Sixth Edition

Microbiology

A Systems Approach

Marjorie Kelly Cowan
Heidi Smith

McGraw Hill

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MICROBIOLOGY: A SYSTEMS APPROACH, SIXTH EDITION

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Brief Contents

About the Authors

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

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

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

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

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

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

Heidi Smith

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

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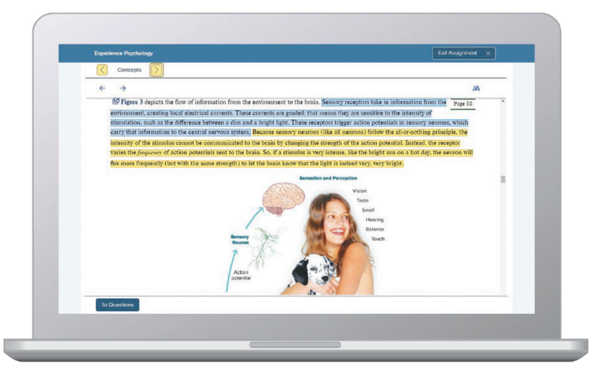

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- Jordan Cunningham,
Eastern Washington University

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Digital Tools for Your Success

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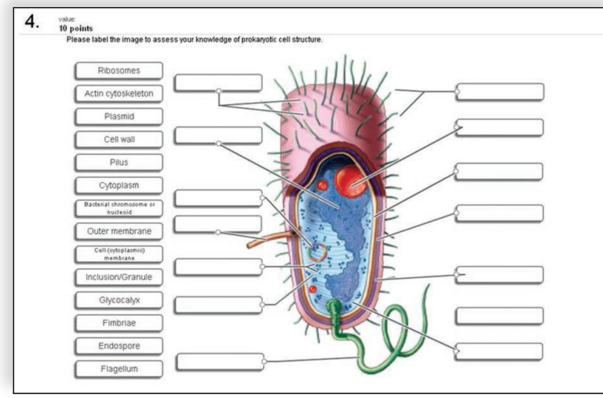
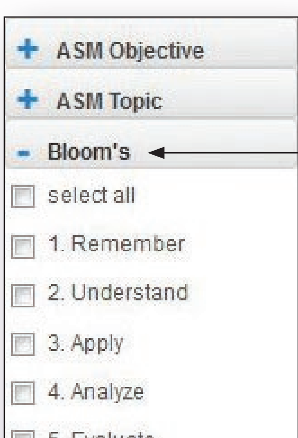
McGraw-Hill Connect for Cowan's Microbiology provides online presentation, assignment, and assessment solutions, connecting your students with the tools and resources they'll need to achieve success.



Homework and Assessment

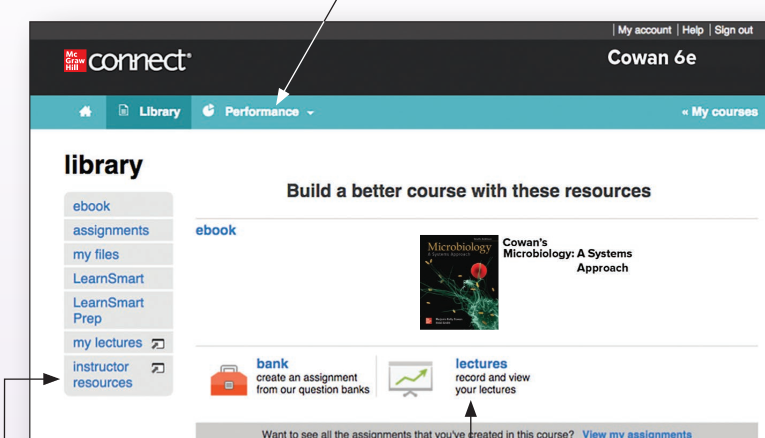
With **Connect for Cowan's Microbiology,** you can deliver auto-graded assignments, quizzes, and tests online. Choose from a robust set of interactive questions and activities using high-quality art from the textbook and animations. Assignable content is available for every Learning Outcome in the book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



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

Detailed Reports

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



Instructor Resources

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

Lecture Capture

McGraw-Hill Tegrity® Tegrity in Connect is a tool that makes class time available 24/7 by automatically capturing every lecture. With a simple one-click, start-and-stop process, you capture all computer screens and corresponding audio in a format that is easy to search, frame by frame. Students can replay any part of any class with easy-to-use, browser-based viewing on a PC, Mac, or other mobile device.

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

- **Case Study:** Case studies come to life in a learning activity that is interactive, self-grading, and assessable. The integration of the cases with videos and animations adds depth to the content, and the use of integrated questions forces students to stop, think, and evaluate their understanding.
- **Media Under The Microscope:** The opening cases in the textbook help students read science articles in the popular media with a critical eye. Questions in Connect are designed to extend these cases in a manner that promotes active student learning, either at home or in the classroom.
- **Concept Maps:** Concept maps allow students to manipulate terms in a hands-on manner in order to assess their understanding of chapter-wide topics. Students become actively engaged and are given immediate feedback, enhancing their understanding of important concepts within each chapter.
- **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 × three increasing Bloom's levels = a robust assessment tool.
- **Study Smarter: Better Together:** A new feature in every chapter, Study Smarter gives guidance for students' group study, either in person or online. No instructor intervention required! Research shows that well-structured group study benefits under-resourced learners and students with lower levels of reading ability.
- **What's the Diagnosis:** Specifically designed for the disease chapters of the text, this is an integrated learning experience designed to assess the student's ability to utilize information learned in the preceding chapters to successfully culture, identify, and treat a disease-causing microbe in a simulated patient scenario. This question type is true experiential learning and allows the students to think critically through a real-life clinical situation.
- **Animations:** Animation quizzes pair our high-quality animations with questions designed to probe student understanding of the illustrated concepts.
- **Animation Learning Modules:** Making use of McGraw-Hill Education's collection of videos and animations, this question type presents an interactive, self-grading, and assessable activity. These modules take a stand-alone, static animation and turn it into an interactive learning experience for your students with real-time remediation.
- **Labeling:** Using the high-quality art from the textbook, check your students' visual understanding as they practice interpreting figures and learning structures and relationships. Easily edit or remove any label you wish!
- **Classification:** Ask students to organize concepts or structures into categories by placing them in the correct "bucket."
- **Sequencing:** Challenge students to place the steps of a complex process in the correct order.
- **Composition:** Fill in the blanks to practice vocabulary, and then reorder the sentences to form a logical paragraph (these exercises may qualify as "writing across the curriculum" activities!).

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

Lab Resources

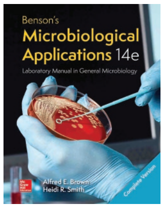
Need a lab manual for your microbiology course? Customize any of these manuals—add your text material—and *Create* your perfect solution!

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

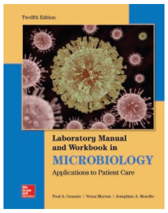
Brown/Smith: *Benson's Microbiological Applications: Laboratory Manual in General Microbiology,* 14th edition

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

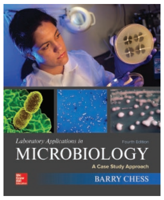
Complete Version (978-1-259-91979-4)



Morello: *Laboratory Manual and Workbook in Microbiology: Applications to Patient Care,* 12th edition (978-1-260-00218-8)



Chess: *Laboratory Applications in Microbiology: A Case Study Approach,* 4th edition (978-1-259-70522-9)



Prep for Microbiology is an adaptive learning tool that prepares students for college-level work in Microbiology. Prep for Microbiology individually identifies concepts the student does not fully understand and provides learning resources to teach essential concepts so he or she enters the classroom prepared. Data-driven reports highlight areas where students are struggling, helping to accurately identify weak areas.

Note from the Authors

This Text's Most Important Distinguishing Features:

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

- SYSTEMATIC ORGANIZATION of the disease chapters that groups microbes by the conditions they cause.
- EPIDEMIOLOGY in every disease table.
- OPENING CASES that teach students how to read science articles in the popular media with a critical eye.
- MICROBIOME findings in all 25 chapters—in form of Microbiome Insight boxes as well as in the text. This reinforces how game-changing the microbiome findings are.
- STUDY SMARTER: BETTER TOGETHER in each chapter that provides guidance for students' group study, either in person or online. No instructor intervention required! Research shows that well-structured group study benefits under-resourced learners and students with lower levels of reading ability.
- SMARTGRIDS in each chapter. The end-of-chapter questions are dramatically reformatted into a 21-question grid that cross-references questions by their Bloom's level and the six core concepts of microbiology (plus the competency of scientific literacy) as identified by the American Society for Microbiology.
- VISUAL feature on the difference between the deadliness and the contagiousness of various microbes that appears in every disease chapter.
- CLEAN, uncluttered, and predictable sequence of chapter content.
- CONNECT UPDATES
  - CRITICAL THINKING applied through higher Bloom's level questions added to the Connect Question Bank.
  - SMARTBOOK LEARNING RESOURCES added based on heat map results from areas where students struggle the most. Help when they need it, with a library of resources available for refresher.
  - SUB-SECTION LEARNSMART assignability to allow for a more narrowed focus of chapters or further ability to assign chapter content in smaller chunks for student understanding.

—Kelly Cowan
—Heidi Smith

Capturing Students' Attention and Learning

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

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

1

The Main Themes of Microbiology

Image Source

MEDIA UNDER THE MICROSCOPE

Filthy Coffee Machine?

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

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

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

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

1

taxonomic units, the **domains,** each being a different type of cell (figure 1.12).

The domains are now the highest level in hierarchy and each one can contain more than one kingdom. Take particular care to notice that Bacteria and Archaea now constitute separate domains and are not in the same kingdom, as they had been thought to be in the past. The domains are

- Bacteria
- Archaea
- Eukarya

Analysis of the ssuRNAs from all organisms in these three domains suggests that all modern and extinct organisms on earth arose from a common ancestor.

The traditional shape of the "tree of life" has given way to something else now, given our discovery of rampant horizontal gene transfer—in microbes and in larger organisms. For example, it is estimated that 40% to 50% of human DNA has been carried to humans from other species (by parasitic eukaryotes or viruses). Another example: The genome of the cow contains a great deal of snake DNA. For these reasons, most scientists like to think of a *web* as the proper representation of life these days. Nevertheless, this new scheme does not greatly affect our

1.7 Naming, Classifying, and Identifying Microorganisms 21

presentation of most microbes because we will discuss them at the genus or species level. But be aware that biological taxonomy and, more important, our view of how organisms evolved on earth are in a permanent state of transition. Keep in mind that our methods of classification or evolutionary schemes reflect our current understanding and will change as new information is uncovered.

Please note that neither viruses nor prions are included in any of the classification or evolutionary schemes because they are not cells or organisms and their position in a "tree of life" has not been definitively determined.

1.7 Learning Outcomes—Assess Your Progress

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.

MEDIA UNDER THE MICROSCOPE WRAP-UP

The article "Your Keurig Machine May Be Covered in Bacteria and Mold" contains some data. Let us examine two statements. First, "More than half of the machines came back with bacterial counts in the millions." The article does not provide links to a research article or to the data source, but it seems reasonable that millions of colonies would arise from swabs of the machines. As microbiology students, we know that millions of bacteria cover the surfaces of our bodies and the surfaces in our environment. We also know that this is normal, and even necessary, and that the vast majority of microbes have positive or neutral effects on our health. To the uninformed public, though, "millions of bacteria" could sound alarming, and it could be argued that the intent of the article is to raise a note of alarm. In this case, the alarm is not justified.

The second fact, that one of the 29 machines tested positive for *E. coli*, points to the possibility that fecal matter contaminated that machine. That, of course, has a certain "eww" factor, particularly for the public. But microbiologists know that fecal matter, carried on a person's hands, frequently contaminates household surfaces. *E. coli* is an indicator organism signaling that fecal matter has been transferred because *E. coli* has its habitat in the digestive tracts of mammals (humans, dogs, cats). But the vast majority of *E. coli* strains do not cause disease, and are, in fact, normal biota. So the presence of *E. coli* in and of itself does not raise alarm bells. It does indicate fecal contamination—but we are surrounded by that in our environments.

Image Source

The data in the article confirm something not so very alarming: that coffeemakers share the characteristics of every other object in our environment. Because we use coffeemakers to make something we put in our mouths, we should simply maintain normal hygienic practices and keep them reasonably clean.

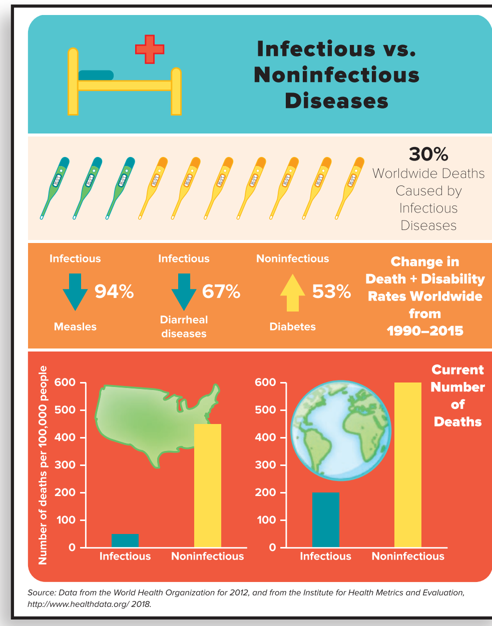
To address the questions from the first part of the case, the **intended message** of the article seems to be that we should be alarmed about all the things growing in our coffeemakers. A **critical reading,** however, suggests that no alarm is called for because of the fact that all surfaces are covered with microbes. The presence of *E. coli* in one of the 29 machines suggests that normal hygiene should be part of our daily lives. And that is how we should **interpret** it to our friends! As for **an overall grade,** I would give this article a grade of D– because its intention—to alarm us—is not supported by the facts; because it does not explain what *E. coli* is; and because there is no link to the data or the research so that we can check it out for ourselves.

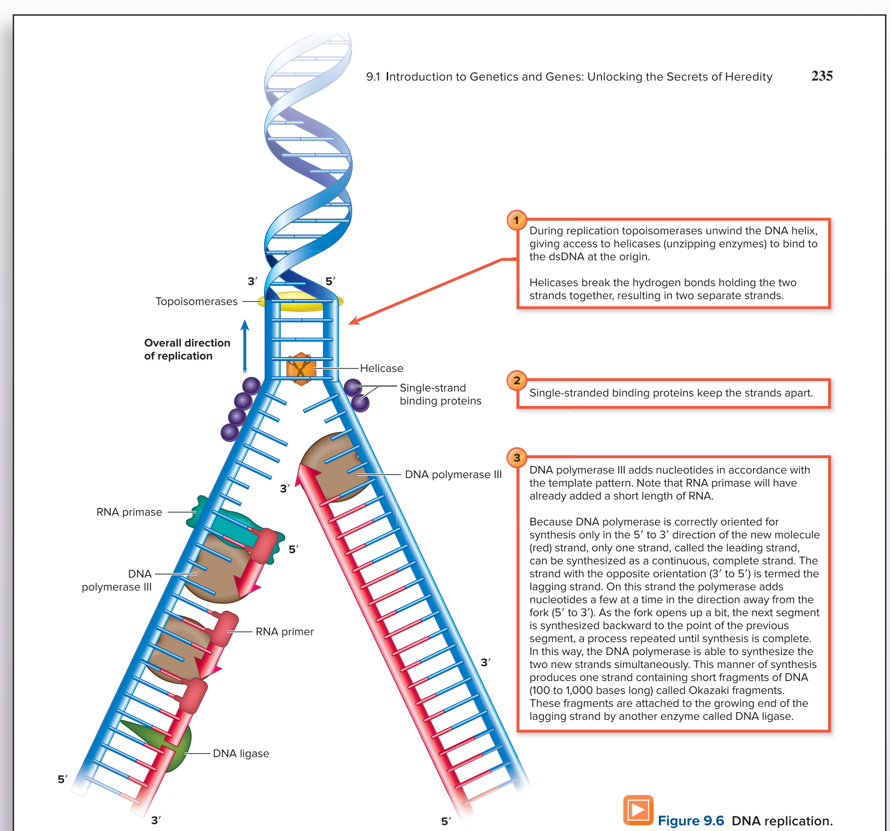
Source: Huffington Post, "Your Keurig Machine May Be Covered in Bacteria and Mold," online article posted 5/21/2015.

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

Student-Focused Instructional Art

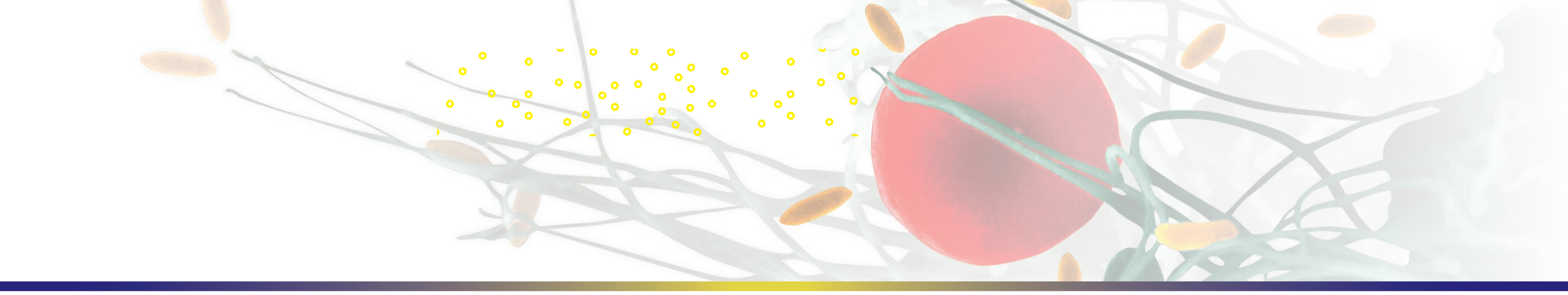
Effective science illustrations not only look pretty but help students visualize complex concepts and processes and paint a conceptual picture for them. The art combines vivid colors, multidimensionality, and self-contained narrative to help students study the challenging concepts of microbiology from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





Figures

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

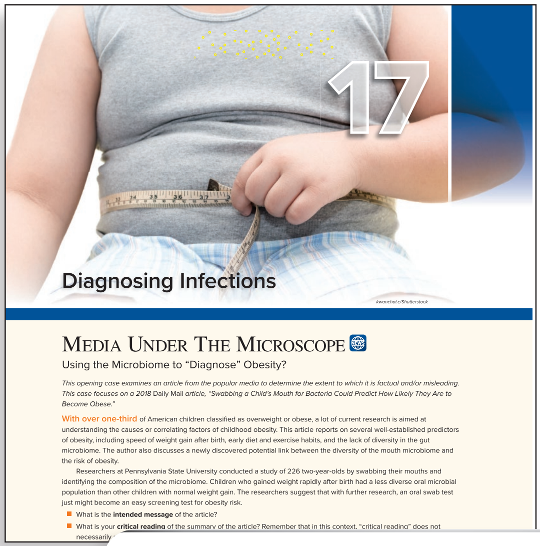


Connecting Students to Their Future Careers

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

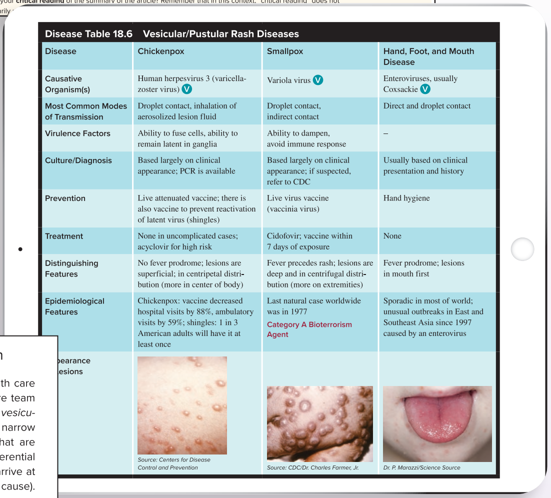
"Diagnosing Infections" Chapter

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



Systematic Presentation of Disease-Causing Organisms

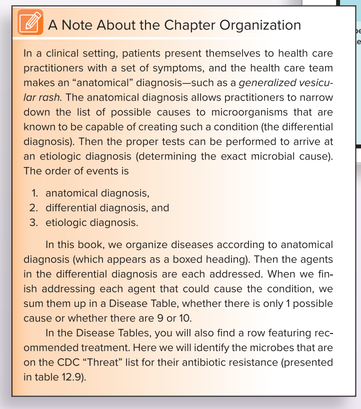
Microbiology: A Systems Approach takes a unique approach to diseases by organizing microbial agents under the heading of the disease condition they cause. After all of them are covered, the agents are summarized in a comparative table. Every condition gets a table, whether there is one possible cause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



Disease Table 18.6 Vesicular/Pustular Rash Diseases

Disease	Chickenpox	Smallpox	Hand, Foot, and Mouth Disease
Causative Organism(s)	Human herpesvirus 3 (varicella-zoster virus) V	Variola virus V	Enteroviruses, usually Coxsackie V
Most Common Modes of Transmission	Droplet contact, inhalation of aerosolized lesion fluid	Droplet contact, indirect contact	Direct and droplet contact
Virulence Factors	Ability to fuse cells, ability to remain latent in ganglia	Ability to dampen, avoid immune response	–
Culture/Diagnosis	Based largely on clinical appearance; PCR is available	Based largely on clinical appearance; if suspected, refer to CDC	Usually based on clinical presentation and history
Prevention	Live attenuated vaccine; there is also vaccine to prevent reactivation of latent virus (shingles)	Live virus vaccine (vaccinia virus)	Hand hygiene
Treatment	None in uncomplicated cases; acyclovir for high risk	Cidofovir; vaccine within 7 days of exposure	None
Distinguishing Features	No fever prodrome; lesions are superficial; in centripetal distribution (more in center of body)	Fever precedes rash; lesions are deep and in centrifugal distribution (more on extremities)	Fever prodrome; lesions in mouth first
Epidemiological Features	Chickenpox: vaccine decreased hospital visits by 88%, ambulatory visits by 59%; shingles: 1 in 3 American adults will have it at least once	Last natural case worldwide was in 1977 Category A Bioterrorism Agent	Sporadic in most of world; unusual outbreaks in East and Southeast Asia since 1997 caused by an enterovirus
…earance …esions	*Source: Centers for Disease Control and Prevention*	*Source: CDC/Dr. Charles Farmer, Jr.*	*Dr. P. Marazzi/Science Source*

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



A Note About the Chapter Organization

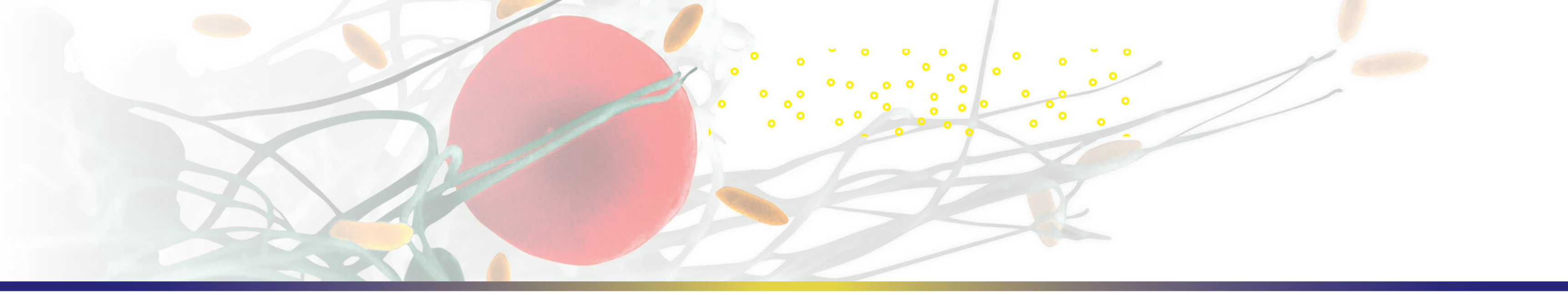
In a clinical setting, patients present themselves to health care practitioners with a set of symptoms, and the health care team makes an "anatomical" diagnosis—such as a *generalized vesicular rash*. The anatomical diagnosis allows practitioners to narrow down the list of possible causes to microorganisms that are known to be capable of creating such a condition (the differential diagnosis). Then the proper tests can be performed to arrive at an etiologic diagnosis (determining the exact microbial cause). The order of events is

1. anatomical diagnosis,
2. differential diagnosis, and
3. etiologic diagnosis.

In this book, we organize diseases according to anatomical diagnosis (which appears as a boxed heading). Then the agents in the differential diagnosis are each addressed. When we finish addressing each agent that could cause the condition, we sum them up in a Disease Table, whether there is only 1 possible cause or whether there are 9 or 10.

In the Disease Tables, you will also find a row featuring recommended treatment. Here we will identify the microbes that are on the CDC "Threat" list for their antibiotic resistance (presented in table 12.9).

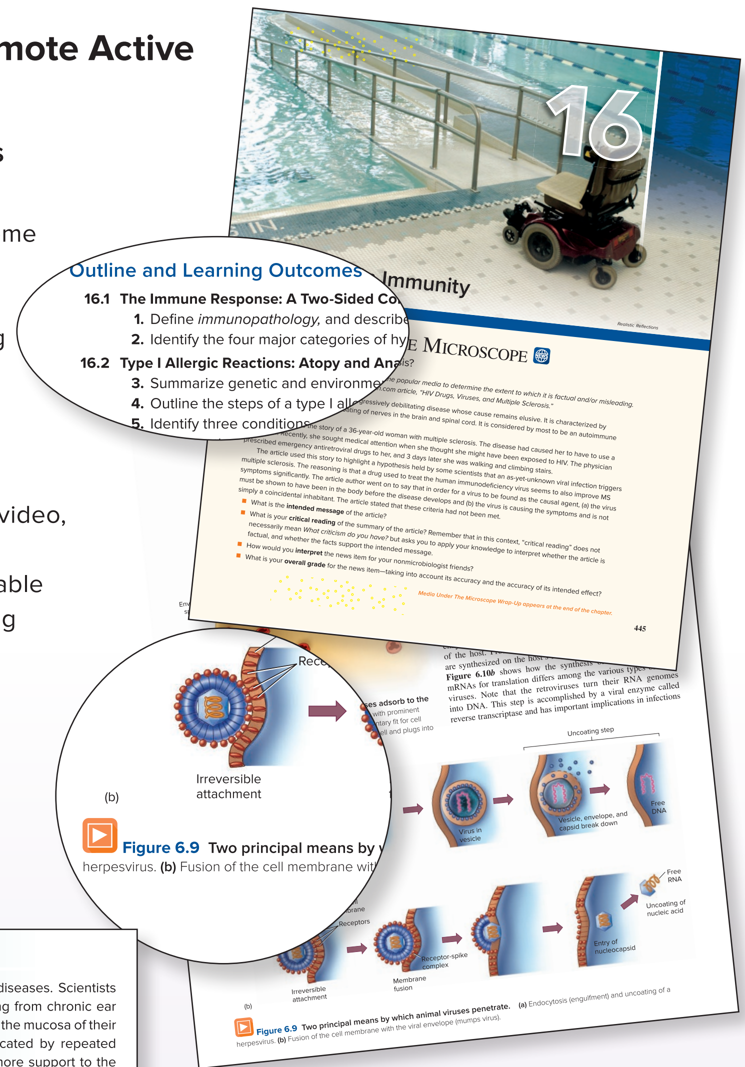
This approach is logical, systematic, and intuitive, as it encourages clinical and critical thinking in students—the type of thinking they will be using if their eventual careers are in health care. Students learn to examine multiple possibilities for a given condition and grow accustomed to looking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



Student-Centered Pedagogy Created to Promote Active Learning

Learning Outcomes and Assess Your Progress Questions

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



Animated Learning Modules

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

Disease Connection

Sometimes it is difficult for students to see the relevance of basic concepts to their chosen professions. So 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,* in these examples).

Disease Connection

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

Insight Readings

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

INSIGHT 12.1 CLINICAL: Using Viruses as Antibiotics

Here are two facts to consider:

- Bacteriophages, as you learned in section 6.5, are viruses that infect and kill bacteria, and they do not infect other types of cells.
- Before the middle of the 20th century, there were no effective treatments for human bacterial infections.

Does reading those two statements lead you to any speculation?

... crobiologist named Felix ... -old boy who had severe ... ages he had isolated from ... ned the bacteriophages by ... nts to remove bacteria and ... acteriophages. D'Herrelle ... ld attack the bacteria that ... istering the phage "soup," ... e of it themselves to deter... o be.

When they administered it to the boy, his symptoms improved immediately and he recovered completely within days. This was the beginning of bacteriophage therapy. Eventually, d'Herrelle created five different commercial preparations of bacteriophages to treat respiratory infections, skin infections, intestinal infections, and so on. They were marketed by a company in France, now known as L'Oreal.

The use of bacteriophages sputtered along until the middle of the 20th century, when antibiotics were discovered. Antibiotics quickly overtook bacteriophage therapy as the treatment of choice for all bacterial infections—in the West, at least. In the Soviet Union and other Eastern bloc countries that had little or no access to antibiotics, bacteriophage use continued. It had never been rigorously vetted according to modern standards of pharmaceutical testing, but it worked effectively throughout the 20th century in those places.

In the early 21st century, we find ourselves with very few effective drug treatments for some antibiotic-resistant bacteria. European and U.S. scientists are turning again to phage therapy. The first major clinical trials of phage therapy started in Europe in summer 2015. The European Commission funded the study, which is examining the efficacy of the treatment on burn patients in France, Belgium, and Switzerland. And the United States National Institute of Allergy and Infectious Diseases in 2014 identified phage therapy as one of seven areas of emphasis in targeting antibiotic resistance. It will be at least 5 years before phage therapy passes through the rigorous testing required to bring a "drug" to market, but it still provides promise that we will have a weapon in our arsenal against drug-resistant infections.

Sources: 2001. *Antimicrob. Agents. Chemother.* Vol. 45(3): 649–659. DOI: 10.1128/AAC.45.3.649-659.2001
Reuters, online article posted 7/2/15.

INSIGHT 15.1 MICROBIOME: Cancer and the Microbiome

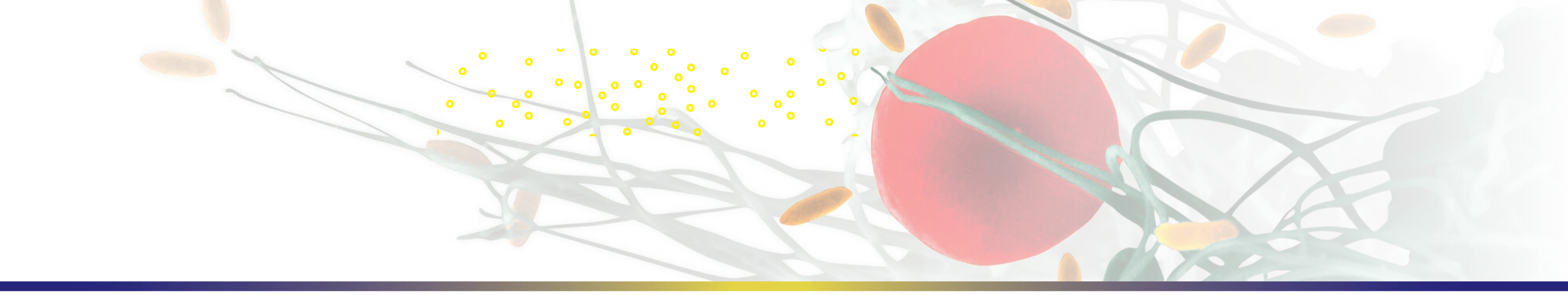
We know that the gut microbiome is critical to the health of its human host. One of the ways it influences health is by having a profound effect on inflammation and immunity. In turn, inflammation and immunity—in all the complexity you have studied in these two chapters—profoundly affect the initiation and progression of tumor cells. The microbiome also impacts the effectiveness of cancer therapies and the susceptibility to toxic side effects. An article that reviews the research in this field was published by two National Institutes of Health scientists, Soumen Roy and Giorgio Trinchieri, in 2017.

Image Point Fr/Shutterstock

They describe the reasons that the microbiome influences cancer occurrence and progression. One important factor is what they call the "crosstalk" among the gut microbiota, immune cells, and the mucosal surfaces. By this they mean the close association and chemical signaling that occur among the three. When the microbiome is healthy, and this crosstalk is functioning well, it is in an optimal state to prevent the initiation of tumors. Disturbances to the microbiome, which can occur because of antibiotic treatment, lifestyle, diet, and disease, can lead to a loss of immune surveillance, allowing tumor growth to begin.

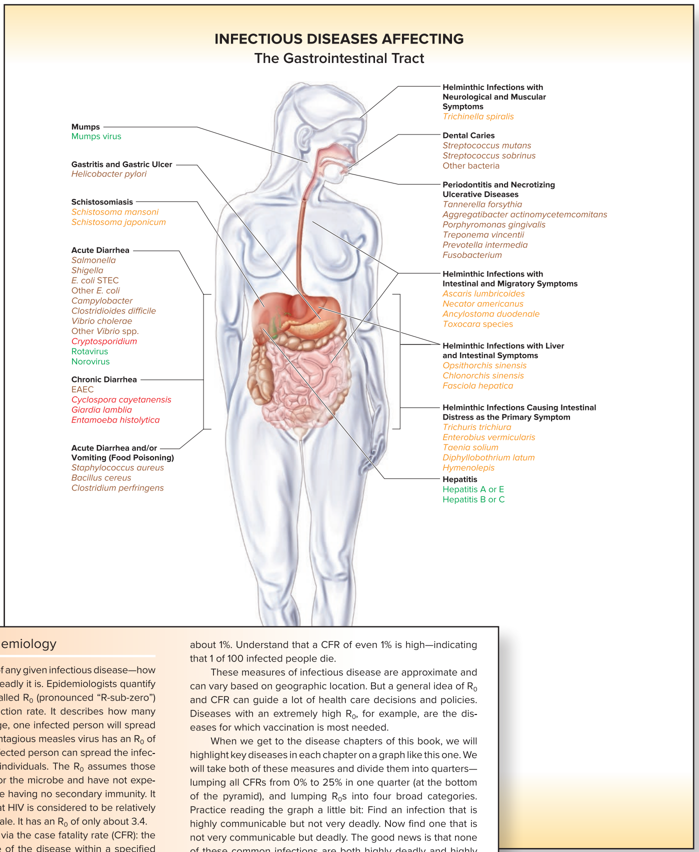
Further, it has become clear that an individual's reaction to cancer treatment is also profoundly affected by the microbiome. Because the microbiota prepare immune cells to release toxic oxygen species and also to provide an effective T-cell response, when the microbiome is dysfunctional, chemotherapy that works through those two mechanisms is less effective. A disturbed microbiome has even been shown to reduce the effectiveness—and increase the side-effects—of radiation therapy. This field of research is only about 4 years old, and, as the researchers point out, has mostly been conducted in mouse models. But the prospects are good that we will eventually be able to improve the treatment of cancer, at least partially through the "engineering" of the microbiome.

Source: 2017. *Nature Reviews: Cancer.* Vol. 17, pp 27–285. DOI: 10.1038/nrc.2017.13



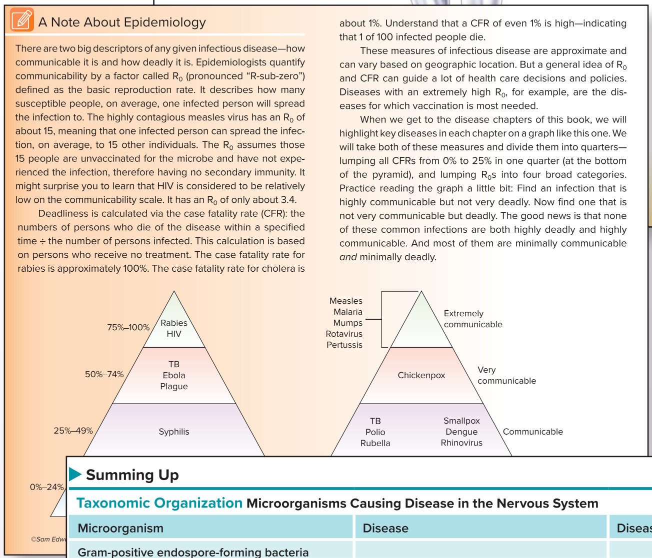
System Summary Figures

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



Communicability vs. Deadliness Feature

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



A Note About Epidemiology

There are two big descriptors of any given infectious disease—how communicable it is and how deadly it is. Epidemiologists quantify communicability by a factor called R_0 (pronounced "R-sub-zero") defined as the basic reproduction rate. It describes how many susceptible people, on average, one infected person will spread the infection to. The highly contagious measles virus has an R_0 of about 15, meaning that one infected person can spread the infection, on average, to 15 other individuals. The R_0 assumes those 15 people are unvaccinated for the microbe and have not experienced the infection, therefore having no secondary immunity. It might surprise you to learn that HIV is considered to be relatively low on the communicability scale. It has an R_0 of only about 3.4.

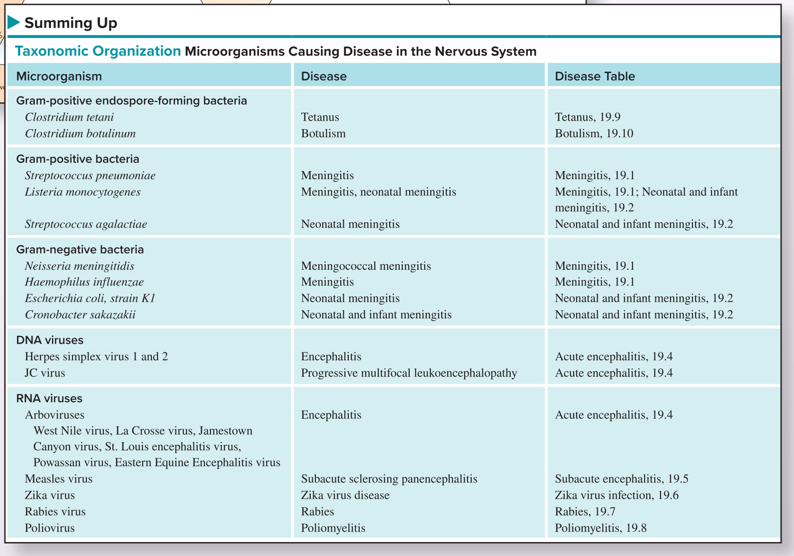
Deadliness is calculated via the case fatality rate (CFR): the numbers of persons who die of the disease within a specified time ÷ the number of persons infected. This calculation is based on persons who receive no treatment. The case fatality rate for rabies is approximately 100%. The case fatality rate for cholera is about 1%. Understand that a CFR of even 1% is high—indicating that 1 of 100 infected people die.

These measures of infectious disease are approximate and can vary based on geographic location. But a general idea of R_0 and CFR can guide a lot of health care decisions and policies. Diseases with an extremely high R_0, for example, are the diseases for which vaccination is most needed.

When we get to the disease chapters of this book, we will highlight key diseases in each chapter on a graph like this one. We will take both of these measures and divide them into quarters—lumping all CFRs from 0% to 25% in one quarter (at the bottom of the pyramid), and lumping R_0s into four broad categories. Practice reading the graph a little bit: Find an infection that is highly communicable but not very deadly. Now find one that is not very communicable but deadly. The good news is that none of these common infections are both highly deadly and highly communicable. And most of them are minimally communicable *and* minimally deadly.

Taxonomic List of Organisms

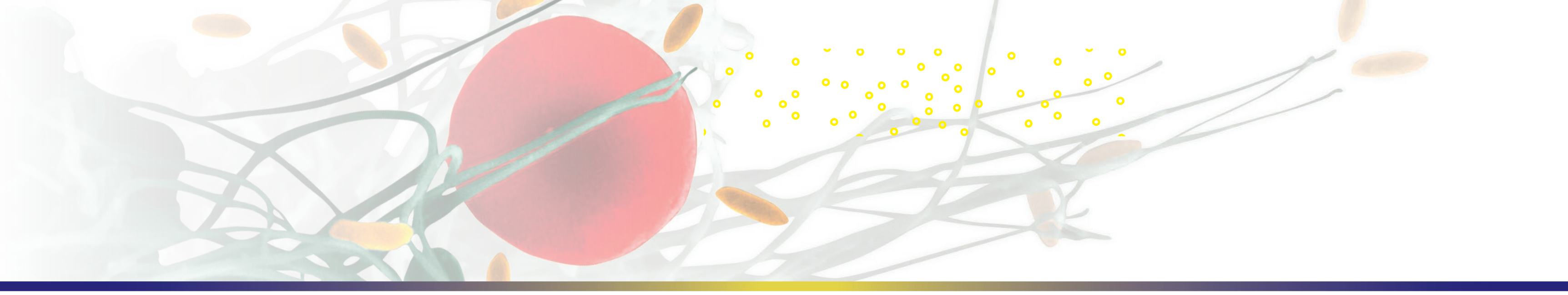
A taxonomic list of organisms is presented at the end of each disease chapter so students can see the taxonomic position of microbes causing diseases in that body system.



Summing Up

Taxonomic Organization Microorganisms Causing Disease in the Nervous System

Microorganism	Disease	Disease Table
Gram-positive endospore-forming bacteria		
Clostridium tetani	Tetanus	Tetanus, 19.9
Clostridium botulinum	Botulism	Botulism, 19.10
Gram-positive bacteria		
Streptococcus pneumoniae	Meningitis	Meningitis, 19.1
Listeria monocytogenes	Meningitis, neonatal meningitis	Meningitis, 19.1; Neonatal and infant meningitis, 19.2
Streptococcus agalactiae	Neonatal meningitis	Neonatal and infant meningitis, 19.2
Gram-negative bacteria		
Neisseria meningitidis	Meningococcal meningitis	Meningitis, 19.1
Haemophilus influenzae	Meningitis	Meningitis, 19.1
Escherichia coli, strain K1	Neonatal meningitis	Neonatal and infant meningitis, 19.2
Cronobacter sakazakii	Neonatal and infant meningitis	Neonatal and infant meningitis, 19.2
DNA viruses		
Herpes simplex virus 1 and 2	Encephalitis	Acute encephalitis, 19.4
JC virus	Progressive multifocal leukoencephalopathy	Acute encephalitis, 19.4
RNA viruses		
Arboviruses: West Nile virus, La Crosse virus, Jamestown Canyon virus, St. Louis encephalitis virus, Powassan virus, Eastern Equine Encephalitis virus	Encephalitis	Acute encephalitis, 19.4
Measles virus	Subacute sclerosing panencephalitis	Subacute encephalitis, 19.5
Zika virus	Zika virus disease	Zika virus infection, 19.6
Rabies virus	Rabies	Rabies, 19.7
Poliovirus	Poliomyelitis	Poliomyelitis, 19.8



Developing Critical Thinkers

The end-of-chapter material is linked to Bloom's Taxonomy. It has been carefully planned to promote active learning and provide review for different learning styles and levels of difficulty.

SmartGrid

This innovative learning tool distributes chapter material among the American Society for Microbiology's six main curricular concepts, plus the competency of *scientific thinking.* Each of the seven areas is probed at three different Bloom's levels. The resulting 21-question grid can be assigned by column (all multiple-choice questions about each core concept, for example) or by row (all questions related to evolution, but at increasing Bloom's level). The highest Bloom's level questions can easily be assigned as a group project or presentation topic.

SmartGrid: From Knowledge to Critical Thinking

This *21 Question Grid* takes the topics from this chapter and arranges them with respect to the American Society for Microbiology's Undergraduate Curriculum guidelines—all six of the important "Concepts" as well as the important "Competency" of scientific literacy. Three questions are supplied, which cover chapter content referring to the Concept or Competency in increasing levels of Bloom's taxonomy for learning.

ASM Concept/ Competency	A. Bloom's Level 1, 2—Remember and Understand (Choose one.)	B. Bloom's Level 3, 4—Apply and Analyze	C. Bloom's Level 5, 6—Evaluate and Create
Evolution	**1.** The best descriptive term for the resident microbiota is **a.** commensal. **b.** parasitic. **c.** pathogenic. **d.** mutualistic.	**2.** In some circumstances, microbes can be quite virulent when they first infect a new species (such as in a zoonosis) but over decades of association with the new human host, cause milder and milder disease. Can you speculate about why this is evolutionarily advantageous to the pathogen?	**3.** Conduct research on germ-free mice. Use what you find to write a paragraph about the coevolution of microbes and humans.
Cell Structure and Function	**4.** Which of the following are virulence factors? **a.** toxins **b.** enzymes **c.** capsules **d.** all of the above	**5.** Why do you suppose specific adhesive structures, such as fimbriae, are critical to the disease-causing capabilities of many bacteria? Be thorough in your answer.	**6.** Discuss the role of endospores in ensuring the ongoing transmission of a bacterium in a population.

High Impact Study Feature

Students benefit most from varied study and assessment methods. We've created a short set of "Terms" and "Concepts" that help students identify the most important 10 to 15 items in a chapter. If they understand these, they are well on their way to mastery.

High Impact Study

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

Concepts

- ☐ Defenses of nervous system
- ☐ Normal microbiota of nervous system
- ☐ Four bacterial causes of meningitis
- ☐ Other causes of meningitis
- ☐ Food-borne cause of meningitis
- ☐ Meningitis vaccines
- ☐ Gram-negative diplococci vs. gram-positive diplococci
- ☐ Difference between CJD and vCJD
- ☐ Global polio eradication
- ☐ Three types of botulism
- ☐ Differences and similarities between tetanus and botulism
- ☐ Organisms in this chapter for which there are vaccines available
- ☐ Organisms in this chapter that display significant antibiotic resistance

Terms

- ☐ Meninges
- ☐ Cerebrospinal fluid
- ☐ Blood-brain barrier
- ☐ Arbovirus
- ☐ Dead-end host
- ☐ Prion
- ☐ Progressive multifocal leukoencephalopathy
- ☐ Postinfection encephalitis
- ☐ Subacute sclerosing parencephalitis

Group Study Guide

The new feature “Study Smarter: Better Together” gives students a format for their self-guided group study. We know that group study can be immensely useful for learning—but only if it is well-structured. This feature, in every chapter, helps students make the best use of their study time with their classmates, either in person or virtually, with no effort on the part of the instructor!

Study Smarter: Better Together

These activities are designed for you to use on your own with a study group—either a face-to-face group or a virtual one, consisting of 3–5 members. Studying together can be very helpful, but there are good ways to do it and there are less good ways. For example, getting together without a clear structure is often not a good use of your time. Use your time efficiently by using one or more of the exercises below.

FACE-TO-FACE GROUPS

Use one or more of the activities below.

Peer Instruction: Assign numbers to your group members to use all semester long. Now look at these five concepts from this chapter. Each group member prepares a 5-minute lesson on the topic corresponding to his or her number. Don't worry if you have fewer than 5 members; just use however many you have! During your group study time, each member presents his or her lesson, and the group spends another 5–10 minutes discussing that lesson.

1. The spectrum of post-infection consequences (sequelae) from *Streptococcus pyogenes*
2. Defenses of the respiratory system
3. Community-acquired pneumonia vs. healthcare-associated pneumonia
4. Explain the “H” and “N” naming system of influenza viruses
5. Explain both antigenic-drift and antigenic-shift in influenza viruses

Concept Maps: Each member of the group should use this list of terms from this chapter to generate his or her own concept map. This can be hand-drawn or created using software (see Appendix C for guidelines). During group study time, compare each others' concept maps and help each other make sure they are correct. Of course, there are many different “correct” maps. Examining each member's map will help you talk through the varied concepts and how they are related.

Concept Terms:

Bordetella pertussis	pertussis toxin	FHA	cilia
mucus	tracheal cytotoxin	coughing	multiplication
endotoxin	secondary infection		

Table Topics: Each group member should identify a concept or topic from this week's class assignments with which he or she is having trouble, and take turns identifying it during group study time. The other group members can then help to clarify confusing issues or share how they figured it out. Aim for 15 minutes per topic max. If the topic remains unclear to the group, bring it up during class or use the instructor's office hours or e-mail to ask for help. Taking the time to struggle with it first makes your questions much more specific and more likely to yield helpful answers.

VIRTUAL GROUPS

Not everyone has the time or opportunity to meet with group members outside of class time. You or your instructor can create a virtual group using e-mail or the course software.

Weekly Discussion Board: Here is a question to be answered by each member of the group sometime before the topic is covered in class, sending your answer to every member of the group. It's best to agree on a deadline based on how your class schedule works (Saturday for the next week's topics, for example). Then, after the topic is discussed in class, each member should send a “Reply All”

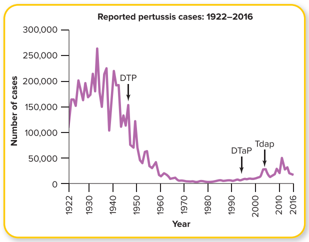
Visual Connections

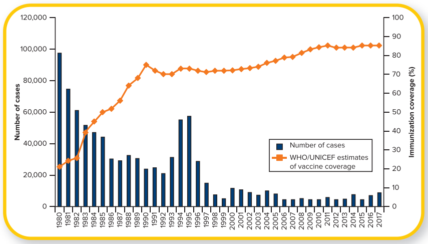
Visual Connections questions take images and concepts learned in previous chapters and ask students to apply that knowledge to concepts newly learned in the current chapter. This helps students evaluate information in new contexts and enhances learning.

Visual Connections

This question uses visual images to connect content within and between chapters.

1. **From this chapter, figure 21.7 and figure 21.9.** Which element in the (bottom or right) image represents the same kind of data as the purple line in the (top or left) graph?





Changes to the Sixth Edition

New to *Microbiology, A Systems Approach*

GLOBAL CHANGES THROUGHOUT THE SIXTH EDITION

- Many art pieces have been turned into infographics, a form of data visualization 21st-century learners are comfortable with.
- Language is simplified throughout the book. Sentences are shortened and general vocabulary is updated.
- Disease Tables now indicate the taxonomy of each microorganism.
- The end-of-chapter materials now include the SmartGrid—21 questions probing chapter content with respect to the ASM curriculum concepts *and* Bloom's taxonomy. Also, each chapter contains a simple guide for students to engage in face-to-face or virtual group study. This is called Study Smarter: Better Together.
- In all disease tables, each organism is denoted as "B, V, F, P, or H"—indicating bacterium, virus, etc. When bacterial, the table also indicates G+ or G-.

Major chapter updates or new material. Note: Each chapter contains between 400 and 700 edits, ranging from minor grammatical improvements to major insertions of content. Listed here are just the highlights.

Chapter 1: The Main Themes of Microbiology

- New infographics for better understanding of cell types
- More time on scientific methods
- Updates on evolutionary history of cell line
- Taxonomy and classification discussions clarified and simplified

Chapter 2: The Chemistry of Biology

- New elements named
- Case study on why saline might not be ideal for hydration (hint: it's the chloride!)

Chapter 3: Tools of the Laboratory

- In this chapter, there is typically a lot of terminology that is used to describe phenomena, yet the terms themselves are not defined (such as "what is growth?"); rewritten with an eye to what the students do not yet know
- New infographic to illustrate the "Five I's"

Chapter 4: Bacteria and Archaea

- New infographics that make different categories of bacteria more visual

Chapter 5: Eukaryotic Cells and Microorganisms

- Updated origins of eukaryotes narrative
- Highlighted increase in fungal opportunistic diseases
- Neglected parasitic infections (NPIs)

Chapter 6: Viruses and Prions

- Discussion of viruses in the microbiome
- New diseases caused by prions

Chapter 7: Microbial Nutrition, and Growth

- Improved the presentation of serial dilution
- Added origin of oxygen

Chapter 8: Microbial Metabolism

- Expands on electricity-eating bacteria

Chapter 9: Microbial Genetics

- Epigenetics and their connection with small RNAs

Chapter 10: Genetic Analysis and Genetic Engineering

- Pangenomes introduced
- CRISPR and gene drives updated

Chapter 11: Physical and Chemical Control of Microbes

- Added the banning by the FDA of triclosan and other chemicals in consumer products

Chapter 12: Antimicrobial Treatment

- The influence of antibiotics on the microbiome, throughout the lifespan
- New approaches to antimicrobials

Chapter 13: Microbe-Human Interactions: Health and Disease

- Added the need to negotiate the host microbiome as one of the steps required for microbes to cause disease
- Several new figures

Chapter 14: Host Defenses I: Overview and Nonspecific Defenses

- Changed overall organization to more logical sequence

Chapter 15: Host Defenses II: Specific Immunity and Immunization

- New infographic about the properties of specific immunity
- Information about vaccines for noninfectious conditions and CAR-T treatments

Chapter 16: Disorders in Immunity

- Updated discussion of causes of autoimmunity
- Several new infographics
- New information on asthma incidence

Chapter 17: Diagnosing Infections

- Point-of-care diagnostics
- More emphasis on genetic testing, qPCR, pan bacterial qPCR
- New infographics summarize the testing procedures for phenotypic, genotypic, and immunological methods in a visually consistent manner

Chapter 18: Infectious Diseases Affecting the Skin and Eyes

- Not new, but important: Retained and updated opening case study about measles transmission in an airport

Chapter 19: Infectious Diseases Affecting the Nervous System

- Zika virus disease added
- New prion described

Chapter 20: Infectious Diseases Affecting the Cardiovascular and Lymphatic Systems

- Updated the section on Rocky Mountain spotted fever to include all spotted fever rickettsias and noted their dramatic increase in the United States
- Discussion of CRISPR techniques for making mosquito populations sterile
- New figure detailing who gets AIDS in the United States

Chapter 21: Infectious Diseases Affecting the Respiratory System

- Updated differential diagnoses for pharyngitis and pneumonia

Chapter 22: Infectious Diseases Affecting the Gastrointestinal Tract

- Updated the *C. diff* genus to *Clostridioides*
- Updated foodborne disease trends

Chapter 23: Infectious Diseases Affecting the Genitourinary System

- More discussion of catheter-associated urinary tract infections
- Updated discussion on role of vaginal microbiome in high infant mortality rates
- Updated STI statistics

Chapter 24: Microbes and the Environment

- Increased emphasis on climate change

Chapter 25: Applied Microbiology and Food and Water Safety

- Clearer illustration of water purification

Acknowledgments

We are most grateful to our students who continually teach us how to more effectively communicate this subject. All the professors who reviewed manuscript or sent e-mails with feedback were our close allies as well, especially when they were liberal in their criticism. Jennifer Lusk contributed invaluable content to the text. Our minders at McGraw-Hill Education are paragons of patience and professionalism: Darlene Schueller is the best editor in the business, which makes it all the more surprising that she continues to work with us on book after book. Other members of our McGraw-Hill Education team upon whom we lean heavily are Lauren Vondra, Kristine Rellihan, Jim Connely, Jessica Portz, Beth Blech, Rachael Hillebrand, Lori Hancock, and Betsy Blumenthal.

—Kelly Cowan
—Heidi Smith

Review Process, Including Heat Maps

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

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

- If the data indicated that the subject covered was more difficult than other parts of the book, as evidenced by a high proportion of students responding incorrectly, we substantively revised or reorganized the content to be as clear and illustrative as possible.
- I (Kelly) have spent some time researching student literacy levels and have found that although most students understand that there is a great deal of technical language they must master for the first time, they can have trouble with the way we (professors, textbook authors) communicate in writing. So the heat maps also point me to places where I wrote a complex sentence when a simple one would do.

Table of Contents

CHAPTER 4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CHAPTER 5


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CHAPTER 6


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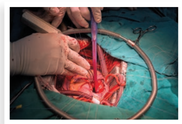
CHAPTER 7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CHAPTER 8


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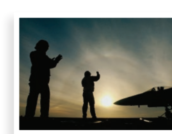
CHAPTER 9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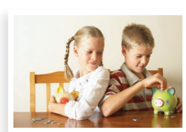
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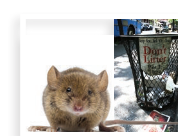
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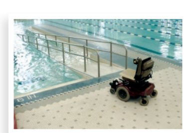
CHAPTER 16



Realistic Reflections

Disorders in Immunity 445

CHAPTER 17

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Diagnosing Infections 475

CHAPTER 18

C. Zachariasen/ PhotoAlto

CHAPTER 19

Arshad Butt/AP Photo

CHAPTER 20

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CHAPTER 21

Image Source

Image Source

1 The Main Themes of Microbiology

Media Under The Microscope

Filthy Coffee Machine?

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

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

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

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

Outline and Learning Outcomes

1.1 The Scope of Microbiology

1. List the six types of microorganisms we will be studying in this book.
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 two types of acellular microorganisms.
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), or **microbes.** 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 tend to emphasize the disagreeable reputation of microorganisms. But, as we will learn throughout the course of this book, only a small minority of microorganisms actually cause harm to other living beings.

Despite that statement, this book does focus on the microorganisms that cause human disease. They can be either cellular or noncellular. The cellular microorganisms we will study are **bacteria, fungi,** and **protozoa.** Another cellular organism that causes human infections is not technically a microorganism. **Helminths** are multicellular animals whose mature form is visible to the naked eye. Acellular microorganisms causing human disease are the **viruses** and **prions. Table 1.1** gives you a first glimpse at these microorganisms. You will see in table 1.1 that the bacterium is paired with something called "archaeon". We will say more later, but for now just know that archaea are single-celled microorganisms as well. So far no clear evidence links them to human disease, so they will receive less emphasis in this book. There is a Note on page 5 that says more about 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.

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

Studies in microbiology have led to greater understanding of many general biological principles. For example, the study of microorganisms established universal concepts concerning the chemistry of life; systems of inheritance; and the global cycles of nutrients, minerals, and gases. Some descriptions of different branches of study appear in **table 1.2.**

1.1 Learning Outcomes—Assess Your Progress

1. List the six types of microorganisms we will be studying in this book.
2. Identify multiple professions using microbiology.

Table 1.1 **The Types of Microorganisms We Will Study in This Book**

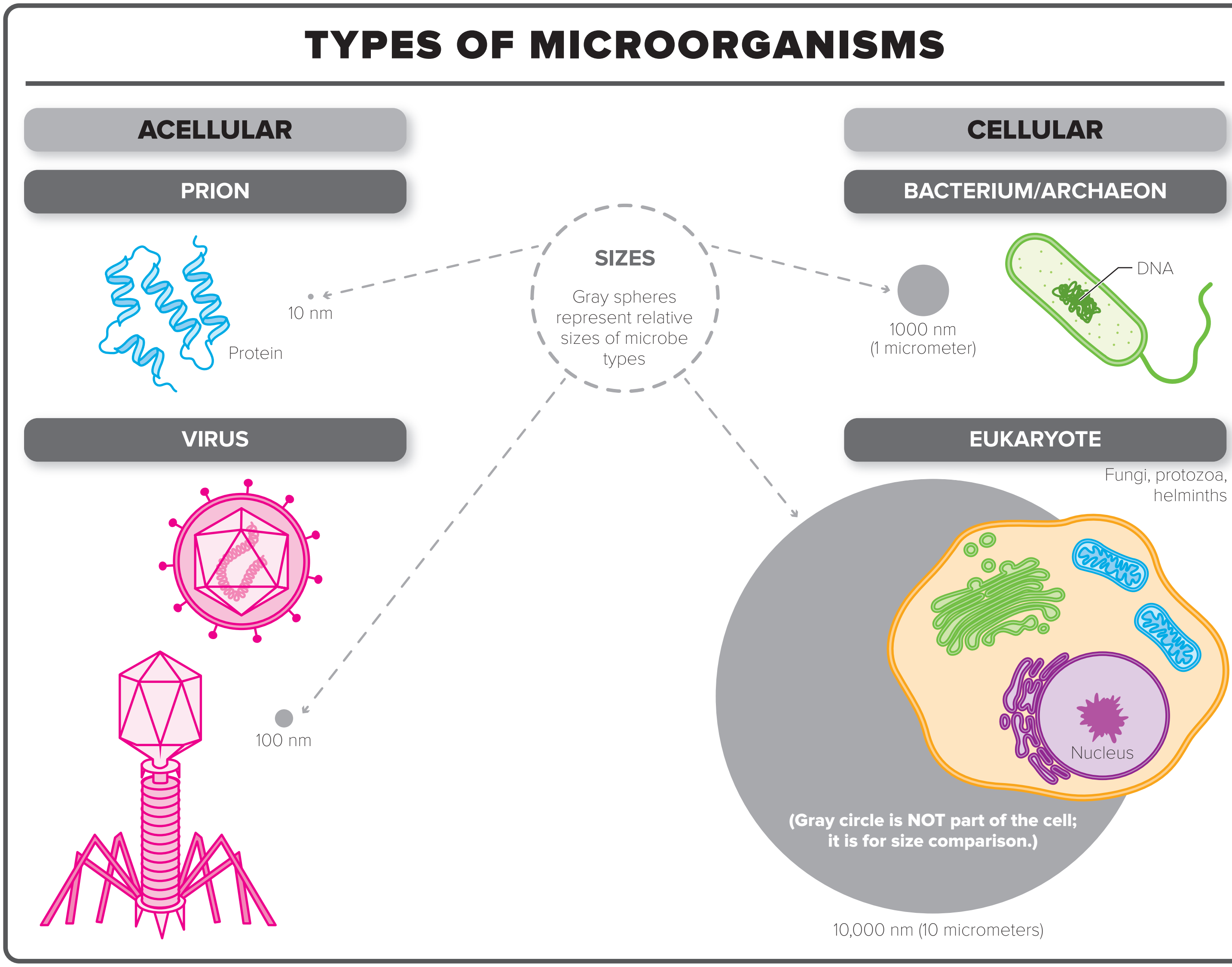


Table 1.2 **Microbiology—A Sampler**

A. Medical Microbiology This branch deals with microbes that cause diseases in humans and animals. Researchers examine factors that make the microbes cause disease 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. *Source: James Gathany/Centers for Disease Control*
B. Public Health Microbiology and Epidemiology These branches monitor and control health and the spread of diseases in communities. Institutions involved in this work are the U.S. Public Health Service (USPHS) with its main agency, the Centers for Disease Control and Prevention (CDC) located in Atlanta, Georgia, and the World Health Organization (WHO), the medical limb of the United Nations.		**Figure B.** Two epidemiologists conducting interviews as part of the effort to curb the cholera epidemic in Haiti. Photograph taken in 2013. *Source: Preetha Iyengar, M.D./CDC*

(continued)

Table 1.2 Microbiology—A Sampler (*continued*)

C. Immunology This branch studies the complex web of protective substances and cells produced in response to infection. It includes such diverse areas as vaccination, blood testing, and allergy. Immunologists also investigate the role of the immune system in cancer and autoimmune diseases.		**Figure C.** An immunologist and students prepare samples. *Ariel Skelley/Blend Images LLC*
D. Industrial Microbiology This branch safeguards our food and water, and also includes biotechnology, the use of microbial metabolism to arrive at a desired product, ranging from bread making to gene therapy. Microbes can be used to create large quantities of substances such as amino acids, beer, drugs, enzymes, and vitamins.		**Figure D.** Scientists use a multispectral imaging system for inspection of chickens. *Source: Stephen R Ausmus/U.S. Department of Agriculture-ARS*
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. *Source:Scott Bauer/ USDA*
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. *Photodiem/Shutterstock*

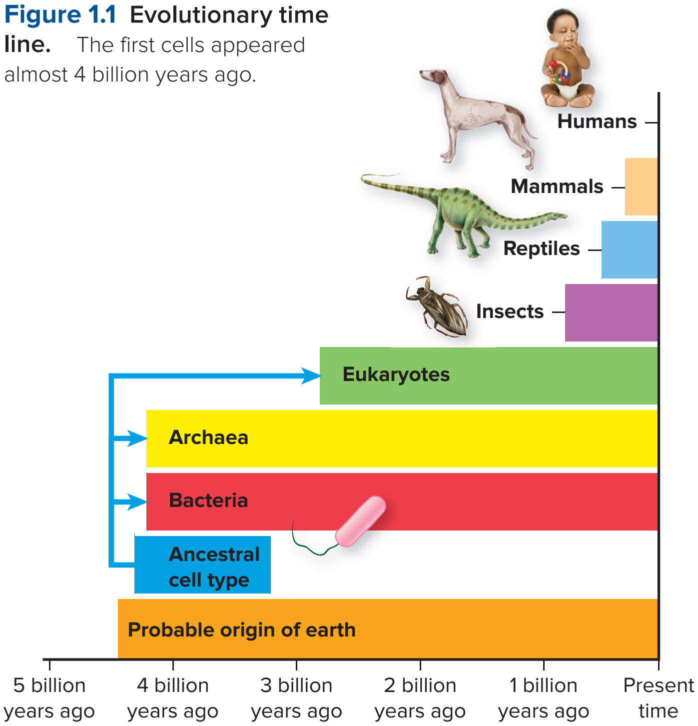
1.2 The Impact of Microbes on Earth: Small Organisms with a Giant Effect

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.

Scientists are constantly discovering new clues to how life formed on our planet. The current view is illustrated in **figure 1.1.** It is believed that soon after the earth was formed, the first ancient cells formed. From these cells two types of single-celled organisms that are still with us today developed, the **bacteria** and the **archaea.** Those were the only types of cells on the planet for more than a billion years, at which time a much more complex cell appeared, called **eukaryotes.** Eukary means *true nucleus* because these were the only cells containing a nucleus. Bacteria and archaea have no true nucleus. For that reason, some scientists have started calling them **akaryotes,** meaning "no nucleus."

On the scale pictured in figure 1.1, humans seem to have just appeared compared to the existence of all life. Bacteria arose before even the earliest animals by billions of years. This is a good indication that humans are not likely to—nor should we try to—eliminate

Figure 1.1 Evolutionary time line. The first cells appeared almost 4 billion years ago.



A Note About Bacteria and Archaea

We've just learned that there are three cell types: eukaryotes, bacteria, and archaea. In this book, we are going to focus on bacteria and the eukaryotes because as far as we know these groups are responsible for the majority of human disease. We will address archaea in various sections of the book where the distinction is useful, but mainly we will refer to bacteria, even when the description might also refer to archaea. It just might get confusing if we continue to say "bacteria and archaea" when the information you need is about bacteria.

bacteria from our environment. They've survived and adapted to many catastrophic changes over the course of their geologic history.

Another indication of the huge influence bacteria exert is how **ubiquitous** they are. That means that 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 being present in large numbers and living in places where many other organisms cannot survive. Above all, they play central roles that are essential to life in the earth's landscape.

When we point out that single-celled organisms have adapted to a wide range of conditions over the billions of 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. In the time 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 soon after the planet itself was formed.

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

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 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, bacteria were responsible for changing the atmosphere of the earth from one without oxygen to one with oxygen. The production of oxygen also led to the use of oxygen for aerobic respiration and the formation of ozone, both of which set off an explosion in species diversification. Today, photosynthetic microorganisms (bacteria and algae) account for more than 70% of the earth's photosynthesis, contributing the majority of the oxygen to the atmosphere **(figure 1.2*a*).**

Another process that helps keep the earth in balance is the process of biological **decomposition** and nutrient recycling. Decomposition involves the breakdown of dead matter and wastes into simple compounds that can be directed back into the natural cycles of living things **(figure 1.2*b*).** When death occurs, the body immediately begins to decompose. Bacteria play a major role in decomposition of the body. The action of bacteria causes the conversion of soft tissues within the body to liquids and gases. The chemicals released as a result of decomposition, including hydrogen sulfide, are responsible for the pungent smell of death. If it were not for multitudes of bacteria and fungi, many chemical elements would become locked up

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

(a) (b)

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

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

and unavailable to organisms; we humans would drown in our own industrial and personal wastes! In the long-term scheme of things, microorganisms are the main forces that drive the structure and content of the soil, water, and atmosphere. For example:

- The very temperature of the earth is regulated by gases, such as carbon dioxide, nitrous oxide, and methane, which create an insulation layer in the atmosphere and help retain heat. Many of these gases are produced by microbes living in the environment and in the digestive tracts of animals.
- Recent studies have found that large numbers of organisms exist within and beneath the earth's crust in sediments, rocks, and even volcanoes. It is increasingly evident that this enormous underground community of microbes is a significant influence on weathering, mineral extraction, and soil formation.
- Bacteria and fungi live in complex associations with plants and assist the plants in obtaining nutrients and water and may protect them against disease. Microbes form similar interrelationships with animals. For example, a rich assortment of bacteria in the stomach of cattle digests the complex carbohydrates of the animals' diets and causes 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.

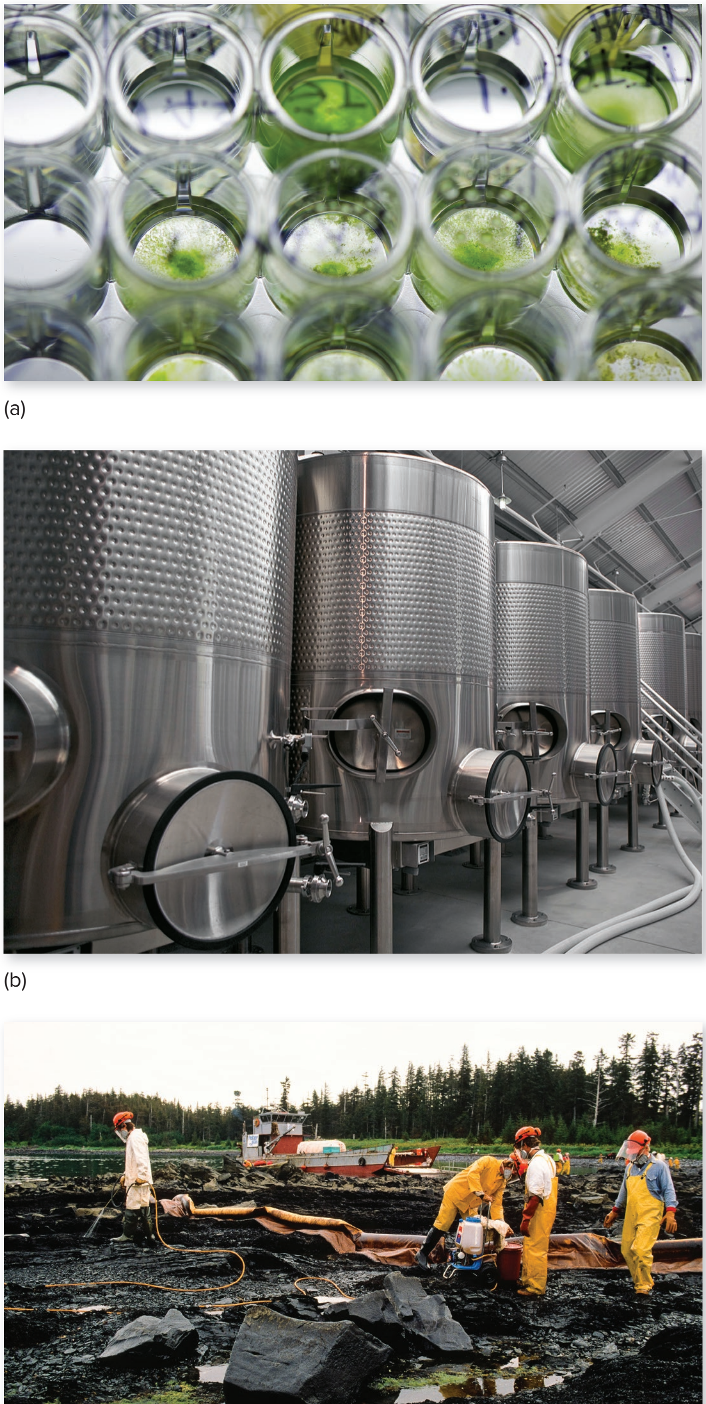
1.3 Human Use of Microorganisms

The diversity and versatility of microorganisms 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 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. 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. This was long before penicillin was discovered in a mold called *Penicillium*. When humans figure something out through experience, rather than through research or being taught it, it is called an **empirical** finding. Empirical discoveries have shaped the development of humans through our whole history. When humans purposely manipulate microorganisms to make products in an industrial setting, it is called biotechnology. For example, some specialized bacteria have unique capacities to mine precious metals or to create energy **(figure 1.3).**

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

Among the genetically unique organisms that have been designed by bioengineers are bacteria that mass produce

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)** Test tubes of yellow and green algae being grown as a possible energy source. **(b)** Microbes as synthesizers—fermenting tanks at a winery. **(c)** Workers spray nutrients on the shore of Prince William Sound in Alaska after the *Exxon Valdez* oil tanker spill (1989) in an attempt to enrich oil-degrading microbes.

(a) Source: Dennis Schroeder/NREL/US Department of Energy; (b) Bloomberg via Getty Images; (c) Accent Alaska.com/Alamy

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.

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

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

1.3 Learning Outcome—Assess Your Progress

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

1.4 Infectious Diseases and the Human Condition

One of the most fascinating aspects of the microorganisms with which we share the earth is that, despite all of the benefits they provide, they also contribute significantly to human misery as **pathogens** (path′-oh-jenz). Please understand: The vast majority of microorganisms that associate with humans cause no harm. In fact, they provide many benefits to their human hosts. It is also important to note that a diverse microbial biota living in and on humans is an important part of human well-being. It is estimated that there are more than 2,000 different microbes that can cause various types of disease. Infectious diseases still devastate human populations worldwide, despite significant strides in understanding and treating them. The World Health Organization (WHO) estimates there are a total of 10 billion new infections across the world every year. **Table 1.3** depicts the 10 top causes of death per year (by all causes, infectious and noninfectious) in the United States and also worldwide. The worldwide death toll from infections is about 13 million people per year. For example, the World Health Organization reports that every 30 seconds a child in Africa 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.

Table 1.3 **Top Causes of Death—All Diseases**

United States	No. of Deaths	Worldwide	No. of Deaths
1. Heart disease	633,842	1. Heart disease	8.7 million
2. Cancer	595,930	2. Stroke	6.2 million
3. Chronic lower respiratory diseases	146,571	3. Lower-respiratory infections (influenza and pneumonia)*	3.2 million
4. Accidents (unintentional injuries)	146,571	4. Chronic obstructive pulmonary disease	3.2 million
5. Stroke (cerebrovascular diseases)	140,323	5. Trachea, bronchus, lung cancers	1.7 million
6. Alzheimer's disease	110,561	6. Diabetes	1.5 million
7. Diabetes	79,535	7. Alzheimer's disease	1.5 million
8. Influenza and pneumonia	57,062	8. Diarrheal diseases	1.4 million
9. Nephritis, nephrotic syndrome, and nephrosis	49,959	9. Tuberculosis	1.3 million
10. Intentional self-harm (suicide)	44,193	10. Road injury	1.3 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. CDC data published in 2016 for year 2015. WHO data published in 2017 representing final figures for the year 2015.

We just used the terms "infectious" and "noninfectious." We'll explore these terms in more detail later. Generally they refer to diseases caused by microbes (infectious) and diseases not caused by microbes (noninfectious). Note that while all microbial diseases are infectious diseases, they are not all communicable (transmitted from person to person) (**table 1.4**).

In **table 1.5** you see that diseases *not* caused by microbes (known as noncommunicable diseases) are much more frequent in both the United States and the world. You will also note that the United States experiences relatively few—*relatively* few—infectious diseases compared to the number of non-infectious diseases.

Malaria, which kills about 450,000 every year worldwide, is caused by a microorganism transmitted by mosquitoes. 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 $10, is too expensive for them.

We are also witnessing an increase in the number of new (emerging) and older (reemerging) diseases. Ebola, AIDS,

Table 1.4 **Terminology**

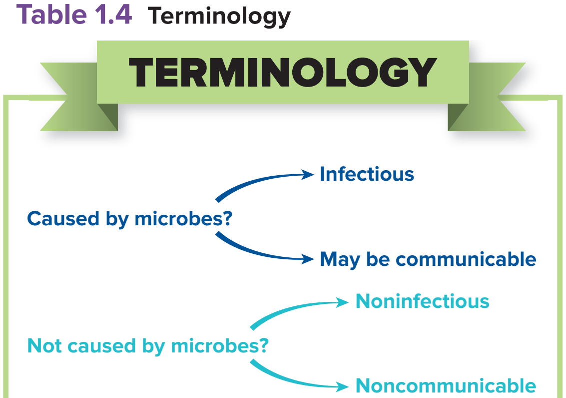
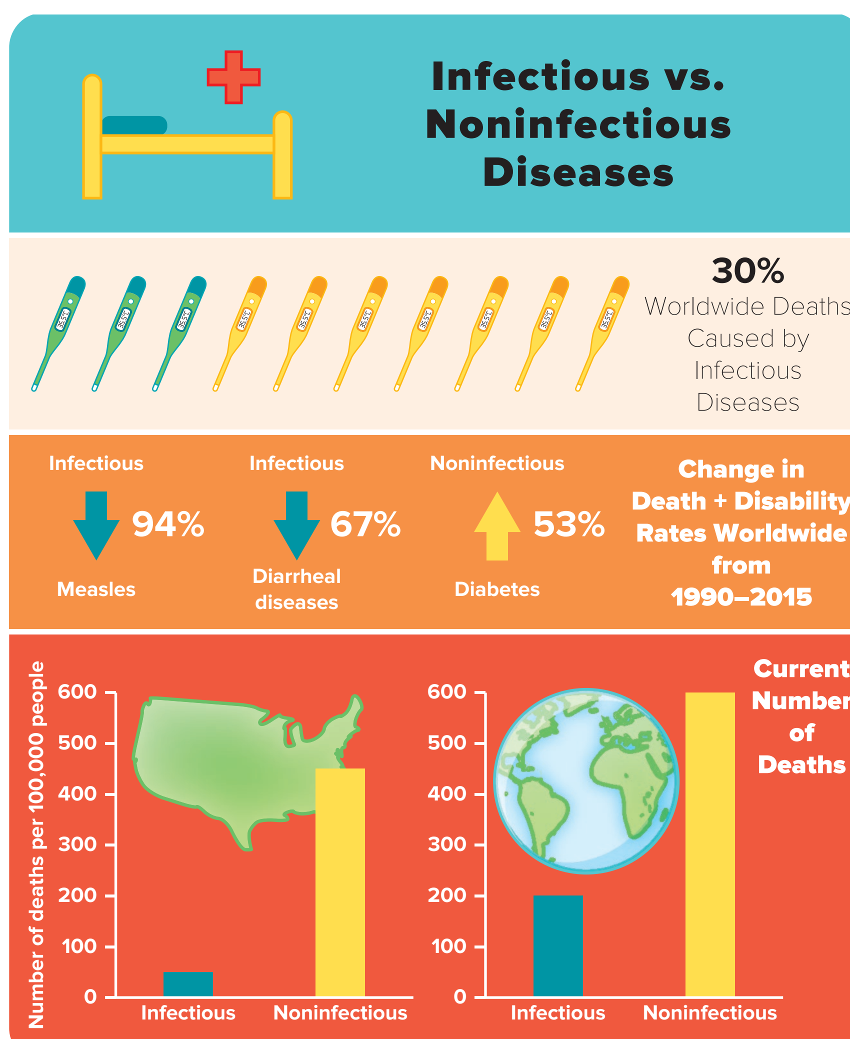


Table 1.5 **Communicable vs. Noncommunicable Diseases**



Source: Data from the World Health Organization for 2012, and from the Institute for Health Metrics and Evaluation, http://www.healthdata.org/ 2018.

INSIGHT 1.1 CLINICAL: Infections of the Heroin Epidemic

This book focuses on the microorganisms that cause disease. But we want to take a moment to emphasize that microorganisms that do NOT cause disease are far more common. "Good" microbes are absolutely critical for the health of humans, animals, plants, and the whole ecosystem on earth. Chapter 24 contains lots of information about the role of microbes in the natural world. Also, each chapter in the book contains a box describing some aspect of the natural microbial inhabitants of our body, known as the human microbiome.

These boxes that we are calling "Insights: Clinical" will contain a short story about some aspect of disease or treatment that is related to microbes. We will start with a look at a serious and widespread problem in the United States: the epidemic of injected drugs. Of course, it is the overdoses that get the most attention, but injecting drug users also constitute from 25–50% of the patient load for infectious disease physicians in hospitals. Many users use dirty needles and end up injecting a variety of microbes directly into their bloodstream, which is the superhighway to the whole body.

The Infectious Disease Society of America identifies the following diseases as the largest problems resulting in hospitalizations and deaths among injecting drug users (IDUs):

- **Infective endocarditis** One study showed that between 2010 and 2015, the hospital admissions rate for this bacterial infection of one or more heart valves increased twelvefold. Often heart valve surgery is required, and the rate of repeat infections and repeat surgeries is very high when a person continues to inject drugs after discharge. As one physician put it: "We release them after surgery with a peripheral catheter ('PICC line') so they can receive intravenous antibiotics. These require meticulous cleaning to prevent infection. This is difficult to achieve with IDUs. Sometimes they even inject their drugs directly into their PICC. They turn right around with a new endocarditis and end up in surgery again. And the cycle continues."
- **Hepatitis C** This is a form of hepatitis that is easily spread through blood-to-blood contact. IDUs who share needles are at very high risk for contracting this disease. While there is now a treatment for hepatitis C, many IDUs do not qualify for it due to their ongoing addictions. **Hepatitis B** is also commonly transmitted between IDUs.
- **HIV** For many years the rates of HIV infection had been falling among IDUs, until the current heroin epidemic. Now the rates are increasing in areas where the drug epidemic is worst. While HIV is now a manageable disease, the treatment requires strict adherence, which is not easy to achieve with many IDUs.
- **Skin, joint, and bone infections** Osteomyelitis (bone infection), flesh-eating skin infections, and MRSA (methicillin-resistant *Staphylococcus aureus*) infections are common among IDUs. These almost always require prolonged treatment, leading to the issues noted above for patients who have peripheral catheters inserted.

Reed Kaestner/Getty Images

hepatitis C, and viral encephalitis are examples of diseases that cause severe mortality and morbidity. To somewhat balance this trend, there have also been some advances in eradication of diseases such as polio and leprosy and diseases caused by certain parasitic worms.

One of the most eye-opening discoveries in recent years is that many diseases that were not previously thought to be caused by microorganisms 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 various bacteria and viruses, between diabetes and the coxsackievirus, and between schizophrenia and the coxsackievirus. Diseases as different as multiple sclerosis, obsessive compulsive disorder, coronary artery disease, and even obesity have been linked to chronic infections with microbes. 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, often caused by *Chlamydia* infection, and malignancies such as liver cancer (hepatitis viruses) and cervical cancer (human papillomavirus). Researchers are currently researching whether Alzheimer's disease is related to microbes found in the brains of people with the disease.

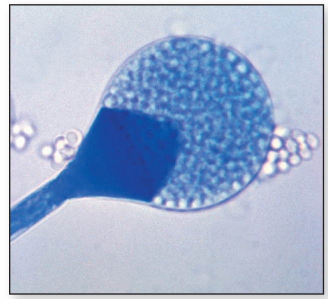
Another important development in infectious disease trends is the increasing number of patients with weakened defenses that are kept alive for extended periods. They are subject to infections by common microbes that are not pathogenic to healthy people. There is also an increase in microbes that are resistant to drugs.

In **Insight 1.1** you will see one of the most recent concerns to scientists and doctors who focus on infectious diseases.

1.4 Learning Outcome—Assess Your Progress

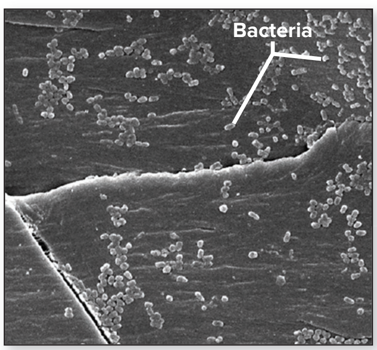
6. Summarize the relative burden of human disease caused by microbes, emphasizing the differences between developed countries and developing countries.

Helminth: Head (scolex) of *Taenia solium*

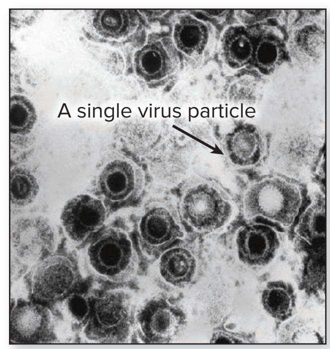


Fungus: *Mucor*

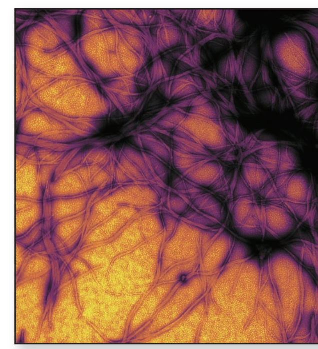
Protozoan: *Vorticella*



Bacterium: *E. coli*



Virus: Herpes simplex



Prion

Figure 1.4 Six types of microorganisms. The photographs are taken at different magnifications to help you see detailed structures, but remember that there are vast size differences among the organisms. The helminths can be visible to the naked eye, while prions, tens of thousands of times smaller, can only be seen with very specialized microscopes.

(top left) Source: Centers for Disease Control and Prevention; (top middle) Source: /Dr. Lucille K. Georg/Centers for Disease Control and Prevention; (top right) Source: Nancy Nehring/E+/Getty Images; (bottom left) Source: Janice Haney Carr/CDC; (bottom center) Source: Dr. Erskine Palmer/CDC; (bottom right) Cultura/Shutterstock

1.5 The General Characteristics of Microorganisms

Cellular Organization

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

A Note About Viruses and Prions

As mentioned before, **viruses** are not independently living, cellular organisms. Instead, they are small particles that exist at the level of complexity somewhere between large molecules and cells. 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.**

Prions are highly unusual "organisms." They contain no DNA or RNA; thus, they have no genetic program. They are small proteins folded in intricate ways. Sometimes these prions behave like microorganisms and are transmitted from one human to another.

To make a broad generalization, bacterial and archaeal cells are about 10 times smaller than eukaryotic cells. They generally do not have many of the eukaryotic cell structures such as **organelles.** Organelles are small, double-membrane-bound structures in the eukaryotic cell that perform specific functions. The nucleus, mitochondria, and chloroplasts are organelles. All bacteria and archaea are microorganisms, but only some eukaryotes are microorganisms. Humans, after all, are eukaryotic organisms. The majority of microorganisms are single-celled (all bacteria and archaea and some eukaryotes), but some are multicellular **(figure 1.4).**

1.5 Learning Outcomes—Assess Your Progress

7. Differentiate among bacteria, archaea, and eukaryotic microorganisms.
8. Identify two types of acellular microorganisms.
9. Compare and contrast the relative sizes of the different microbes.

1.6 The Historical Foundations of Microbiology

If not for the extensive interest, curiosity, and devotion of thousands of microbiologists over the last 350 years, we would know little about the microscopic realm that surrounds us. Many of the discoveries in this science have resulted from the prior work of men and women who toiled long hours in dimly lit laboratories with the crudest of tools. Each additional insight, whether large or small, has added to our current knowledge of living things and processes. This section summarizes the prominent discoveries made in the past 350 years: microscopy; the rise of the scientific method; and the development of medical microbiology, including the germ theory and the origins of modern microbiology techniques.

The Development of the Microscope: "Seeing Is Believing"

From very earliest history, humans noticed that when certain foods spoiled, they became inedible or caused illness, and yet other "spoiled" foods did no harm and even had enhanced flavor. Indeed, several centuries ago, there was already a sense that diseases such as the black plague and smallpox were caused by some sort of transmissible matter. But the causes of such phenomena were vague and obscure because the technology to study them was lacking. So scientists were left to speculate. One great example of a misguided understanding is a phenomenon called spontaneous generation. This incorrect concept was finally proven wrong in spectacular fashion by a very clever experiment by Louis Pasteur in the mid-1800s.

Disproving Spontaneous Generation

It is hard for us to imagine today, but for thousands of years, people thought that diseases were a curse from God or were caused by damp fogs. One very widely held belief was that plants, animals, and even people came from an invisible life-giving force. This was formally known as **abiogenesis** (a = without, bio = life, genesis = beginning), literally, "beginning in the absence of life." It was also called **spontaneous generation,** or being generated from thin air.

In 1745 a scientist named John Needham came close to disproving spontaneous generation, but his experimental design had one fatal flaw. He believed that boiling liquid broth would kill all organisms in it, so he boiled it, then immediately sealed the flasks. But the liquid became cloudy, indicating microbial growth. What nobody knew at the time was that some bacteria form endospores, extremely hardy structures that are not killed by boiling. The boiled liquid held viable endospores in it, though the experiment was interpreted to mean that life could indeed come from "the air." Another scientist, thinking that Needham's flasks must have been contaminated between boiling and sealing, boiled the liquid inside a sealed flask. It was true that no growth occurred, but abiogenesis proponents countered that the "life force" couldn't get in a sealed flask and that this experiment actually supported their view.

In 1859 French scientist Louis Pasteur, with a combination of skill and luck, seems to have put the belief in spontaneous generation to rest. He had to keep his flasks open to the air so that if there was a "life force" in it, it could access the boiled liquid. He designed a long, bent "swan neck" for his flasks, which meant that any microbes that fell (by gravity) into the flask would settle into the crook at the bottom of the flask neck and not make it into the broth (**figure 1.5**) . In this way, he could allow the flask to remain open to the air. The results: As long as the neck of the flask was intact, no microbes grew. If the neck of the flask was broken off, so that only the straight vertical part was intact, microbes from the air fell in and the broth became cloudy. Pasteur had the immense luck that there were no endospore-forming bacteria in his broth. If there had been, even his swan-necked flask could have become cloudy. Because it did not, the idea of spontaneous generation was finally abandoned. Pasteur was lucky, indeed. A quote attributed to him seems especially relevant to this situation: *Chance favors the prepared mind.*

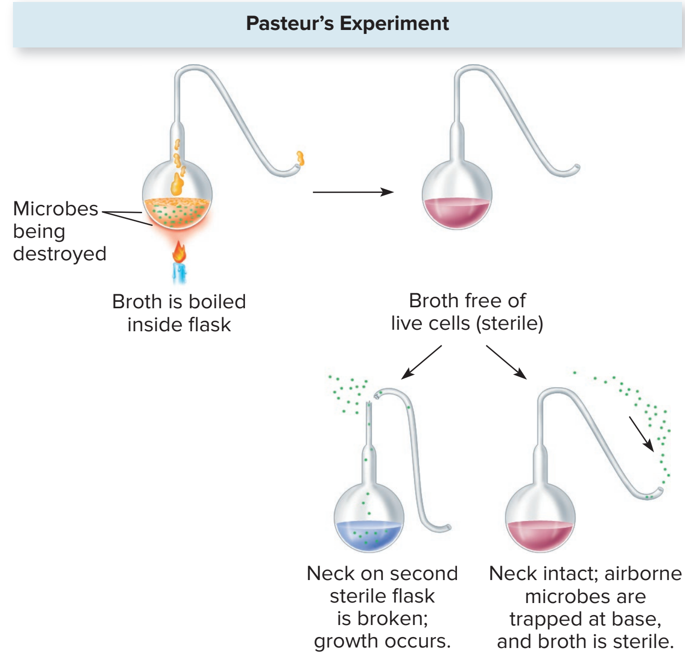


Figure 1.5 Pasteur's experiment disproving spontaneous generation.

True awareness of the widespread distribution of microorganisms and some of their characteristics was finally made possible by the development of the first microscopes. These devices revealed microbes as discrete entities sharing many of the cellular characteristics of larger, visible plants and animals. Several early scientists fashioned magnifying lenses, but their microscopes lacked the optical clarity needed for examining bacteria and other small, single-celled organisms. The likely earliest record of microbes is in the works of Englishman Robert Hooke. In the 1660s, Hooke studied various everyday things like household objects, plants, and trees. He described for the first time cellular structures in tree bark and drew sketches of "little structures" that seemed to be alive. Using a single-lens microscope he made himself, Hooke described spots of mold he found on the sheepskin cover of a book:

> These spots appear'd, through a good Microscope, to be a very pretty shap'd vagetative body, which, from almost the same part of the Leather, shot out multitudes of small long cylindrical and transparent stalks, not exactly straight, but a little bended with the weight of a round and white knob that grew on the top of each of them. . . .

Figure 1.6*a* is a reproduction of the drawing he made to accompany his written observations. Hooke paved the way for even more exacting observations of microbes by Antonie van Leeuwenhoek (pronounced "Lay′-oow-un-hook"), a Dutch linen merchant and self-made microbiologist.

Imagine a dusty linen shop in Holland in the late 1600s. Ladies in traditional Dutch garb came in and out, choosing among the bolts of

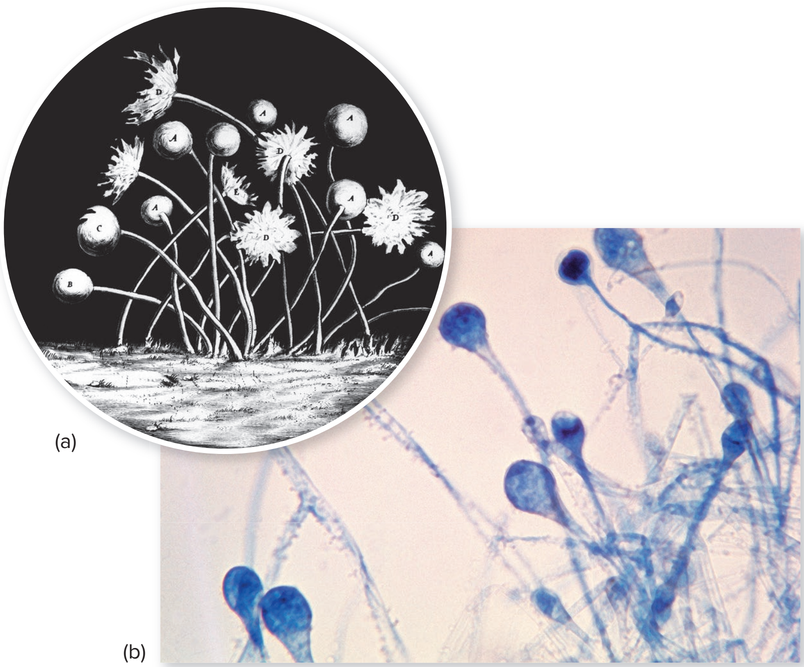


Figure 1.6 The first drawing of microorganisms.
(a) Drawing of "hairy mould" colony made by Robert Hooke in 1665.
(b) Photomicrograph of the fungus probably depicted by Hooke. It is a species of *Mucor,* a common indoor mold.
(a) Biophoto Associates/Science Source; (b) BSIP/UIG/Getty Images

linens for their draperies and upholstery. Between customers, Leeuwenhoek retired to the workbench in the back of his shop, grinding glass lenses to ever-finer specifications so he could see with increasing clarity the threads in his fabrics. Eventually, he became interested in things other than thread counts. He took rainwater from a clay pot, smeared it on his specimen holder, and peered at it through his finest lens. He found "animals appearing to me ten thousand times less than those which may be perceived in the water with the naked eye."

He didn't stop there. He scraped the plaque from his teeth, and from the teeth of some volunteers who had never cleaned their teeth in their lives, and took a good, close look at that. He recorded: "In the said matter there were many very little living animalcules, very prettily a-moving. . . . Moreover, the other animalcules were in such enormous numbers, that all the water . . . seemed to be alive." Leeuwenhoek started sending his observations to the Royal Society of London, and eventually he was recognized as a scientist of great merit.

Leeuwenhoek constructed dozens of small, powerful microscopes that could magnify up to 300 times **(figure 1.7).** Considering that he had no formal training in science, his descriptions of bacteria and protozoa (which he called "animalcules") were astute and precise. Because of Leeuwenhoek's extraordinary contributions to microbiology, he is known as the father of bacteriology and protozoology (the study of protozoa).

From the time of Hooke and Leeuwenhoek, microscopes became more complex and improved with the addition of refined lenses, a condenser, finer focusing devices, and built-in light sources. The prototype of the modern compound microscope, in use from about the mid-1800s, was capable of magnifications of 1,000 times or more. Our modern student microscopes are not greatly different in basic structure and function from those microscopes. The technical characteristics of microscopes and microscopy are a major focus of chapter 3.

These events marked the beginning of our understanding of microbes and the diseases they can cause. Discoveries continue at a breakneck pace, however. In fact, the 2000s are being widely called the Century of Biology, fueled by our new abilities to study genomes and harness biological processes. Microbes have led the way in these discoveries and continue to play a large role in the new research.

Of course, between the "Golden Age of Microbiology" and the "Century of Biology," there have been thousands of important discoveries. But to give you a feel for what has happened most recently, **table 1.6** contains some recent discoveries that have had huge impacts on our understanding of microbiology.

These examples highlight a feature of biology—and all of science—that is perhaps underappreciated. Because we have thick textbooks containing all kinds of assertions and "facts," many people think science is an iron-clad collection of facts. Wrong! Science is an ever-evolving collection of new information, gleaned

Disease Connection

The teeth are a perfect surface for accumulating a large assortment of bacteria. The clean tooth surface (immediately after a visit to the dental hygienist, for instance) immediately begins accumulating proteins from the saliva. This coated surface is then colonized by streptococcal bacteria, which are then colonized by other species of bacteria, which are then colonized by more bacteria, and so on. This creates a thick community of bacteria that eventually becomes visible as plaque—especially if you never brush your teeth, as with Leeuwenhoek's subjects. This plaque can lead to cavities (known as *caries*) or gum disease.

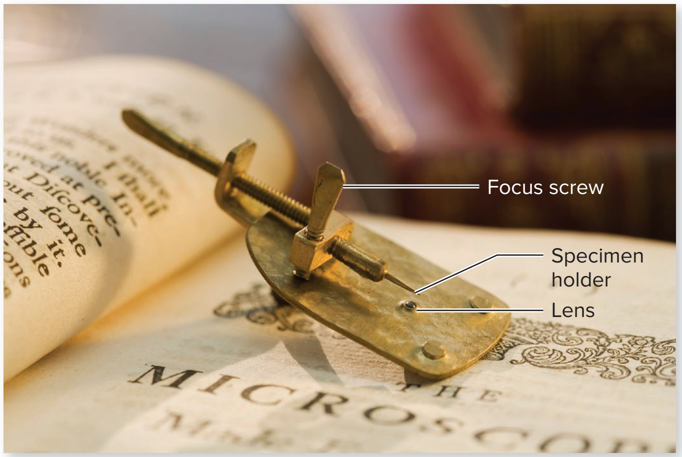
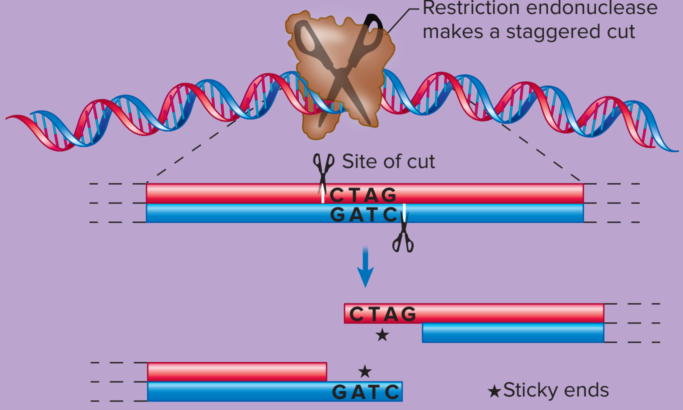


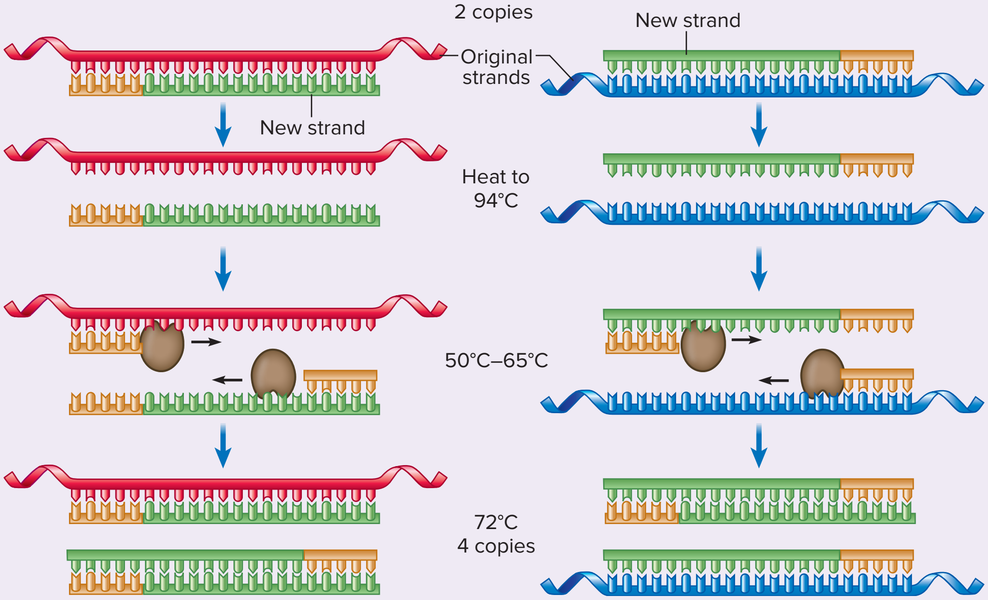
Figure 1.7 Leeuwenhoek's microscope. A brass replica of a Leeuwenhoek microscope. The lens is held in front of one eye with the specimen holder facing outward.
Tetra Images/Alamy Stock Photo

Table 1.6 Recent Advances in Microbiology

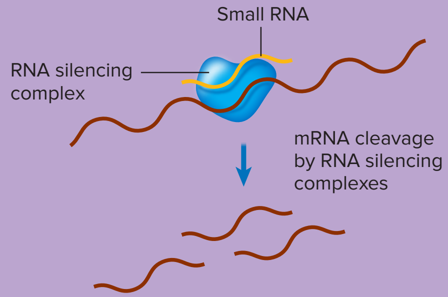
Discovery of restriction enzymes—1970s. Three scientists, Daniel Nathans, Werner Arber, and Hamilton Smith, discovered these little molecular "scissors" inside bacteria. They chop up DNA in specific ways. This was a huge moment that led to the ability of scientists to use these enzymes to cut DNA in tailor-made ways. This opened the floodgates to genetic engineering—and all that has meant for the treatment of diseases, the investigation into biological processes, and the biological "revolution" of the 21st century.



The invention of the PCR technique—1980s. The polymerase chain reaction (PCR) was a breakthrough in our ability to detect tiny amounts of DNA and then amplify them into quantities sufficient for studying. It has provided a new and powerful method for discovering new organisms, diagnosing infectious diseases, and doing forensic work such as crime scene investigation. Its inventor is Kary Mullis, a scientist working at a company in California at the time. He won the Nobel Prize for this invention in 1993.



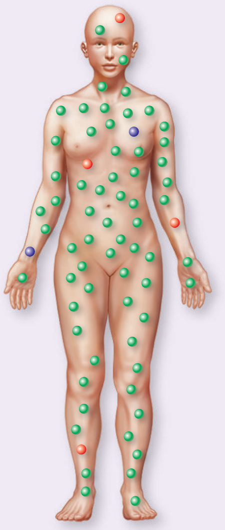
The importance of small RNAs—2000s. Once we were able to sequence entire genomes (another big move forward), scientists discovered something that turned a concept we literally used to call "dogma" on its head. The previously held "Central Dogma of Biology" was that DNA makes RNA, which leads to the creation of proteins. Genome sequencing has revealed that perhaps only 2% of DNA actually codes for a protein. Much RNA doesn't end up with a protein counterpart. These pieces of RNA are usually small. It now appears that they have critical roles in regulating what happens in the cell. It has led to new approaches to how diseases are treated. For example, if the small RNAs are important in bacteria that infect humans, they can be new targets for antimicrobial therapy.



(continued)

Table 1.6 Recent Advances in Microbiology (*continued*)

Genetic identification of the human microbiome—2010s and beyond. The first detailed information produced by the Human Microbiome Project (HMP) was astounding: Even though the exact types of microbes found in and on different people are highly diverse, the overall set of metabolic capabilities the bacterial communities possess is remarkably similar among people. This and other groundbreaking discoveries have set the stage for new knowledge of our microbial guests and their role in our overall health and disease. See Insight 1.2.



INSIGHT 1.2 MICROBIOME: What Is a Microbiome?

In the past few years, a new word has popped up on newsfeeds and sites: microbiome. It refers to the sum total of all the microbes in a certain environment. Unless something goes wrong, they do not cause disease, and, in fact, are necessary parts of human development and ongoing life.

The Human Microbiome Project (HMP) began producing significant results in 2012. It used techniques to identify body microbes that did not require growing the microbes separately in the lab (a technique scientists have relied on since the mid-1800s), but instead identified them on the basis of their genetic material. The HMP produced a staggering array of results, and they keep coming at breakneck pace.

We have learned that the microbiome differs based on whether you were delivered via cesarian or vaginal birth. We have learned that the gut microbiome—the microbes living in your intestinal tract—influences not just your intestinal health but also your likelihood of experiencing autoimmune disease, your weight, and even your mood! We know how the composition of the microbiome of different body systems (your skin, your eyes, your lungs) differs in health and in disease. We have learned that the microbiome *in utero* influences your embryonic development.

In short, we have learned that the characteristics of your microbiome determine your own, human, biology—and what types of experiences you will have as an organism. In every chapter of this book, we will tell a short story in an Insight box about the microbiome as it relates to the subject matter in the chapter.

from observable phenomena and synthesized with old information to come up with the current understandings of nature. Some of these observations have been confirmed so many times over such a long period of time that they are, if not "fact," very close to fact. Many other observations will be altered over and over again as new findings emerge. And that is the beauty of science.

The Establishment of the Scientific Method

A serious impediment to the development of true scientific reasoning and testing was the tendency of early scientists to explain natural phenomena by a mixture of belief, superstition, and argument. The development of an experimental system that answered questions objectively and was not based on prejudice marked the beginning of true scientific thinking. These ideas gradually crept into the consciousness of the scientific community during the 1600s. The general approach taken by scientists to explain a certain natural phenomenon is called the **scientific method.** A primary aim of this method is to formulate a **hypothesis,** a tentative explanation to account for what has been observed or measured. A good hypothesis should be in the form of a statement. It must be capable of being either supported or discredited by careful observation or experimentation. For example, the statement that "microorganisms cause diseases" can be experimentally determined by the tools of science, but the statement "diseases are caused by evil spirits" cannot. The scientific method is illustrated in **figure 1.8.**

Deductive and Inductive Reasoning

Science is a process of investigation using observation, experimentation, and reasoning. In some investigations, you make individual decisions by using broadly accepted general principles as a guide. This is called deductive reasoning. Deductive reasoning is the reasoning of mathematics, philosophy, politics, and ethics; deductive reasoning is also the way a computer works. All of us rely on deductive reasoning as a way to make everyday decisions—like whether you should open attachments in e-mails from unknown senders **(figure 1.9).** We use general principles as the basis for examining and evaluating these decisions.

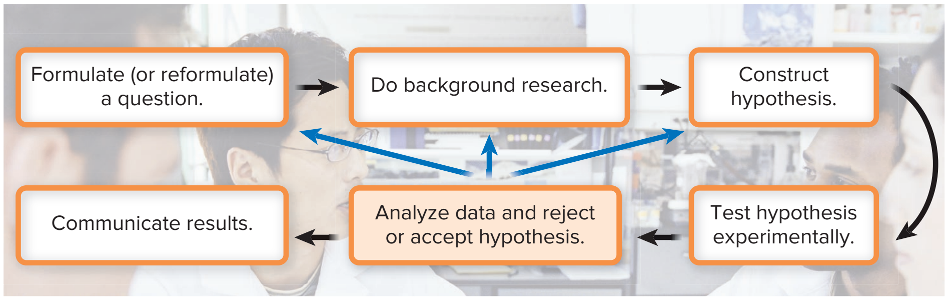


Figure 1.8 An overview of the scientific method.
Ryan McVay/Getty Images

Inductive Reasoning

Where do general principles come from? Religious and ethical principles often have a religious foundation; political principles reflect social systems. Some general principles, however, such as those behind the deductive reasoning example just given, are derived not from religion or politics but from observation of the physical world around us. If you drop an apple, it will fall whether or not you want it to and despite any laws you may pass that forbid it to do so. Science is devoted to discovering the general principles that govern the operation of the physical world.

How do scientists discover such general principles? Scientists are, above all, observers: They look at the world to understand how it works. It is from observations that scientists determine the principles that govern our physical world.

The process of discovering general principles by careful examination of specific cases is termed *inductive reasoning*. This way of thought first became popular about 400 years ago, when Isaac Newton, Francis Bacon, and others began to conduct experiments. They used the results of these experiments to infer general principles about how the world operates. Their experiments were sometimes quite simple. Newton's consisted simply of releasing an apple from his hand and watching it fall to the ground. From a host of particular observations, each no more complicated than the falling of an apple, Newton inferred a general principle—that all objects fall toward the center of the earth. This principle was a possible explanation, or hypothesis, about how the world works. You also make observations and formulate general principles based on your observations, like forming a general principle about the reliability of unknown e-mail attachments in figure 1.9. Like Newton, scientists work by forming and testing hypotheses, and observations are the materials on which they build them.

As you can see, the deductive process is used when a general principle has already been established; inductive reasoning involves a discovery process and leads to the creation of a general principle.

A lengthy process of experimentation, analysis, and testing eventually leads to conclusions that either support or fail to support the hypothesis. If experiments do not uphold the hypothesis—that is, if it is found to be flawed—the hypothesis or some part of it is rejected; it is either discarded or modified to fit the results of the experiment. If the hypothesis is supported by the results from the experiment, it is not (or should not be) immediately accepted as fact. It then must be tested and retested. Indeed, this is an important guideline in the acceptance of a hypothesis. The results of the experiment should be published so that they can be repeated by other investigators.

In time, as each hypothesis is supported by a growing body of data and survives rigorous scrutiny, it moves to the next level of acceptance—the **theory.** A theory is a collection of statements, propositions, or concepts that explains or accounts for a natural event. A theory is not the result of a single experiment repeated over and over again but is an entire body of ideas that expresses or explains many aspects of a phenomenon. It is not a fuzzy or weak speculation (which is the way the word is used in everyday conversation) but a viable declaration that has stood the test of time and has yet to be disproved by serious scientific endeavors. Often, theories develop and progress through decades of research and are added to and modified by new findings. At some point, evidence of the accuracy and predictability of a theory is so compelling that the next level of confidence is reached and the theory becomes a law, or principle. For example, although we still refer to the germ *theory* of disease, so little question remains that microbes can cause disease that it has clearly passed into the realm of law. The theory of evolution falls in this category as well.

Science and its hypotheses and theories must progress along with technology. As advances in instrumentation allow new, more detailed views of living phenomena, old theories may be reexamined and altered and new ones proposed. But scientists do not take the stance that theories or even "laws" are ever absolutely proved.

The characteristics that make scientists most effective in their work are curiosity, open-mindedness, skepticism, creativity, cooperation, and readiness to revise their views of natural processes as new discoveries are made.

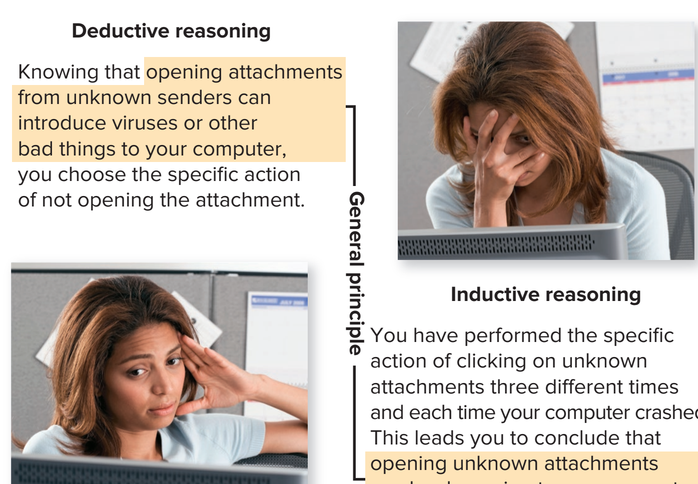


Figure 1.9 Deductive and inductive reasoning.
Tom Grill/Corbis

The Development of Medical Microbiology

Early experiments on the sources of microorganisms led to the profound realization that microbes are everywhere: Not only are air and dust full of them, but the entire surface of the earth, its waters, and all objects are inhabited by them. This discovery led to immediate applications in medicine. Thus, the seeds of medical microbiology were sown in the mid to latter half of the 19th century (the 1800s) with the introduction of the germ theory of disease and the resulting use of sterile, aseptic, and pure culture techniques.

The Discovery of Spores and Sterilization

Following Pasteur's inventive work with swan-neck flasks, while disproving spontaneous generation, it was not long before English physicist John Tyndall provided the initial evidence that some of the microbes in dust and air have very high heat resistance and that something stronger than boiling is required to destroy them. Later, the discovery and detailed description of heat-resistant bacterial endospores by Ferdinand Cohn, a German botanist, clarified the reason that heat would sometimes fail to completely eliminate all microorganisms. The modern sense of the word **sterile,** meaning completely free of all life forms (including spores) and virus particles, was established from that point on. The capacity to sterilize objects and materials is an absolutely essential part of microbiology, medicine, dentistry, and many industries.

The Development of Aseptic Techniques

From earliest history, humans experienced a vague sense that "unseen forces" or "poisonous vapors" emanating from decomposing matter could cause disease. As the study of microbiology became more scientific and the invisible was made visible, the fear of such mysterious vapors was replaced by the knowledge and sometimes even the fear of "germs." About 125 years ago, the first studies by Robert Koch clearly linked a microscopic organism with a specific disease. Since that time, microbiologists have conducted a continuous search for disease-causing agents.

At the same time that abiogenesis was being hotly debated, a few physicians began to suspect that microorganisms could cause not only spoilage and decay but also infectious diseases. It occurred to these pioneers that even the human body itself was a source of infection. Dr. Oliver Wendell Holmes, an American physician, observed that mothers who gave birth at home experienced fewer infections than did mothers who gave birth in the hospital. The Hungarian Dr. Ignaz Semmelweis showed quite clearly that women became infected in the maternity ward after examinations by physicians coming directly from the autopsy room without washing their hands.

The English surgeon Joseph Lister took notice of these observations and was the first to introduce **aseptic** (ay-sep′-tik) **techniques.** These are aimed at reducing microbes in a medical setting and preventing wound infections. Lister's concept of asepsis was much more limited than our modern precautions. It mainly involved disinfecting the hands and the air with strong antiseptic chemicals, such as phenol, prior to surgery **(figure 1.10).** It is hard for us to believe, but as recently as the late 1800s, surgeons wore street clothes in the operating room and had little idea that hand washing was important. Lister's techniques and the application of heat for sterilization became the foundations for microbial control by physical and chemical methods, which are still in use today.

Figure 1.10 Joseph Lister's operating room in the mid-1800s. This misting machine is releasing phenol.
Bettmann/Getty Images

Disease Connection

Marketed in schools, restrooms, workplaces, and health care settings, the benefits of hand washing have been widely publicized. Institutions such as the Centers for Disease Control and Prevention (CDC) and World Health Organization (WHO) have targeted the general public to promote the importance of hand hygiene and how to perform it well. Evidence shows that proper hand washing is the single most effective method of preventing infectious disease transmission in health care settings. However, not all hand washing is created equal. Techniques for each step in the process of hand washing are supported by evidence, and when these guidelines are followed, transmission of pathogens is reduced.

The Discovery of Pathogens and the Germ Theory of Disease

Louis Pasteur of France introduced techniques that are still used today. Pasteur made enormous contributions to our understanding of the microbial role in wine and beer formation. He invented pasteurization and completed some of the first studies showing that human diseases could arise from infection. These studies, supported by the work of other scientists, led to the **germ theory of disease.** Pasteur's contemporary, Robert Koch, established *Koch's postulates,* a series of proofs that verified the germ theory and could establish whether an organism was pathogenic and which disease it caused. Around 1875, Koch used this experimental system to show that anthrax was caused by a bacterium called *Bacillus anthracis.* Koch's postulates were so useful that within 25 years the causative agents of 20 other diseases were discovered. They have had to be modernized over the years but still form the basis for identifying new pathogenic microbes.

Numerous exciting technologies emerged from Koch's laboratory work. During this golden age of the 1880s, he realized that study of the microbial world would require separating microbes from each other and growing them in culture. It is not an overstatement to say that he and his colleagues invented most of the techniques that are described in chapter 3: inoculation, isolation, media, maintenance of pure cultures, and preparation of specimens for microscopic examination. Other highlights in this era of discovery are presented in later chapters on microbial control and vaccination.

1.6 Learning Outcomes—Assess Your Progress

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

Students just beginning their microbiology studies are often dismayed by the seemingly endless array of new, unusual, and sometimes confusing names for microorganisms. Learning microbial **nomenclature** is very much like learning a new language, and occasionally it may feel a bit overwhelming. But paying attention to proper microbial names is just like following a baseball game or a theater production: You cannot tell the players apart without a program! Your understanding and appreciation of microorganisms will be greatly improved by learning a few general rules about how they are named.

The science of classifying living beings into categories is **taxonomy.** It originated more than 250 years ago when Carl von Linné (also known as Linnaeus; 1701–1778), a Swedish botanist, laid down the basic rules for *classification* and established taxonomic categories, or **taxa** (singular, *taxon*).

Von Linné realized early on that a system for recognizing and defining the properties of living beings would prevent chaos in scientific studies by providing each organism with a unique name and an exact "slot" in which to catalog it. The von Linné system has served well in categorizing the millions of different kinds of organisms that have been discovered since that time, including organisms that have gone extinct.

The primary concerns of modern taxonomy are still naming, classifying, and identifying. These three areas are interrelated and play a vital role in keeping a dynamic inventory of the extensive array of living and extinct beings. In general,

Nomenclature is the assignment of scientific names to the various taxonomic categories and individual organisms. You can remember this by recalling that "nom" means *name*.

Classification tries to arrange organisms into a hierarchy of taxa (categories).

Identification is the process of discovering and recording the traits of organisms so that they may be recognized or named and placed in an overall taxonomic scheme. Identification will be thoroughly discussed in chapter 3, so the rest of this chapter will focus on nomenclature and classification.

If you have studied biology before, you may recall that species are often defined as organisms that can successfully produce offspring together. Species also can be defined as having shared evolutionary history and ancestry. Categorizing bacteria, viruses, and other microorganisms is especially difficult because of the fact that a large amount of genetic exchange takes place *horizontally*—that is, between organisms living together at the same time. This is as opposed to the type of genetic transfer that occurs from one generation to another. (That is called *vertical gene transfer*.) When even the cells of the same species of bacteria have a different genetic makeup because some of them have picked up genes from other species, the very idea of a species is difficult to pin down. Nevertheless, microbiologists continue to assign relatedness and categories to microorganisms.

Nomenclature: Assigning Specific Names

Many **macroorganisms** are known by a common name suggested by certain dominant features. For example, a bird species might be called a red-headed blackbird or a flowering plant species a black-eyed Susan. Some species of microorganisms are also called by informal names, including human pathogens such as "gonococcus" (*Neisseria gonorrhoeae*) or fermenters such as "brewer's yeast" (*Saccharomyces cerevisiae*), or the more recent "Iraqabacter" (*Acinetobacter baumannii*), but this is not the usual practice. If we were to adopt common names such as the "little yellow coccus," the terminology would become even more cumbersome and challenging than scientific names. Even worse, common names are notorious for varying from region to region, even within the same country. A big advantage of standardized nomenclature is that it provides a universal language, thereby enabling scientists from all countries to accurately exchange information.

The method of assigning a scientific or specific name is called the **binomial** (two-name) **system** of nomenclature. The scientific name is always a combination of the genus name followed by the species name. The genus part of the scientific name is capitalized, and the species part begins with a lowercase letter. Both should be italicized (or underlined if using handwriting), as follows:

Staphylococcus aureus

The two-part name of an organism is sometimes abbreviated to save space, as in *S. aureus,* but only if the genus name has already been stated. The source for nomenclature is usually Latin or Greek. If other languages such as English or French are used, the endings of these words are revised to have Latin endings. An international group oversees the naming of every new organism discovered, making sure that standard procedures have been followed and that there is not already an earlier name for the organism or another organism with that same name. The inspiration for names is extremely varied and often rather imaginative. Some species have been named in honor of a microbiologist who originally discovered the microbe or who has made outstanding contributions to the field. Other names may designate a characteristic of the microbe (shape, color), a location where it was found, or a disease it causes. Some examples of specific names, their pronunciations, and their origins are

- *Staphylococcus aureus* (staf′-i-lo-kok′-us ah′-ree-us) Gr. *staphule,* bunch of grapes; *kokkus,* berry; and *aureus*, golden. Under a microscope this bacterium looks like a bunch of grapes, and often has a yellow color when grown on agar.
- *Campylobacter jejuni* (cam′-peh-loh-bak-ter jee-joo′-neye) Gr. *kampylos,* curved; *bakterion,* little rod; and *jejunum,* a section of intestine. This curved rod causes intestinal infection.
- *Lactobacillus sanfranciscensis* (lak′-toh-bass-ill′-us san-fran-siss′-koh) L. *lacto,* milk, and *bacillus,* little rod. A bacterial species used to make sourdough bread.
- *Vampirovibrio chlorellavorus* (vam-py′-roh-vib-ree-oh klor-ell-ah′-vor-us) Fr. *vampire;* L. *vibrio,* curved cell; *Chlorella,* a genus of green algae; and *vorus,* to devour. A small, curved bacterium that sucks out the cell juices of *Chlorella.*
- *Giardia lamblia* (jee-ar′-dee-uh lam′-blee-uh) for Alfred Giard, a French microbiologist, and Vilem Lambl, a Bohemian physician, both of whom worked on the organism. A protozoan that causes a severe intestinal infection.

Here is a helpful hint: These names may seem difficult to pronounce and the temptation is to simply "slur over them." But when you encounter the names of microorganisms in the chapters ahead, it will be extremely useful to take the time to sound them out and repeat them until they seem familiar. There are also a variety of websites that will sound out the words for you in audio. Just do an Internet search for "microbial names audio." You are much more likely to remember them that way—and they are less likely to end up in a tangled heap with all of the new language you will be learning.

Classification: Constructing Taxonomy

The main units of a classification scheme are organized into several descending ranks. They begin with the most general all-inclusive taxonomic category as a common denominator for organisms to exclude all others. They end with the smallest and most specific category. This means that all members of the highest category share only one or a few general characteristics, whereas members of the lowest category are essentially the same kind of organism—that is, they share the majority of their characteristics. The taxonomic categories from top to bottom are **domain, kingdom, phylum** or **division,**[3] **class, order, family, genus,** and **species.** Thus, each kingdom can be subdivided into a series of phyla or divisions, each phylum is made up of several classes, each class contains several orders, and so on. Because taxonomic schemes are to some extent artificial, certain groups of organisms may not exactly fit into the main categories. In such a case, additional taxonomic levels can be imposed above (super) or below (sub) a taxon, giving us such categories as "superphylum" and "subclass."

In **figure 1.11,** we compare the taxonomic breakdowns of a human and a protozoan (proh′-tuh-zoh′-uhn) to illustrate the fine points of this system. Humans and protozoa are both organisms with nucleated cells (eukaryotes); therefore, they are in the same domain, but they are in different kingdoms. Humans are multicellular animals (Kingdom Animalia), whereas protozoa are single-celled organisms that, together with algae, belong to the Kingdom Protozoa. To emphasize just how broad the category "kingdom" is, ponder the fact that we humans belong to the same kingdom as jellyfish. Of the several phyla within this kingdom, humans belong to the Phylum Chordata, but even a phylum is rather all-inclusive, considering that humans share it with other vertebrates as well as with creatures called sea squirts. The next level, Class Mammalia, narrows the field considerably by grouping only those vertebrates that have hair and suckle their young. Humans belong to the Order Primates, a group that also includes apes, monkeys, and lemurs. Next comes the Family Hominoidea, containing only humans and apes. The final levels are our genus, *Homo* (all races of modern and ancient humans), and our species, *sapiens* (meaning *wise*). Notice that for the human as well as the protozoan, the taxonomic categories in descending order become less inclusive and the individual members more closely related. In this text, we are usually concerned with only the most general (kingdom, phylum) and specific (genus, species) taxonomic levels.

The Origin and Evolution of Microorganisms

Taxonomy, the classification of biological species, is used to organize all of the forms of modern and extinct life. In biology today, there are different methods for deciding on taxonomic categories, but they all rely on the degree of relatedness among organisms. The scheme that represents the natural relatedness (relation by descent) between groups of living beings is called their *phylogeny* (Gr. *phylon,* race or class; L. *genesis,* origin or beginning). Biologists use phylogenetic relationships to determine taxonomy.

To understand the relatedness among organisms, we must understand some fundamentals of the process of evolution. Evolution is an important theme that underlies all of biology, including the biology of microorganisms. As we said earlier, evolution states that the hereditary information in living beings changes gradually through time and that these changes result in various structural and functional changes through many generations. The process of evolution is selective in that those changes that most favor the survival of a particular organism or group of organisms

3. The term *phylum* is used for bacteria, protozoa, and animals; the term *division* is used for algae, plants, and fungi.

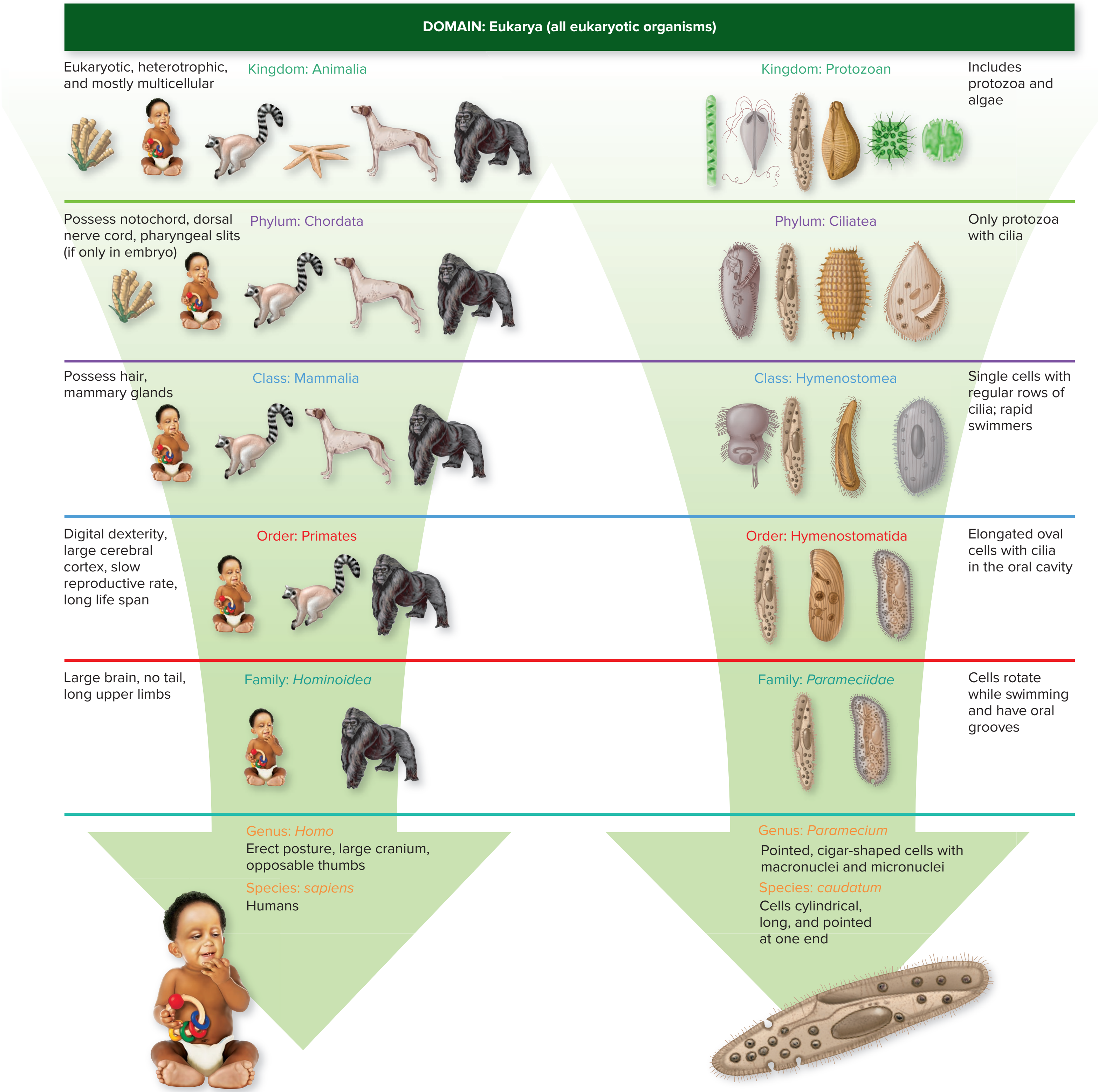


Figure 1.11 Sample taxonomy. Two organisms belonging to the Eukarya domain, traced through their taxonomic series; on the left, a modern human, *Homo sapiens;* on the right, a common protozoan, *Paramecium caudatum.*

tend to be retained, whereas those that are less beneficial to survival tend to be lost. This is not always the case, but it often is. Charles Darwin called this process *natural selection.*

Evolution is founded on the two principles that (1) all new species originate from preexisting species and (2) closely related organisms have similar features because they evolved from a common ancestor; hence, difference emerged by divergence. Usually, evolution progresses toward greater complexity, but there are many examples of evolution toward lesser complexity (reductive evolution). This is because individual organisms never evolve in isolation but as populations of organisms in their specific environments, which exert the functional pressures of selection. The phylogeny, or relatedness by descent, of organisms is often represented by a diagram of a tree. The trunk of the tree represents the origin of ancestral lines, and the branches show offshoots into specialized groups (called clades) of organisms. This sort of arrangement places taxonomic groups with less divergence (less change in the heritable information) from the common ancestor closer to the root of the tree and taxa with more divergence closer to the top **(figure 1.12).**

A Universal Tree of Life

The phylogenetic relationships of all organisms on the planet are often depicted as "trees of life." Over the course of many years, five kingdoms of organisms were recognized. These kingdom designations were based on their structural similarities and differences, and the way they obtained their nutrition.

- Plants
- Animals
- Protista (protozoa)
- Monera (which at the time contained both Bacteria and what we now know as Archaea)
- Fungi

With the rise of genetics as a molecular science, newer methods for determining phylogeny led to the development of a differently shaped tree—with important implications for our understanding of evolutionary relatedness. Molecular genetics allowed an in-depth study of the structure and function of the genetic material at the molecular level. The findings were starkly different than the categories created using structural similarities. These studies have revealed that two of the four macromolecules that contribute to cellular structure and function, the proteins and nucleic acids, are very well suited to study how organisms differ from one another because they can be directly compared. One particular macromolecule, the ribonucleic acid in the small subunit of the ribosome (ssuRNA), was highly "conserved"—meaning that it was nearly identical in all of the organisms within the smallest taxonomic category, the species. Because of that, ssuRNA provides a "biological chronometer," or a "living record," of the evolutionary history of a given organism. Extended analysis of this molecule in prokaryotic and eukaryotic cells indicated that all members of one kind of non-eukaryotic cell type had ssuRNA with a sequence that was significantly different from the ssuRNA found in the bacteria. This discovery led scientists to propose a separate taxonomic unit for this group, which they named Archaea. Under the microscope, they resembled the structure of bacteria, but molecular biology has revealed that the archaea, though seeming to be prokaryotic in nature, were actually more closely related to eukaryotic cells than to bacterial cells (see table 4.1). To reflect these relationships, a new system was born. It assigns all known organisms to one of the three major

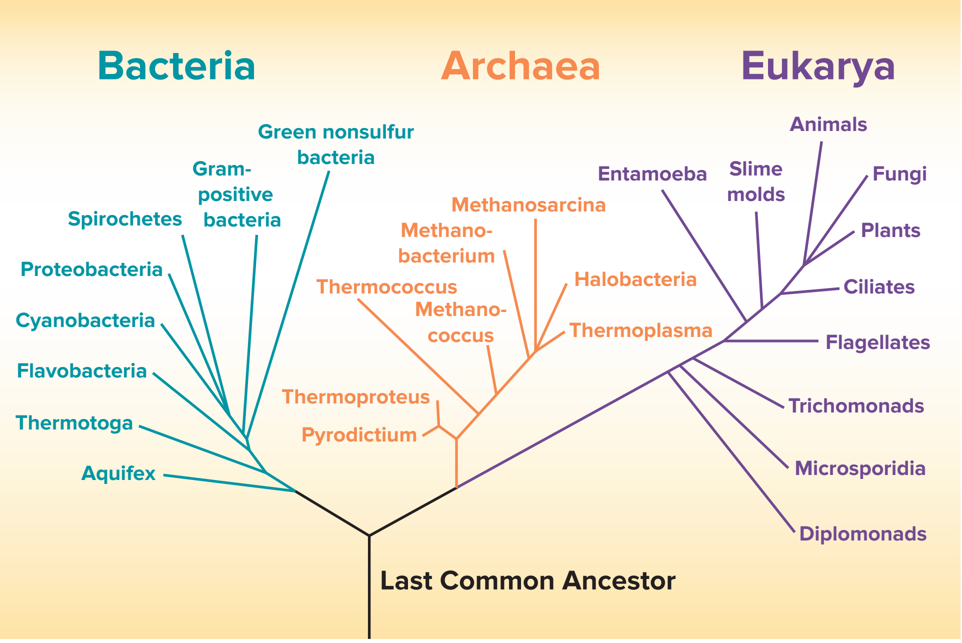


Figure 1.12 The tree of life: A phylogenetic system. A system for representing the origins of cell lines and major taxonomic groups. There are three distinct cell lines placed in superkingdoms called domains.

taxonomic units, the **domains,** each being a different type of cell (figure 1.12).

The domains are now the highest level in hierarchy and each one can contain more than one kingdom. Take particular care to notice that Bacteria and Archaea now constitute separate domains and are not in the same kingdom, as they had been thought to be in the past. The domains are

- Bacteria
- Archaea
- Eukarya

Analysis of the ssuRNAs from all organisms in these three domains suggests that all modern and extinct organisms on earth arose from a common ancestor.

The traditional shape of the "tree of life" has given way to something else now, given our discovery of rampant horizontal gene transfer—in microbes and in larger organisms. For example, it is estimated that 40% to 50% of human DNA has been carried to humans from other species (by parasitic eukaryotes or viruses). Another example: The genome of the cow contains a great deal of snake DNA. For these reasons, most scientists like to think of a *web* as the proper representation of life these days. Nevertheless, this new scheme does not greatly affect our presentation of most microbes because we will discuss them at the genus or species level. But be aware that biological taxonomy and, more important, our view of how organisms evolved on earth are in a permanent state of transition. Keep in mind that our methods of classification or evolutionary schemes reflect our current understanding and will change as new information is uncovered.

Please note that neither viruses nor prions are included in any of the classification or evolutionary schemes because they are not cells or organisms and their position in a "tree of life" has not been definitively determined.

1.7 Learning Outcomes—Assess Your Progress

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.

Media Under The Microscope Wrap-Up

Image Source

The article "Your Keurig Machine May Be Covered in Bacteria and Mold" contains some data. Let us examine two statements. First, "More than half of the machines came back with bacterial counts in the millions." The article does not provide links to a research article or to the data source, but it seems reasonable that millions of colonies would arise from swabs of the machines. As microbiology students, we know that millions of bacteria cover the surfaces of our bodies and the surfaces in our environment. We also know that this is normal, and even necessary, and that the vast majority of microbes have positive or neutral effects on our health. To the uninformed public, though, "millions of bacteria" could sound alarming, and it could be argued that the intent of the article is to raise a note of alarm. In this case, the alarm is not justified.

The second fact, that one of the 29 machines tested positive for *E. coli,* points to the possibility that fecal matter contaminated that machine. That, of course, has a certain "eww" factor, particularly for the public. But microbiologists know that fecal matter, carried on a person's hands, frequently contaminates household surfaces. *E. coli* is an indicator organism signaling that fecal matter has been transferred because *E. coli* has its habitat in the digestive tracts of mammals (humans, dogs, cats). But the vast majority of *E. coli* strains do not cause disease, and are, in fact, normal biota. So the presence of *E. coli* in and of itself does not raise alarm bells. It does indicate fecal contamination—but we are surrounded by that in our environments.

The data in the article confirm something not so very alarming: that coffeemakers share the characteristics of every other object in our environment. Because we use coffeemakers to make something we put in our mouths, we should simply maintain normal hygienic practices and keep them reasonably clean.

To address the questions from the first part of the case, the **intended message** of the article seems to be that we should be alarmed about all the things growing in our coffeemakers. A **critical reading,** however, suggests that no alarm is called for because of the fact that all surfaces are covered with microbes. The presence of *E. coli* in one of the 29 machines suggests that normal hygiene should be part of our daily lives. And that is how we should **interpret** it to our friends! As for **an overall grade,** I would give this article a grade of D− because its intention—to alarm us—is not supported by the facts; because it does not explain what *E. coli* is; and because there is no link to the data or the research so that we can check it out for ourselves.

Source: Huffington Post, "Your Keurig Machine May Be Covered in Bacteria and Mold," online article posted 5/21/2015.

Study Smarter: Better Together

These activities are designed for you to use on your own with a study group—either a face-to-face group or a virtual one, consisting of 3–5 members. Studying together can be very helpful, but there are effective and ineffective ways to do it. For example, getting together without a clear structure is often not a good use of your time. Use your time efficiently by using one or more of the exercises below.

FACE-TO-FACE GROUPS

Use one or more of the activities below.

Peer Instruction: Assign numbers to your group members to use all semester long. Now look at these five concepts from this chapter. Each group member prepares a 5-minute lesson on the topic corresponding to his or her number. Don't worry if you have fewer than 5 members; just use however many you have! During your group study time, each member presents his or her lesson, and the group spends another 5–10 minutes discussing that lesson.

1. The three biological cell types in evolutionary history
2. The role of deduction in the scientific method
3. Spontaneous generation
4. Phylogeny and taxonomy
5. The web of life

Concept Maps: Each member of the group should use this list of terms from this chapter to generate his or her own concept map. This can be hand-drawn or created using software (see Appendix C for guidelines). During group study time, compare each other's concept maps and help each other make sure they are correct. Of course, there are many different "correct" maps. Examining each member's map will help you talk through the varied concepts and how they are related.

Concept Terms:

microorganisms	helminths	protozoa	fungi
bacteria	viruses	prokaryote	eukaryote
pathogen	organelles		

Table Topics: Each group member should identify a concept or topic from this week's class assignments with which he or she is having trouble and share it during group study time. The other group members can then help to clarify confusing issues or share how they figured it out. Aim for a maximum of 15 minutes per topic. If the topic remains unclear to the group, bring it up during class or use the instructor's office hours or e-mail to ask for help. Taking the time to struggle with a difficult concept first makes your questions much more specific and more likely to yield helpful answers.

VIRTUAL GROUPS

Not everyone has the time or opportunity to meet with group members outside of class time. You or your instructor can create a virtual group using e-mail or the course software.

Weekly Discussion Board: This forum can be used as a way for groups to discuss topics, via e-mail, before they are covered in class. As each member of the group answers the current week's question, they should send their responses to every other member of their group. It's best to agree on a deadline based on how your class schedule works (Saturday for the next week's topics, for example). Then, after the topic is discussed in class, each member should send a "Reply All" response with a follow-up post on the same topic. If you cover more than one chapter in a week, someone can be designated to choose which chapter Discussion Board question you will use. Or simply decide up front that you will always use the first-chapter-of-the week's question, to keep the schedule simple.

Discussion Question
What are the three domains in the tree of life, and why do scientists prefer the term "web of life" rather than "tree of life"?

Chapter Summary

1.1 The Scope of Microbiology

- Microorganisms are defined as "living organisms too small to be seen with the naked eye." The types of microorganisms we will be studying are the bacteria, fungi, protozoa, helminths, viruses, and prions.
- Microorganisms live nearly everywhere and influence many biological and physical activities on earth.
- There are many kinds of relationships between microorganisms and humans; most are beneficial, but some are harmful.

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

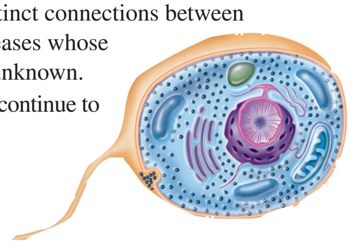
- Groups of organisms are constantly evolving to produce new forms of life.
- Microbes are crucial to the cycling of nutrients and energy that are necessary for all life on earth.

1.3 Human Use of Microorganisms

- Humans have learned how to manipulate microbes to do important work for them in industry, medicine, and caring for the environment.

1.4 Infectious Diseases and the Human Condition

- In the last 160 years, microbiologists have identified the causative agents for many infectious diseases. In addition, they have discovered distinct connections between microorganisms and diseases whose causes were previously unknown.
- While microbial diseases continue to cause disease worldwide, low-income countries are much harder hit by them directly and indirectly.



1.5 The General Characteristics of Microorganisms

- Microorganisms fall into all three of the cellular types: Bacteria, Archaea, and Eukarya.
- Two types of microorganisms are not cells at all. Viruses are dependent on host cells for their activity and reproduction, and prions are folded proteins that act like infectious particles.

1.6 The Historical Foundations of Microbiology

- The microscope made it possible to see microorganisms and thus to identify their widespread presence, particularly as agents of disease.
- The theory of spontaneous generation of living organisms from "vital forces" in the air was disproved once and for all by Louis Pasteur.
- The scientific method is a process by which scientists seek to explain natural phenomena. It uses specific procedures that either support or discredit an initial hypothesis.
- Knowledge gained through the scientific method is rigorously tested by repeated experiments by many scientists to verify its validity. A theory supported by much data collected over time is sometimes called a law, but the term *theory* may remain associated with it.

Biophoto Associates/ Science Source

- Scientific understandings change through time as new research brings new information.

1.7 Naming, Classifying, and Identifying Microorganisms

- The taxonomic system has three primary functions: naming, classifying, and identifying species.
- The major groups in the most advanced taxonomic system are (in descending order) domain, kingdom, phylum or division, class, order, family, genus, and species.
- Evolutionary patterns show a treelike or weblike branching that describes the diverging evolution of all life forms from the gene pool of a common ancestor.

SmartGrid: From Knowledge to Critical Thinking

This *21 Question Grid* takes the topics from this chapter and arranges them with respect to the American Society for Microbiology's Undergraduate Curriculum guidelines—all six of the important "Concepts" as well as the important "Competency" of scientific literacy. Three questions are supplied, which cover chapter content referring to the Concept or Competency in increasing levels of Bloom's taxonomy for learning.

ASM Concept/ Competency	A. Bloom's Level 1, 2—Remember and Understand (Choose one.)	B. Bloom's Level 3, 4—Apply and Analyze	C. Bloom's Level 5, 6—Evaluate and Create
Evolution	**1.** Which of the following is an acellular microorganism lacking a nucleus? **a.** bacterium **b.** helminth **c.** protozoan **d.** virus	**2.** Name six types of microorganisms that we are studying in this book and use each one in a sentence.	**3.** Defend the argument that a web of life is a more accurate representation of evolutionary relatedness than a tree of life.

(continued)

ASM Concept/ Competency	A. Bloom's Level 1, 2—Remember and Understand (Choose one.)	B. Bloom's Level 3, 4—Apply and Analyze	C. Bloom's Level 5, 6—Evaluate and Create
Cell Structure and Function	**4.** Which of the following is a microorganism that contains organelles? **a.** prion **b.** bacterium **c.** fungus **d.** virus	**5.** Often when there is a local water main break, a town will post an advisory to boil water before ingesting it. Identify the biological basis behind the effectiveness of this procedure in minimizing illness.	**6.** Imagine a way you might design a drug that will destroy microbes without harming human cells.
Metabolic Pathways	**7.** Identify the process or environment in this list that is not affected by microorganisms. **a.** oxygen cycles **b.** recycling of dead organisms **c.** human health **d.** all of the above have microbial involvement	**8.** Discuss the current view of the evolution of eukaryotic cells.	**9.** Describe how microorganisms can accomplish bioremediation.
Information Flow and Genetics	**10.** Which of these organisms do not contain DNA? **a.** helminths **b.** fungi **c.** bacteria **d.** prions	**11.** Summarize some important facets of the human microbiome.	**12.** Suggest an argument for why eukaryotic cells have developed an enclosed nucleus unlike bacteria and archaea.
Microbial Systems	**13.** Microbes are found in which habitat? **a.** human body **b.** earth's crust **c.** oceans **d.** all of the above	**14.** Argue for or against this statement: *Microbes intend to cause human disease.*	**15.** Coevolution is a term describing the influence that two organisms occupying the same niche have on each other. Sketch a scenario for coevolution between a bacterium and a human living in the same environment.
Impact of Microorganisms	**16.** Which of the following processes can be the result of human manipulation of microbial genes? **a.** the central dogma **b.** natural selection **c.** bioremediation **d.** abiogenesis	**17.** Speculate about why scientists believe there are more microbial species that we do not yet know about than those that we do know about.	**18.** Imagine you are a guest speaker in a middle school science class. Explain to the students why human life would not be possible without microorganisms.
Scientific Thinking	**19.** When a hypothesis has been thoroughly supported by long-term study and data, it is considered **a.** a law. **b.** a speculation. **c.** a theory. **d.** proven.	**20.** Defend the use of complicated-sounding names for identifying microorganisms.	**21.** Identify the most important component of the scientific method and defend your answer.

Answers to the multiple-choice questions appear in Appendix A.