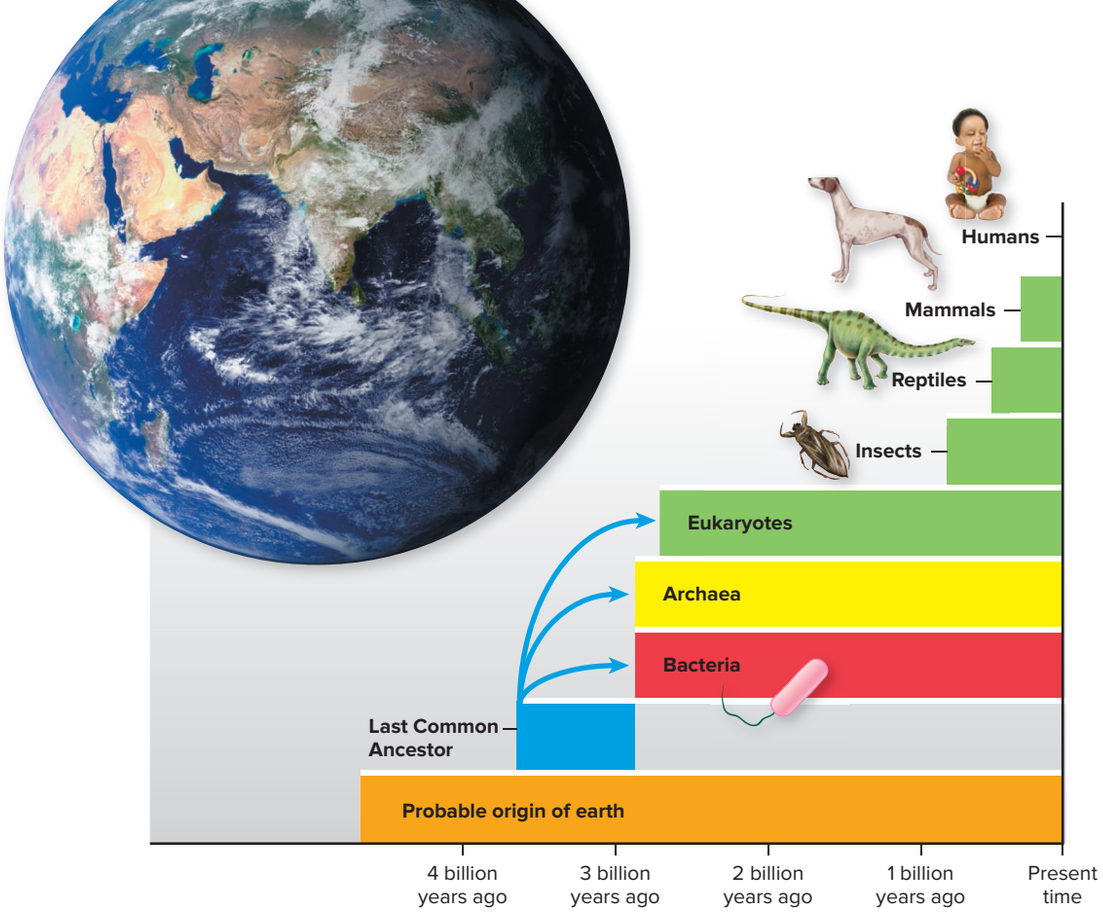


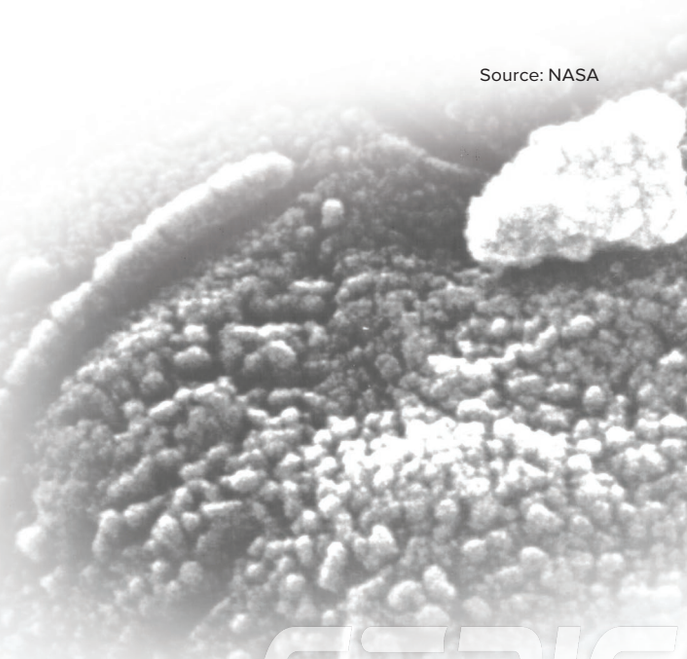
Figure 1.2 **Evolutionary time line.**
(photo): Source: NASA GSFC image by Robert Simmon and Reto Stöckli

Bacteria and archaea are predominantly single-celled organisms. Many, many eukaryotic organisms are also single-celled; but the eukaryotic cell type also developed into highly complex multicellular organisms, such as worms and humans. In terms of numbers, eukaryotic cells are a small minority compared to the bacteria and archaea, but their larger size (and our own status as eukaryotes!) makes us perceive them as dominant to–and more important than–bacteria and archaea.

Figure 1.2 depicts the time line of appearances of different types of organisms on earth. Starting on the left, you see that the ancestor cell type was here alone for quite a while before giving rise to the three domains of life. Eukaryotes came along last, and it took a very long time for single-celled eukaryotes to develop into more complex eukaryotic organisms (insects, reptiles, and mammals). On the scale pictured in the figure, humans just barely appeared in very recent earth history. Bacteria and archaea 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 have survived and adapted to many catastrophic changes over the course of our geologic history.

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 their immense numbers and by living in places that many other organisms cannot survive. Above all, they play central roles in the earth's landscape that are essential to life.

When we point out that single-celled organisms have adapted to a wide range of conditions over the 3.5 billion years of their presence on this planet, we are talking about evolution. The presence of 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 1.2 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.


Source: NASA

Medical Moment

Medications from Microbes

Penicillin is a worthy example of how microorganisms can be used to improve human life. Alexander Fleming, a Scottish bacteriologist, discovered penicillin quite by accident in 1928. While growing several bacterial cultures in Petri dishes, he accidentally forgot to cover them. They remained uncovered for several days. When Fleming checked the Petri dishes, he found them covered with mold. Just before Fleming went to discard the Petri dishes, he happened to notice that there were no bacteria to be seen around the mold—in other words, the mold was killing all of the bacteria in its vicinity.

Recognizing the importance of this discovery, Fleming experimented with the mold (of the genus *Penicillium*) and discovered that it effectively stopped or slowed the growth of several bacteria. The chemical that was eventually isolated from the mold—penicillin—became widely used during the Second World War and saved many soldiers' lives, in addition to cementing Fleming's reputation.

Q. Can you think of a logical reason that a microbe (the fungus) would produce a chemical that harms another microbe (the bacteria)?

Answer in Appendix B.

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. Scientists use the term *theory* in a different way than the general public does, which often leads to great confusion. In science, a theory begins as a hypothesis, or an educated guess to explain an observation. By the time a hypothesis has been labeled a *theory* in science, it has undergone years and years of testing and not been disproved. It is taken as fact. This is much different from 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, refers to a well-studied and well-established natural phenomenon, not just a random guess.

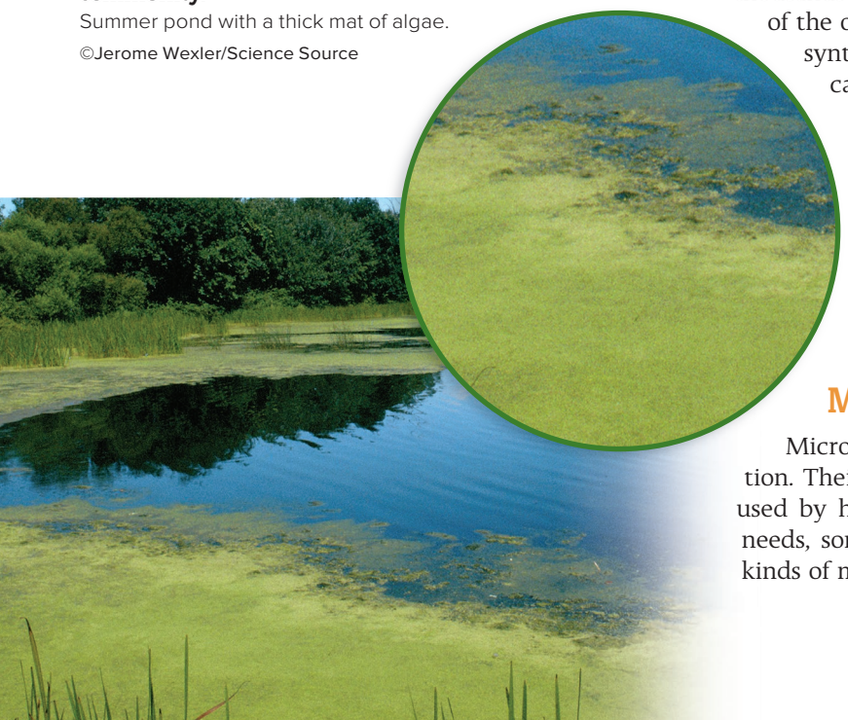
How Microbes Shape Our Planet

Microbes are deeply involved in the flow of energy and food through the earth's ecosystems. 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 the 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, these ancient, single-celled microbes 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 (mainly bacteria and algae) account for more than 70% of the earth's photosynthesis, contributing the majority of the oxygen to the atmosphere **(figure 1.3).**

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:

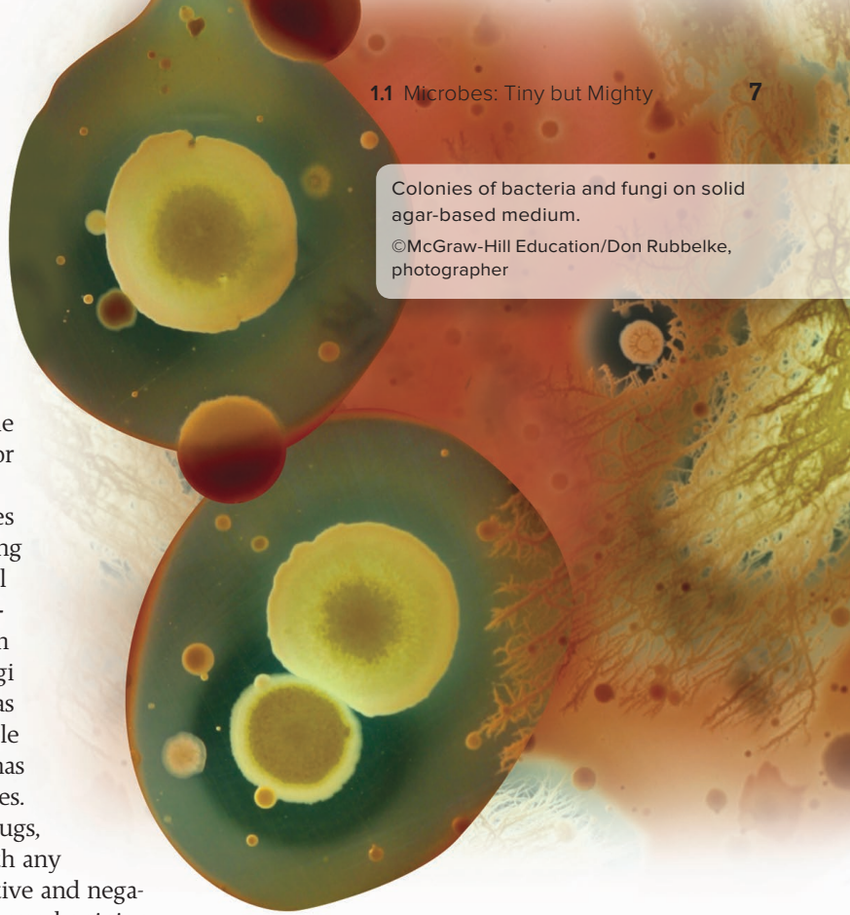
- The temperature of the earth is regulated by gases emitted by living organisms. These gases include carbon dioxide, nitrous oxide, and methane, which create an insulation layer in the atmosphere and help retain heat. Many of these gases are produced by microbes living in the environment and the digestive tracts of animals.
- The most abundant cellular organisms in the oceans are not fish but bacteria. Think of a 2-liter soda bottle. Two liters of surface ocean water contains approximately 1,000,000,000 (1 billion) bacteria. Each of these bacteria likely harbors thousands of viruses inside of it, making viruses the most abundant inhabitants of the oceans. The bacteria and their viruses are major contributors to photosynthesis and other important processes that create our environment. (Be careful here. The first sentence in this paragraph said that bacteria are the most abundant *cellular* organisms in oceans. But viruses, which are not cellular, far outnumber them.)
- 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 digests the complex carbohydrates of the animals' diets and causes the animals to release large amounts of methane into the atmosphere.

Figure 1.3 A rich photosynthetic community.
Summer pond with a thick mat of algae.



Microbes and Humans

Microorganisms clearly have monumental importance to the earth's operation. Their diversity and versatility make them excellent candidates for being used by humans for our own needs, and for them to "use" humans for their needs, sometimes causing disease along the way. We'll look at both of these kinds of microbial interactions with humans in this section.



Colonies of bacteria and fungi on solid agar-based medium.

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 yeasts, 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. 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.

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. 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 medical, industrial, and agricultural uses. Microbes can be engineered to synthesize desirable products such as drugs, hormones, and enzymes. It has become popular to dislike GMOs. As with any technological advance, the capacity to create GMOs can have both positive and negative aspects. Your job is to learn about them, so that you can have an informed opinion.

Another way of tapping into the unlimited potential of microorganisms is the science of **bioremediation** (by′-oh-ree-mee-dee-ay″-shun). This term refers to the ability of microorganisms–ones already present or those introduced intentionally–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 **(figure 1.4).** This includes even human-made chemicals that scientists have developed and for which there are no natural counterparts.

Microbes Harming Humans

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. 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. Any disease caused by a microorganism is termed an **infectious disease.** Many diseases are not caused by microorganisms, but by genetic defects, imbalances in body systems, exposure to chemicals in the environment, among others. 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 1.1** depicts the 10 top causes of death per year (by all causes, infectious and noninfectious) in the United States and worldwide.

We are also witnessing an increase in the number of new (emerging) and older (reemerging) diseases. AIDS, hepatitis C, Zika virus, West Nile virus, and tuberculosis are examples. It is becoming clear that human actions in the form of deforestation, industrial farming techniques, and chemical and antibiotic usage can foster the emergence or reemergence of particular infectious diseases. These patterns will be discussed in chapter 22.

Figure 1.4 The 2011 Gulf oil spill. There is evidence that ocean bacteria metabolized ("chewed up") some of the spilled oil.

Source: U.S. Coast Guard/Chief Petty Officer John Kepsimelis, Atlantic Strike Team

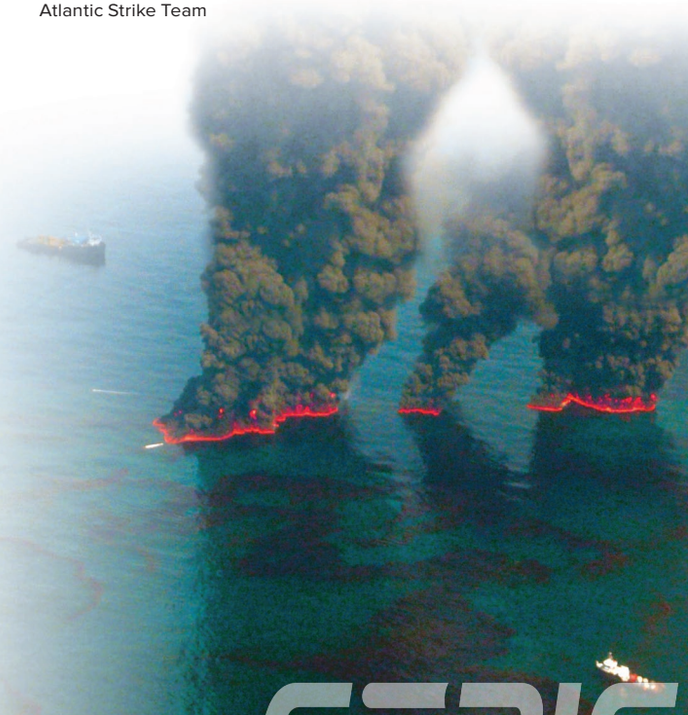
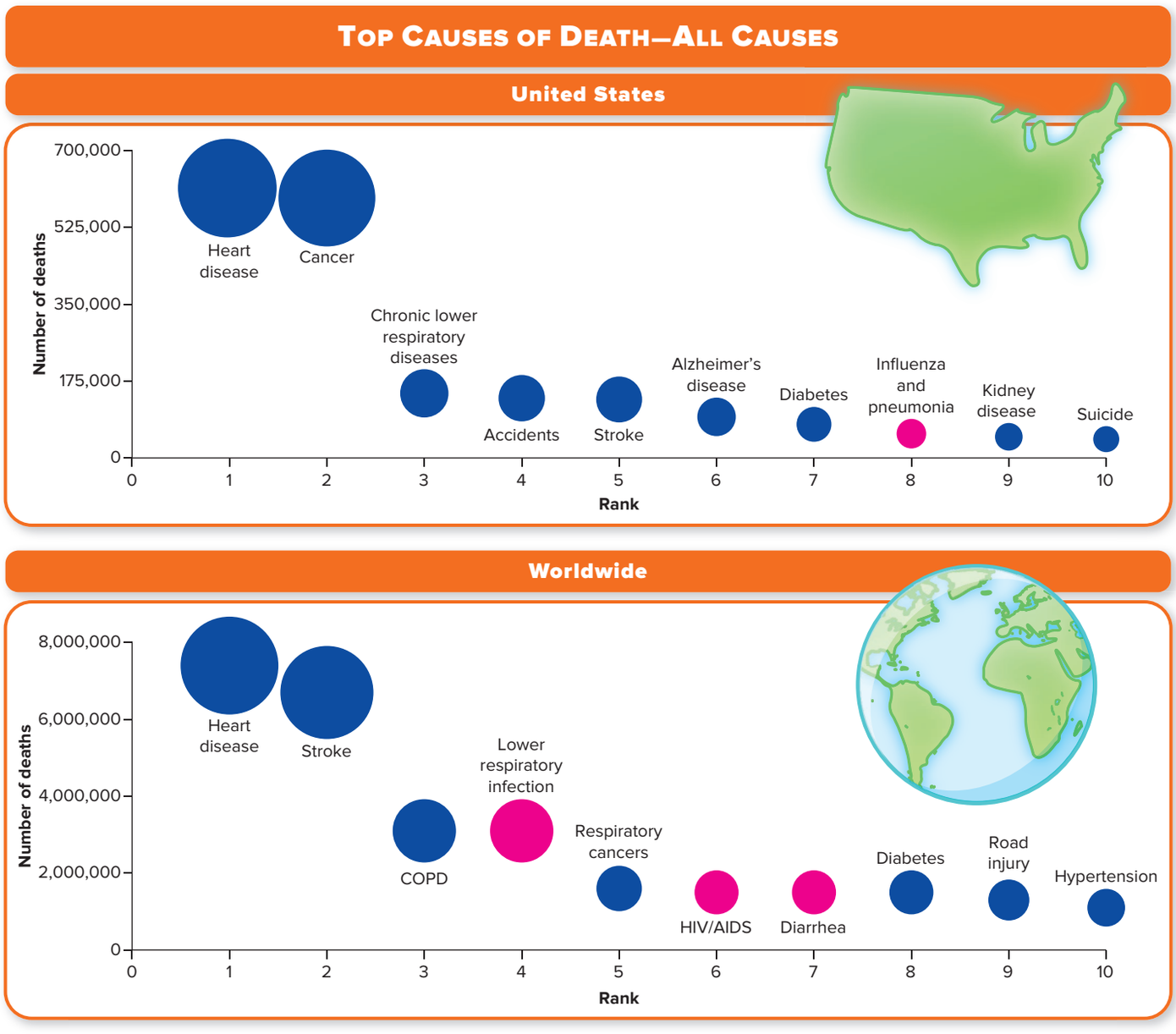


Table 1.1 Top Causes of Death—All Causes



United States data from 2014.
World data from 2012.

Source: CDC, 2009–2012

Diseases most clearly caused by microorganisms
Not currently known to have infectious cause

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. One well-known example is that of gastric ulcers, now known to be caused by a bacterium called *Helicobacter*. But there are more. 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. Later in this chapter we will introduce the human microbiome–the microbes that call the human body home from birth onward. We will see that variations in the microbiome also determine a person's tendency to develop both infectious and noninfectious conditions.

Another important development in infectious disease trends is the increasing number of patients with weakened defenses, who, because of welcome medical advances, are living active lives instead of enduring long-term disability or death from their conditions. 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.

What Are They Exactly?

Cellular Organization

As discussed earlier, two basic cell types appeared during evolutionary history. The bacteria and archaea, along with eukaryotic cells, differ not only in the complexity of their cell structure but also in contents and function.

In general, bacterial and archaeal cells are about 10 times smaller than eukaryotic cells, and they 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 and include the nucleus, mitochondria, and chloroplasts. Examples of bacteria, archaea, and eukaryotic microorganisms are covered in more detail in chapters 3 and 4.

All bacteria and archaea are microorganisms, but only some eukaryotes are microorganisms **(figure 1.5).** Also, of course, humans are eukaryotes. Certain small eukaryotes–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.

Let's look at viruses. As stated previously, they are not independently living cellular organisms. Instead, they are small particles that are at a level of complexity somewhere between large molecules and cells. Viruses are much simpler than cells. Outside their host, they are composed of a small amount of hereditary material (either DNA or RNA but never both) wrapped up in a protein covering. Some viruses have an additional layer, a lipid membrane that is exterior to the protein part. When inside their host organism, in the intracellular state, viruses usually exist only in the form of genetic material.

1.1 LEARNING OUTCOMES—Assess Your Progress

1. List the various types of microorganisms that can colonize humans.
2. Describe the role and impact of microbes on the earth.
3. Explain the theory of evolution and why it is called a theory.
4. Explain the ways that humans manipulate organisms for their own uses.
5. Summarize the relative burden of human disease caused by microbes.
6. Differentiate among bacteria, archaea, and eukaryotic microorganisms.
7. Identify an acellular infectious agent that is studied in microbiology.
8. Compare and contrast the relative sizes of the different microbes.

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1. For which of the following disease processes has microbial infection been implicated? Select all that apply.
   - **a.** *gastric ulcers*
   - **b.** *diabetes type 1*
   - **c.** *renal artery stenosis*
   - **d.** *schizophrenia*
   - **e.** *obesity*
   - **f.** *deep vein thrombosis*