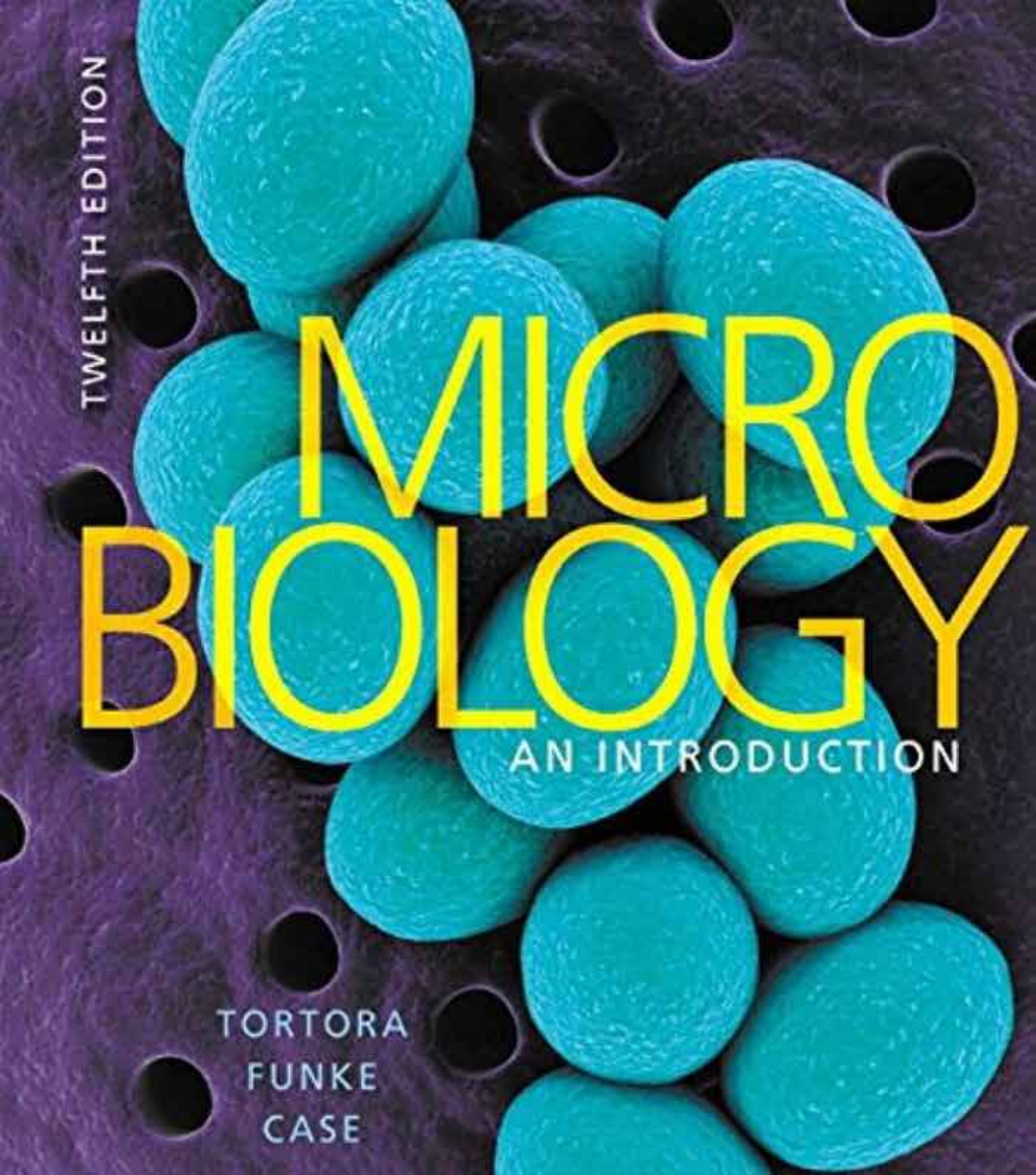

TWELFTH EDITION
MICRO
BIOLOGY
AN INTRODUCTION
TORTORA
FUNKE
CASE

Master Microbiology Where it Matters…

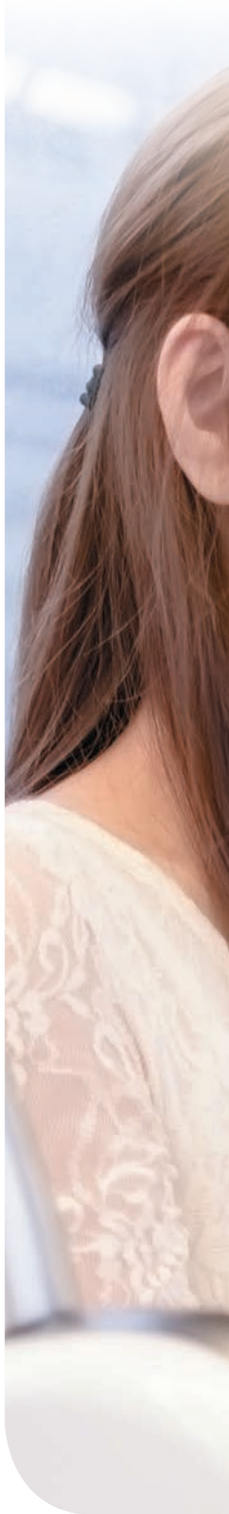
Brief Contents

Big Picture Tough Topics

Big Picture Disease

AMERICAN SOCIETY FOR MICROBIOLOGY

All chapter content is tagged to ASM Curriculum Guidelines for Undergraduate Microbiology



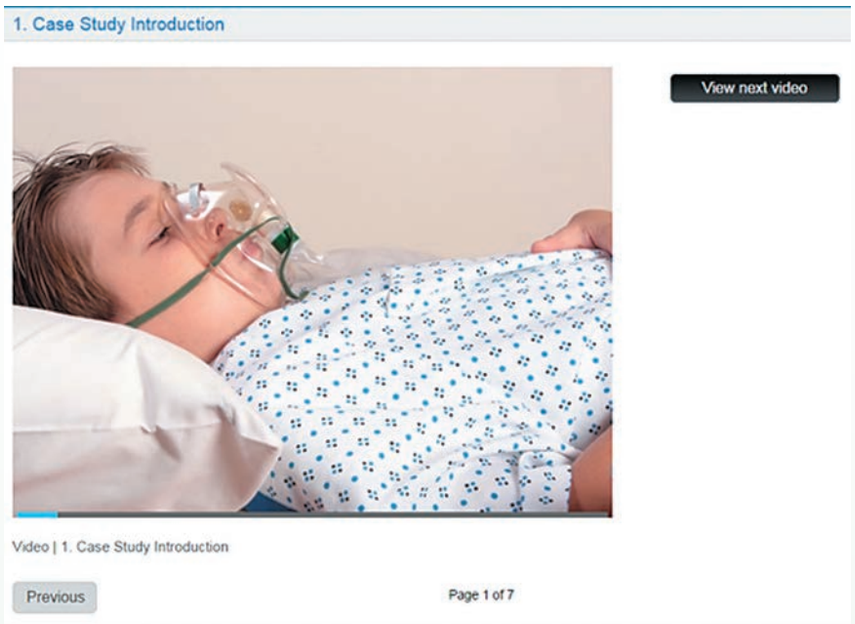
…Everywhere


AT&T
5:48 PM
Modules
Chapter 24: Microbial Diseases of the Second Group
A 35-year-old woman presents with violent, uncontrollable coughing fits and reports that she is just getting over a cold. Her sputum does NOT contain blood. Which of the following is the most likely diagnosis?
tuberculosis
walking pneumonia
the flu
pertussis
I DON'T KNOW YET

Explore and Apply Key Concepts with Interactive Microbiology!

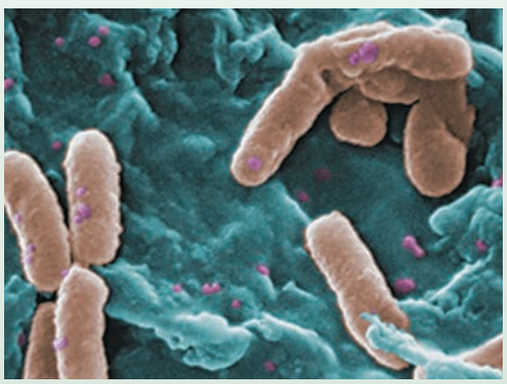
NEW!

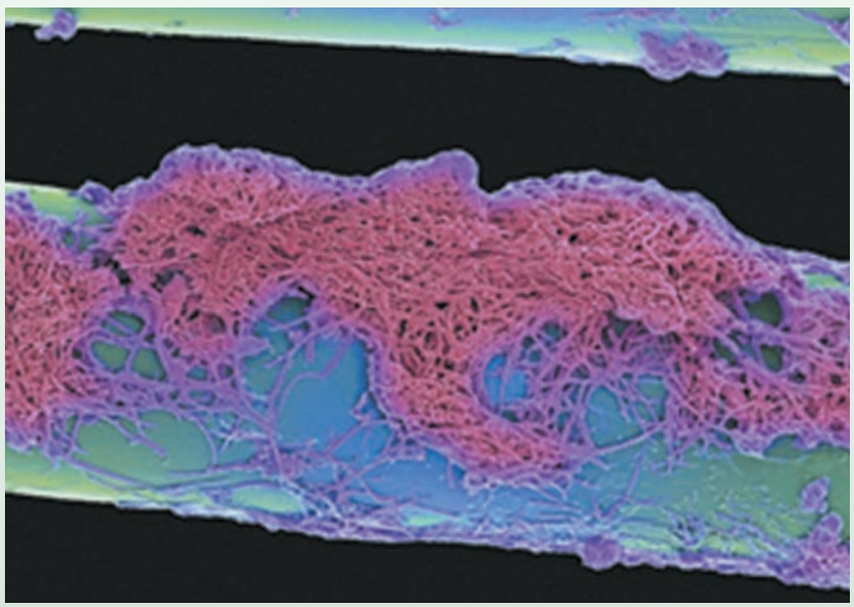
interactivemicrobiology is a dynamic suite of interactive tutorials and animations that teach key concepts in microbiology. Students actively engage with each topic and learn from manipulating variables, predicting outcomes, and answering formative and summative assessment questions.



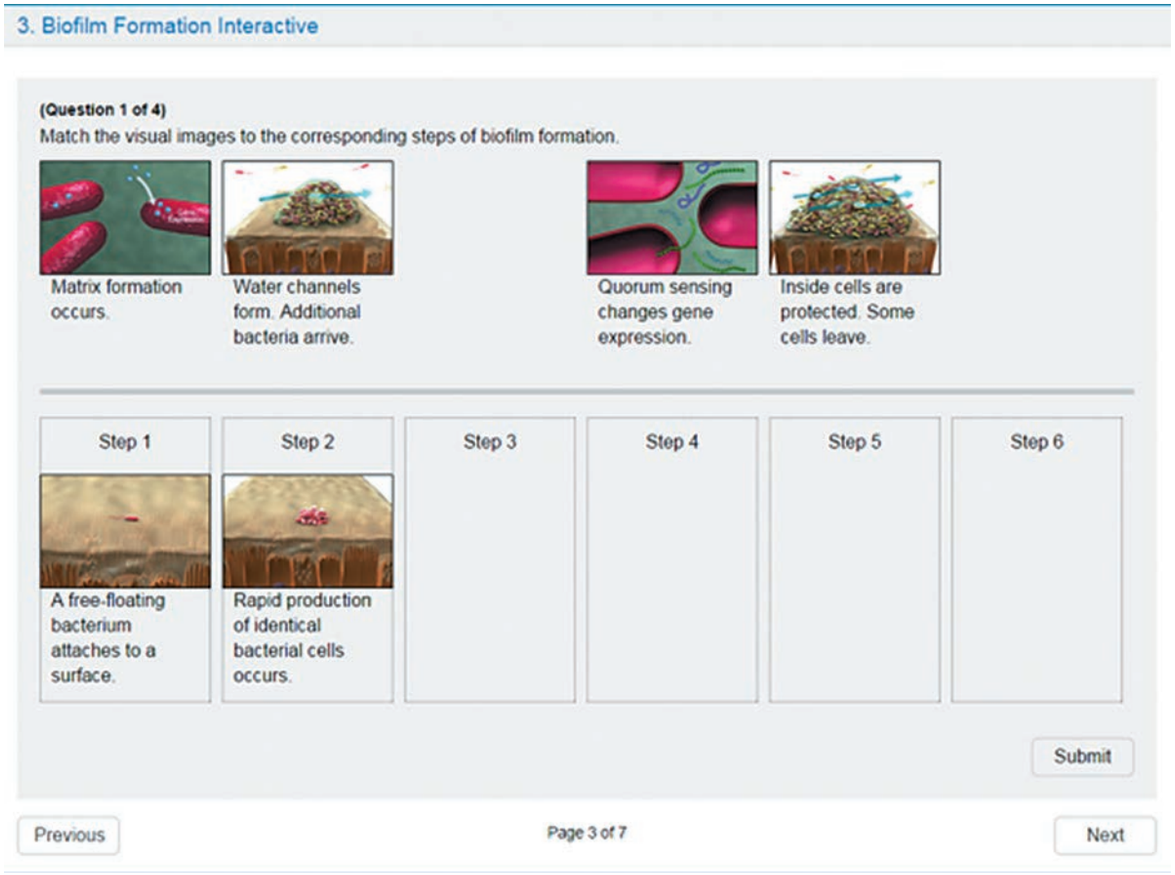
Each Interactive Microbiology tutorial begins with a clinical case scenario, allowing you, the learner, to explore different real world health care situations.

Experience and learn microbiology principles by engaging with interactive animations.





Each Interactive Microbiology module is supported by interactive tutorials that reinforce concepts presented in the animations.



Accessible in the Study Area for on-the-go studying with mobile devices and assignable through MasteringMicrobiology®, Interactive Microbiology explores challenging and important topics including Operons, Biofilms and Quorum Sensing, Aerobic Respiration in Bacteria, Complement, and more.

Focus on the Big Picture

NEW!
Big Picture spreads have been added to the Twelfth Edition, integrating text and illustrations to help students gain a broad, "big picture" understanding of important course topics.

Seven Big Picture spreads focus on **a particular disease with an application to a related real-world challenge.** Many of the featured diseases explore public health issues:

BIG PICTURE

Human Microbiome and IBD

The Human Microbiome Project uses genetic sequencing to study correlations between changes in the microbiome and inflammatory bowel disease.

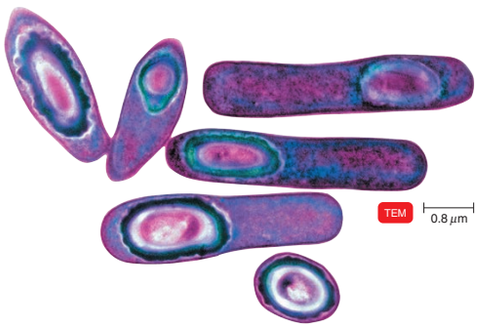
Our bodies are complex sets of ecosystems, with segments that come into contact with the outer world, each having its own microbial population. Our relationship with gut microbiota is usually commensal or mutualistic. However, a change in microbiota can result in dysbiosis, an imbalance that causes adverse effects in the human. For example, *Clostridium difficile,* or C-diff, is usually a minor component of the normal gut microbiota. But when antibiotic therapy kills normal microbiota, C-diff proliferates, producing two toxins that create significant inflammation and gas production in the intestines.

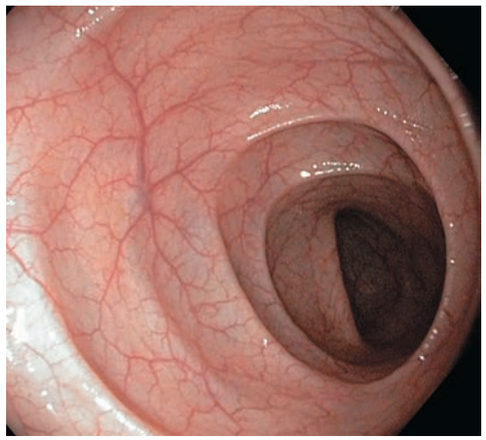
Could Dysbiosis Be the Cause of Inflammatory Bowel Diseases (IBD)?

Dysbiosis is now being closely studied as a possible cause for inflammatory bowel diseases such as ulcerative colitis and Crohn's disease. Rationale for this hypothesis hinges on the fact that some metabolic products of normal microbiota, such as butyrates, exert an antiinflammatory effect on the body.

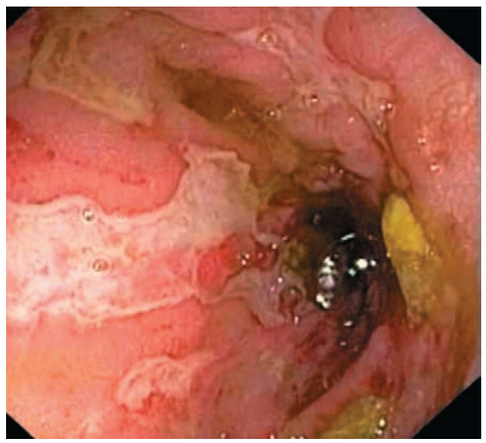
Crohn's disease, whose symptoms include swelling of the GI tract, is often characterized by excessive amounts of the cytokines tumor necrosis factor alpha (TNF-α) and interleukin-12 (IL-12). Researchers hypothesize that this excess could result from a disruption in the balance of normal microbiota that would usually help keep inflammatory cytokines under control.

Another clue being investigated regarding the link between IBD and microbiota is that these diseases are more common in developed countries than less-developed countries. Antibiotic usage tends to be higher in developed countries. Studies have demonstrated that the microbiome may not recover its full diversity after antibiotic treatment, which may lead to loss of organisms that would keep inflammation under control.





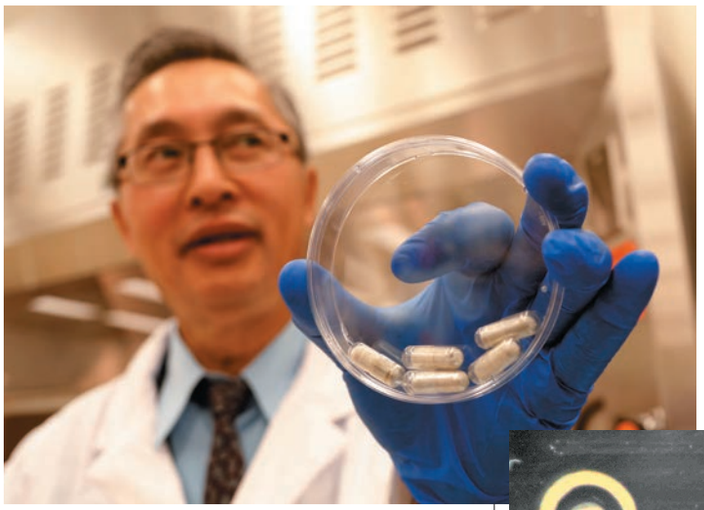
Endoscope view of a healthy colon



Endoscope view of an inflamed and ulcerated colon of a patient with Crohn's disease

Left: *Clostridium difficile,* or C-diff, can proliferate when antibiotics kill normal microbiota, leading to inflammation of the intestines.

Harnessing Microbes to Fight Inflammatory Bowel Diseases



Dr. Thomas Louie at the University of Calgary holds a dish of "poop pills" used for fecal transplantation. Photo credit: Associated Press

Below, eggs of *Trichuris suis*, the pig whipworm used to treat Crohn's disease

Fecal Transplants Shown to Successfully Treat *Clostridium difficile* Infections

Scientists have found success treating C-diff infections and some IBD with fecal microbiota transplants. Fecal transplants involve taking gut microbiota from a healthy individual (usually a family member) and then transplanting it into the patient via an enema, gastroscope, or nasojejunal tube, which is placed through the nose and runs down to the small intestine. Because this technique has been much more effective than antibiotic treatment, the FDA recently relaxed the restrictions it had placed on this procedure.

Researchers are working on ways to transplant microbiota in a more palatable fashion. Dr. Thomas Louie, an infectious disease specialist at the University of Calgary, has developed a method to deliver the microbiota in pills surrounded by a triple layer of gel, to prevent breakdown in the stomach. These "poop pills" have been successful in treating his patients with C-diff, and it is hoped that the process can also be used for IBD.

Treating Crohn's Disease with Worms

Hypotheses of how normal microbiota may assist our immune systems have led to some unusual treatments. One clinical study at the University of Iowa, where Crohn's patients were treated with pig whipworm eggs, found a 73% remission rate. Helminths, such as the whipworm, suppress certain T helper cell pathways – the exact pathways that are overactive in Crohn's disease. Since the worms don't take up residence in humans, the treatment must be repeated periodically to maintain the effect.

KEY CONCEPTS

- Normal microbiota are important in maintaining a healthy immune system. **(See Chapter 14, "Relationships Between Normal Microbiota and the Host," pages 391–393.)**
- The Human Microbiome Project is sequencing the genes for 16S ribosomal RNA to help scientists to catalogue normal microbiota that are difficult to culture and identify in the laboratory **(See Chapter 9, "Genome Projects," page 252.)**
- *Trichuris suis* is a roundworm related to *T. trichiura*. **(See Chapter 12, "Nematodes," page 349.)**
- Inflammatory diseases are characterized by increased amounts of cytokines produced by T helper cells, including tumor necrosis factor alpha and interleukins. **(See Chapter 16, "Inflammation," pages 452–455.)**

3

Each Big Picture spread is paired with a coaching activity and assessment questions within MasteringMicrobiology®.

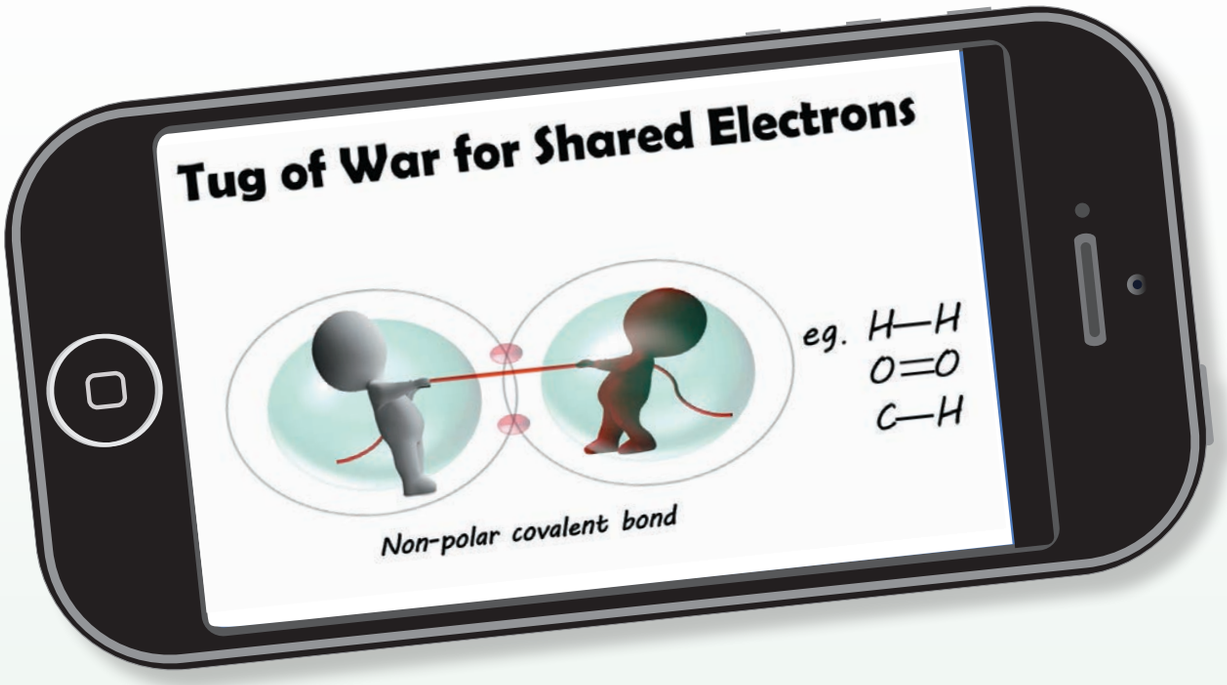
Big Picture spreads include Key Concepts that encourage students to make the connection between the presented topic and previously learned microbiology principles.

Three Big Picture spreads focus on the **most complex microbiology topics** and include an easy-to-reference overview that breaks down important concepts into manageable steps and gives students a clear learning framework for the related chapters:

Metabolism pp. 108–109
Genetics pp. 202–203
Immunity pp. 440–441

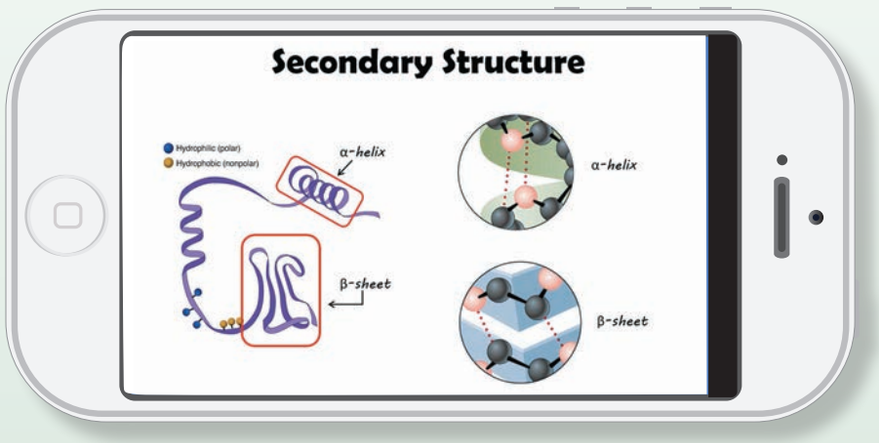
Access Study Tools Whenever and

MasteringMicrobiology® is now more mobile-friendly, allowing instructors to easily create 100% mobile-ready assignments that students can access using smartphones, tablets, and computers.

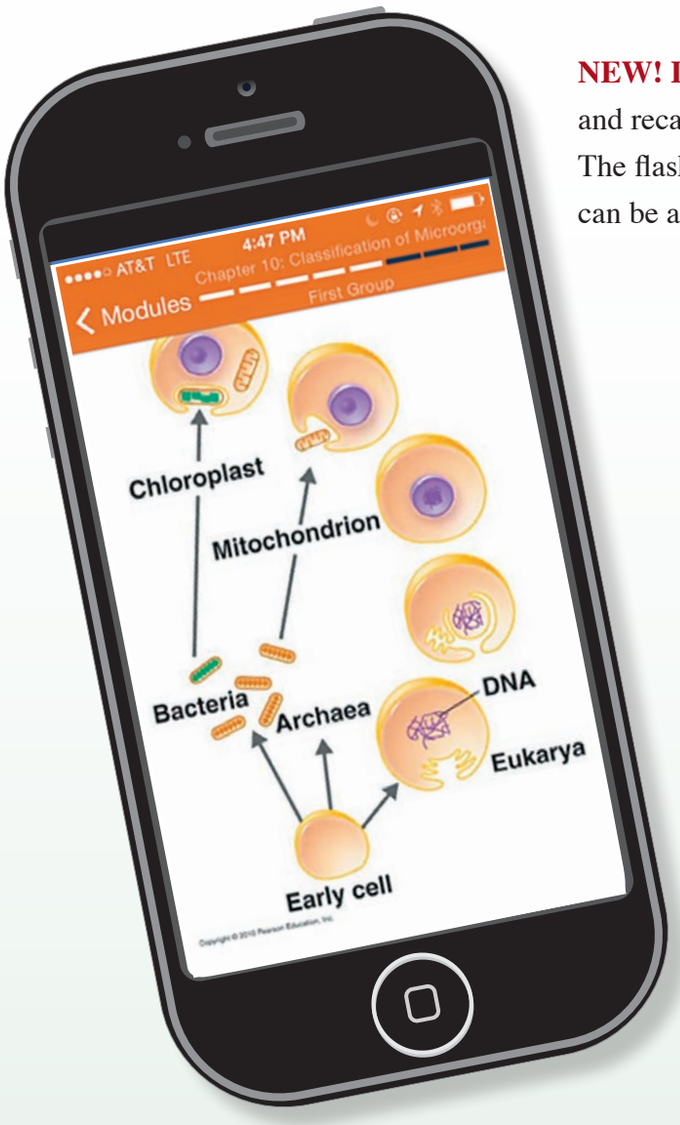


NEW! MicroBoosters are a suite of brief video tutorials that cover key concepts that some students may need to review or re-learn, including Study Skills, Math, Scientific Terminology, Basic Chemistry, Cell Biology, and Basic Biology.

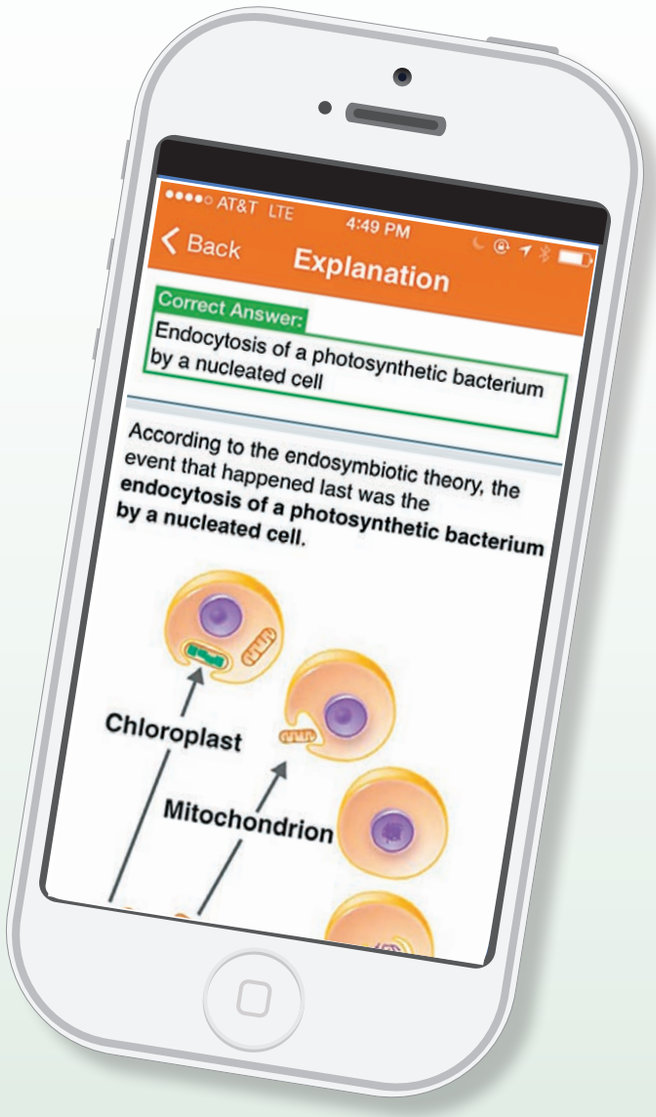
MicroBoosters can be assigned in the MasteringMicrobiology® Item Library or as Dynamic Study Modules, and are also available for student self-study in the Mastering Study Area.



Wherever You Need Them



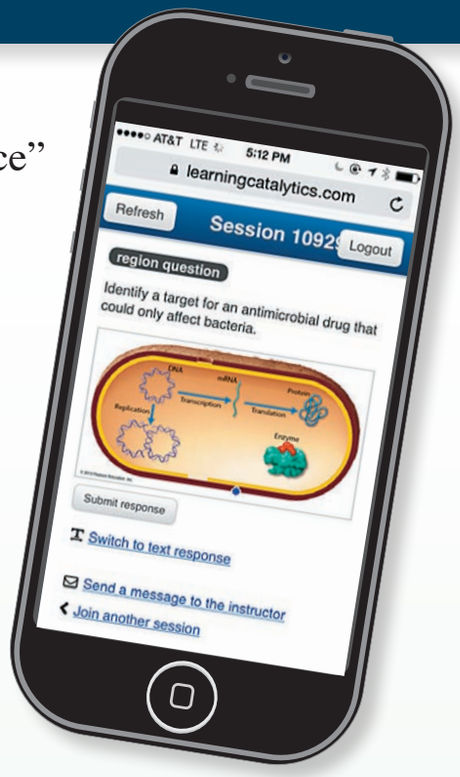
NEW! Dynamic Study Modules help students acquire, retain, and recall information faster and more efficiently than ever before. The flashcard-style modules are available as a self-study tool or can be assigned by the instructor.



NEW! Adaptive Follow-Up Assignments can be optionally assigned based on each student's performance on the original homework assignment and provide additional coaching and practice as needed. Exclusively available with ***Microbiology: An Introduction***, these question sets continuously adapt to each student's needs, making efficient use of study time.

Classroom Resources for Active Learning

NEW! Learning Catalytics is a "bring your own device" (laptop, smartphone, or tablet) student engagement, assessment, and classroom intelligence system. With Learning Catalytics, instructors can assess students in real time using open-ended tasks to probe student understanding. MasteringMicrobiology® users may select from Pearson's new library of questions designed especially for use with Learning Catalytics.



Instructor's Resource DVD for Microbiology: An Introduction
0-13-390553-5 / 978-0-13-390553-3

The Instructor's Resource DVD (IR-DVD) organizes all instructor media resources by chapter into one convenient and easy-to-use package. It contains:

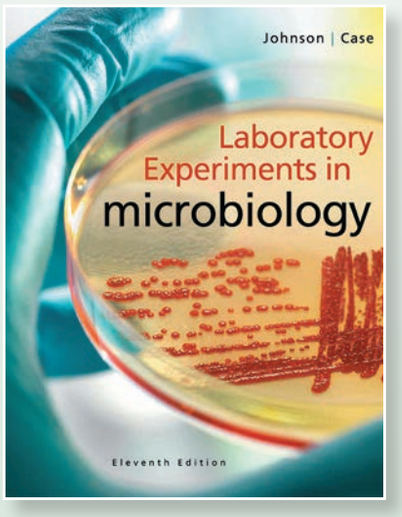
- All figures, photos, and tables from the textbook in both labeled and unlabeled formats
- TestGen Test Bank
- MicroFlix animations
- Instructor's Guide

A wealth of additional classroom resources can be downloaded from the "Instructor Resources" area of MasteringMicrobiology®.

Laboratory Experiments in Microbiology 11e
Johnson/Case
0-321-99493-0 / 978-0-321-99493-6

Engaging, comprehensive and customizable, ***Laboratory Experiments in Microbiology*** is the perfect companion lab manual for ***Microbiology: An Introduction***, Twelfth Edition.

Fourteen New Part-opening Case Studies show how the exercises are medically relevant to the students' future careers.



Lab and Lecture: Putting it All Together. Each exercise contains a feature in MasteringMicrobiology® that prompts students to connect the lab experiment to what they have learned in lecture.

Updates include new ASM biosafety protocols. Updates to the ASM BSL guidelines have changed how and what instructors do in lab. The authors revised each exercise to show which procedural steps and alternate bacteria are more appropriate for BSL-2 facilities.

MICRO BIOLOGY

AN INTRODUCTION

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MICROBIOLOGY

AN INTRODUCTION

TWELFTH EDITION

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Skyline College

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About the Authors

Courtesy of Rev. Dr. James F. Tortora

Gerard J. Tortora Jerry Tortora is a professor of biology and teaches microbiology, human anatomy and physiology at Bergen Community College in Paramus, New Jersey. He received his M.A. in Biology from Montclair State College in 1965. He belongs to a number of biology/microbiology organizations, such as the American Society for Microbiology (ASM), Human Anatomy and Physiology Society (HAPS), American Association for the Advancement of Science (AAAS), National Education Association (NEA), New Jersey Educational Association (NJEA), and the Metropolitan Association of College and University Biologists (MACUB). Jerry is the author of numerous biological science textbooks. In 1995, he was selected as one of the finest faculty scholars of Bergen Community College and was named Distinguished Faculty Scholar. In 1996, Jerry received a National Institute for Staff and Organizational Development (NISOD) excellence award from the University of Texas and was selected to represent Bergen Community College in a campaign to increase awareness of the contributions of community colleges to higher education.

Berdell R. Funke Bert Funke received his Ph.D., M.S., and B.S. in microbiology from Kansas State University. He has spent his professional years as a professor of microbiology at North Dakota State University. He taught introductory microbiology, including laboratory sections, general microbiology, food microbiology, soil microbiology, clinical parasitology, and pathogenic microbiology. As a research scientist in the Experiment Station at North Dakota State, he has published numerous papers in soil microbiology and food microbiology.

Christine L. Case Chris Case is a registered microbiologist and a professor of microbiology at Skyline College in San Bruno, California, where she has taught for the past 44 years. She received her Ed.D. in curriculum and instruction from Nova Southeastern University and her M.A. in microbiology from San Francisco State University. She was Director for the Society for Industrial Microbiology (SIM) and is an active member of the ASM and Northern California SIM. She received the ASM and California Hayward outstanding educator awards. In 2008, Chris received the SACNAS Distinguished Community/Tribal College Mentor Award for her commitment to her students, several of whom have presented at undergraduate research conferences and won awards. In addition to teaching, Chris contributes regularly to the professional literature, develops innovative educational methodologies, and maintains a personal and professional commitment to conservation and the importance of science in society. Chris is also an avid photographer, and many of her photographs appear in this book.

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Preface

Since the publication of the first edition nearly 30 years ago, well over 1 million students have used *Microbiology: An Introduction* at colleges and universities around the world, making it the leading textbook for non-majors microbiology. The twelfth edition continues to be a comprehensive beginning text, assuming no previous study of biology or chemistry. The text is appropriate for students in a wide variety of programs, including the allied health sciences, biological sciences environmental science, animal science, forestry, agriculture, home economics, and the liberal arts.

The twelfth edition has retained the features that have made this book so popular:

- **An appropriate balance between microbiological fundamentals and applications, and between medical applications and other applied areas of microbiology.** Basic microbiological principles are given greater emphasis, and health-related applications are featured.
- **Straightforward presentation of complex topics.** Each section of the text is written with the student in mind.
- **Clear, accurate, and pedagogically effective illustrations and photos.** Step-by-step diagrams that closely coordinate with narrative descriptions aid student comprehension of concepts.
- **Flexible organization.** We have organized the book in what we think is a useful fashion while recognizing that the material might be effectively presented in other sequences. For instructors who wish to use a different order, we have made each chapter as independent as possible and have included numerous cross-references. The Instructor's Guide provides detailed guidelines for organizing the material in several other ways.

NEW TO THE TWELFTH EDITION

The twelfth edition focuses on big-picture concepts and themes in microbiology, encouraging students to visualize and synthesize more difficult topics such as microbial metabolism, immunology, and microbial genetics.

The twelfth edition meets all students at their respective levels of skill and understanding while addressing the biggest challenges that instructors face. Updates to the twelfth edition enhance the book's consistent pedagogy and clear explanations. Some of the highlights follow.

- **Cutting-edge media integration.** MasteringMicrobiology (www.masteringmicrobiology.com) provides unprecedented, cutting-edge assessment resources for instructors as well as self-study tools for students. Big Picture Coaching Activities are paired with the book's new Big Picture: Tough Topics and Big Picture: Disease features; Interactive Microbiology is a dynamic suite of interactive tutorials and animations that teach key concepts in microbiology; and MicroBoosters are brief video tutorials that cover key concepts that some students need to review or re-learn.
- **Big Picture "tough topic" features.** These two-page spreads focus on the most challenging topics for students to master: metabolism (Chapter 5), genetics (Chapter 8), and immunology (Chapter 16). Each spread breaks down these important concepts into manageable steps and gives students a clear learning framework for the related chapters. Each includes a quick-reference (QR) code that allows students to link to related MicroFlix videos with their smartphones.
- **Big Picture Disease features.** These two-page spreads appear within each organ-system disease chapter (Chapters 21–26) as well as Chapter 19 (Disorders of the Immune System). Each spread focuses on a particular disease and applies it to a related real-world challenge, many dealing with public health issues.
- **Reworked complement section in Chapter 16 (Innate Immunity: Nonspecific Defenses of the Host).** New art and more straightforward discussions make this challenging and critical material easier for students to understand and retain.
- **In the Clinic.** This new feature, appearing at the start of every chapter, includes critical thinking questions that encourage students to think as health care professionals would in various clinical scenarios and spark student interest in the forthcoming chapter content.
- **ASM guidelines.** The American Society of Microbiology has released six underlying concepts and 22 related topics to provide a framework for key microbiological topics deemed to be of lasting importance beyond the classroom. The twelfth edition explains the themes and competencies at the beginning of the book and incorporates callouts when chapter content matches one of these 22 topics. Doing so addresses two key challenges: it helps students and instructors focus on the enduring principles of the course, and it provides another pedagogical tool for instructors to assess students' understanding and encourage critical thinking.

CHAPTER-BY-CHAPTER REVISIONS

Every chapter in this edition has been thoroughly revised, and data in the text, tables, and figures have been updated. The main changes to each chapter are summarized below.

Chapter 1

- New sections on Middle East respiratory syndrome (MERS), coronavirus, and severe acute respiratory syndrome (SARS) have been added.
- A new table, Table 1.2, addresses representative discoveries of the Golden Age of Microbiology.

Chapter 2

- The section on activation energy has been revised.

Chapter 3

- Foundation Figure 3.2, Microscopes and Magnification, has been revised.

Chapter 4

- The discussion of facilitated diffusion has been revised.
- The cell art has been revised.

Chapter 5

- A new Big Picture feature, addressing metabolism, has been added.
- The discussion of enzyme specificity has been revised.
- Figure 5.25, showing photophosphorylation, has been revised.
- The discussion of chemoheterotrophs has been revised.

Chapter 8

- A new Big Picture feature, addressing genetics, has been added.
- The central dogma of genetics is described.
- Mutation and gene transfers are now included in a new section.

Chapter 9

- Vectors are defined.

Chapter 10

- Figure 10.9, showing the new EnteroPluri-test, is revised.

Chapter 11

- The order Thiotrichales is now included.
- Discussion of the new genus *Cronobacter* has been added.
- Several of the figures have been replaced with improved illustrations.
- The tables have been revised and simplified.
- Nomenclature has been updated.

Chapter 12

- The discussion of algal and protozoan taxonomy is updated.

Chapter 13

- A discussion of the use of oncolytic viruses to treat cancer has been added.
- The discussion of viral enzymes has been revised.

Chapter 14

- The chapter has been updated to reflect the use of the term *healthcare-associated infection*.

Chapter 16

- A new Big Picture feature, addressing immunity, has been added.
- A new figure and discussion of hematopoiesis have been added.
- Figure 16.14 has been revised.
- The discussions of the complement system and interferons have been extensively revised.

Chapter 17

- The introductory material has been revised.
- Several figures have been revised.

Chapter 18

- The tables showing vaccination schedules have been updated.
- A discussion of virus-like particle (VLP) vaccines has been added.
- Clinical Focus box has been rewritten and updated.
- The discussions of vaccination technologies and monoclonal antibodies have been updated.

Chapter 19

- A new Big Picture Disease feature, Human Microbiome and IBD, has been added.
- The discussion of HIV/AIDS has been updated with new, informative maps.
- The chemotherapy of AIDS section has been completely revised, including new figures depicting the action of HIV therapies.

Chapter 20

- The discussion of antiviral drugs has been updated.
- The discussion of antibiotics effective against dormant cells has been expanded.

Chapter 21

- A new Big Picture Disease feature, Fungal Keratitis, has been added.
- A discussion of hand-foot-and-mouth disease is now included.

Chapter 22

- A new Big Picture Disease feature, Neglected Tropical Diseases, has been added.
- The discussion of developments in testing for leprosy has been updated.

Chapter 23

- A new Big Picture Disease feature, Climate Change and Disease, has been added.
- Several of the maps have been updated.
- The discussion of sepsis and septic shock has been revised.
- The discussion of Lyme disease has been revised to include the topic of immunity to reinfection.
- A discussion of Kawasaki syndrome has been added.
- The discussion of dengue and severe dengue is updated.

Chapter 24

- A new Big Picture Disease feature, Pertussis, has been added.
- The discussion of melioidosis has been updated.

Chapter 25

- A new Big Picture Disease feature, Cholera After Natural Disasters, has been added.

Chapter 26

- A new Big Picture Disease feature, STI Home Test Kits, has been added.

Acknowledgments

In preparing this textbook, we have benefited from the guidance and advice of a large number of microbiology instructors across the country. These reviewers have provided constructive criticism and valuable suggestions at various stages of the revision. We gratefully acknowledge our debt to these individuals.

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Gerard J. Tortora ***Berdell R. Funke*** ***Christine L. Case***

Brief Contents

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ASM Recommended Curriculum Guidelines for Undergraduate Microbiology

The American Society for Microbiology (ASM) endorses a concept-based curriculum for introductory microbiology, emphasizing skills and concepts that remain important long after students exit the course. The ASM *Curriculum Guidelines for Undergraduate Microbiology Education* provide a framework for key microbiological topics and agree with scientific literacy reports from the American Association for the Advancement of Science and Howard Hughes Medical Institute. This textbook references part one of curriculum guidelines throughout chapters. When a discussion touches on one of the concepts, readers will see the ASM icon, along with a summary of the relevant statement.

ASM GUIDELINE CONCEPTS AND STATEMENTS

Evolution:

- Cells, organelles (e.g., mitochondria and chloroplasts), and all major metabolic pathways evolved from early prokaryotic cells.
- Mutations and horizontal gene transfer, with the immense variety of microenvironments, have selected for a huge diversity of microorganisms.
- Human impact on the environment influences the evolution of microorganisms (e.g., emerging diseases and the selection of antibiotic resistance).
- Traditional concept of species is not readily applicable to microbes due to asexual reproduction and the frequent occurrence of horizontal gene transfer.
- Evolutionary relatedness of organisms is best reflected in phylogenetic trees.

Cell Structure and Function:

- Structure and function of microorganisms have been revealed by the use of microscopy (including brightfield, phase contrast, fluorescent, and electron).
- Bacteria have unique cell structures that can be targets for antibiotics, immunity, and phage infection.
- Bacteria and Archaea have specialized structures (e.g. flagella, endospores, and pili) that often confer critical capabilities.
- While microscopic eukaryotes (for example, fungi, protozoa, and algae) carry out some of the same processes as bacteria, many of the cellular properties are fundamentally different.
- Replication cycles of viruses (lytic and lysogenic) differ among viruses and are determined by their unique structures and genomes.

Metabolic Pathways:

- Bacteria and Archaea exhibit extensive, and often unique, metabolic diversity (e.g. nitrogen fixation, methane production, anoxygenic photosynthesis).
- Interactions of microorganisms among themselves and with their environment are determined by their metabolic abilities (e.g., quorum sensing, oxygen consumption, nitrogen transformations).
- Survival and growth of any microorganism in a given environment depends on its metabolic characteristics.
- Growth of microorganisms can be controlled by physical, chemical, mechanical, or biological means.

Information Flow and Genetics:

- Genetic variations can impact microbial functions (e.g. in biofilm formation, pathogenicity, and drug resistance).
- Although the central dogma is universal in all cells, the processes of replication, transcription, and translation differ in Bacteria, Archaea, and Eukaryotes.
- Regulation of gene expression is influenced by external and internal molecular cues and/or signals.
- Synthesis of viral genetic material and proteins is dependent on host cells.
- Cell genomes can be manipulated to alter cell function.

Microbial Systems:

- Microorganisms are ubiquitous and live in diverse and dynamic ecosystems.
- Most bacteria in nature live in biofilm communities.
- Microorganisms and their environment interact with and modify each other.
- Microorganisms, cellular and viral, can interact with both human and nonhuman hosts in beneficial, neutral, or detrimental ways.

Impact of Microorganisms:

- Microbes are essential for life as we know it and the processes that support life (e.g., in biogeochemical cycles and plant and/or animal microbiota).
- Microorganisms provide essential models that give us fundamental knowledge about life processes.
- Humans utilize and harness microorganisms and their products.
- Because the true diversity of microbial life is largely unknown, its effects and potential benefits have not been fully explored.

In the Clinic

As the nurse practitioner in a rural hospital, you are reviewing a microscope slide of a skin scraping from a 12-year-old girl. The slide shows branched, intertwined nucleated hyphae. The girl has dry, scaly, itchy patches on her arms.

What is causing her skin problem?

Hint: Read about types of microorganisms (pages 3–5).

Note: Answers to In the Clinic questions are found online at MasteringMicrobiology.

1 The Microbial World and You

The overall theme of this textbook is the relationship between microbes—very small organisms that usually require a microscope to be seen—and our lives. This relationship involves not only the familiar harmful effects of certain microorganisms, such as disease and food spoilage, but also their many beneficial effects. In this chapter we introduce you to some of the many ways microbes affect our lives. We begin by discussing how organisms are named and classified, followed by a short history of microbiology that reveals how much we have learned in just a few hundred years. Then we discuss the incredible diversity of microorganisms and their ecological importance, noting how they maintain balance in the environment by recycling chemical elements such as carbon and nitrogen among the soil, organisms, and the atmosphere. We also examine how microbes are used in commercial and industrial applications to produce foods, chemicals, and drugs (such as antibiotics); and to treat sewage, control pests, and clean up pollutants. We will discuss microbes as the cause of such diseases as avian (bird) flu, West Nile encephalitis, mad cow disease, diarrhea, hemorrhagic fever, and AIDS, and we examine the growing public health problem of antibiotic-resistant bacteria.

ASM: Microorganisms provide essential models that give us fundamental knowledge about life processes.

Staphylococcus aureus (STAF-i-lō-kok'kus OR-ē-us) bacteria on human nasal epithelial cells are shown in the photograph. These bacteria live harmlessly on skin or inside the nose. Misuse of antibiotics allows the survival of bacteria with antibiotic-resistance genes, such as methicillin-resistant *S. aureus* (MRSA). As illustrated in the Clinical Case, an infection caused by these bacteria is resistant to antibiotic treatment.

Staphylococcus aureus **bacteria on human nasal epithelial cells.**

Microbes in Our Lives

LEARNING OBJECTIVE

1-1 List several ways in which microbes affect our lives.

For many people, the words *germ* and *microbe* bring to mind a group of tiny creatures that do not quite fit into any of the categories in that old question, "Is it animal, vegetable, or mineral?" **Microbes,** also called **microorganisms,** are minute living things that individually are usually too small to be seen with the unaided eye. The group includes bacteria, fungi (yeasts and molds), protozoa, and microscopic algae. It also includes viruses, those noncellular entities sometimes regarded as straddling the border between life and nonlife (Chapters 11, 12, and 13, respectively).

We tend to associate these small organisms only with uncomfortable infections, with common inconveniences such as spoiled food, or with major diseases such as AIDS. However, the majority of microorganisms actually help maintain the balance of life in our environment. Marine and freshwater microorganisms form the basis of the food chain in oceans, lakes, and rivers. Soil microbes help break down wastes and incorporate nitrogen gas from the air into organic compounds, thereby recycling chemical elements among soil, water, living organisms, and air. Certain microbes play important roles in *photosynthesis,* a food- and oxygen-generating process that is critical to life on Earth. Humans and many other animals depend on the microbes in their intestines for digestion and the synthesis of some vitamins that their bodies require, including some B vitamins for metabolism and vitamin K for blood clotting.

Microorganisms also have many commercial applications. They are used in the synthesis of such chemical products as vitamins, organic acids, enzymes, alcohols, and many drugs. For example, microbes are used to produce acetone and butanol, and the vitamins B_2 (riboflavin) and B_{12} (cobalamin) are made biochemically. The process by which microbes produce acetone and butanol was discovered in 1914 by Chaim Weizmann, a Russian-born chemist working in England. With the outbreak of World War I in August of that year, the production of acetone became very important for making cordite (a smokeless form of gunpowder used in munitions). Weizmann's discovery played a significant role in determining the outcome of the war.

The food industry also uses microbes in producing, for example, vinegar, sauerkraut, pickles, soy sauce, cheese, yogurt, bread, and alcoholic beverages. In addition, enzymes from microbes can now be manipulated to cause the microbes to produce substances they normally don't synthesize, including cellulose, digestive aids, and drain cleaner, plus important therapeutic substances such as insulin. Microbial enzymes may even have helped produce your favorite pair of jeans (see the Applications of Microbiology box).

Though only a minority of microorganisms are **pathogenic** (disease-producing), practical knowledge of microbes is necessary for medicine and the related health sciences. For example, hospital workers must be able to protect patients from common microbes that are normally harmless but pose a threat to the sick and injured.

Today we understand that microorganisms are found almost everywhere. Yet not long ago, before the invention of the microscope, microbes were unknown to scientists. Thousands of people died in devastating epidemics, the causes and transmission of which were not understood. Entire families died because vaccinations and antibiotics were not available to fight infections.

We can get an idea of how our current concepts of microbiology developed by looking at a few historic milestones in microbiology that have changed our lives. First, however, we will look at the major groups of microbes and how they are named and classified.

CHECK YOUR UNDERSTANDING

- Describe some of the destructive and beneficial actions of microbes. **1-1***

Naming and Classifying Microorganisms

LEARNING OBJECTIVES

1-2 Recognize the system of scientific nomenclature that uses two names: a genus and a specific epithet.

1-3 Differentiate the major characteristics of each group of microorganisms.

1-4 List the three domains.

Nomenclature

The system of nomenclature (naming) for organisms in use today was established in 1735 by Carolus Linnaeus. Scientific names are latinized because Latin was the language traditionally used by scholars. Scientific nomenclature assigns each organism two names—the **genus** (plural: *genera*) is the first name and is always capitalized; the **specific epithet** (**species** name) follows and is not capitalized. The organism is referred to by both the genus and the specific epithet, and both names are underlined or italicized. By custom, after a scientific name has been mentioned once, it can be abbreviated with the initial of the genus followed by the specific epithet.

Scientific names can, among other things, describe an organism, honor a researcher, or identify the habitat of a species. For example, consider *Staphylococcus aureus,* a bacterium commonly found on human skin. *Staphylo-* describes the clustered arrangement of the cells; *-coccus* indicates that they are shaped like spheres. The specific epithet, *aureus,* is Latin for golden,

*The numbers following Check Your Understanding questions refer to the corresponding Learning Objectives.

Designer Jeans: Made by Microbes?

Denim blue jeans have been popular ever since Levi Strauss and Jacob Davis first made them for California gold miners in 1873. Now, companies that manufacture blue jeans are turning to microbiology to develop environmentally sound production methods that minimize toxic wastes and the associated costs.

Soft, Faded Jeans

A softer, faded denim is made with enzymes called *cellulases* from *Trichoderma* fungus. They digest some of the cellulose in the cotton. Unlike many chemical reactions, enzymes usually operate at safe temperatures and pH. Moreover, enzymes are proteins, so they are readily degraded for removal from wastewater.

Fabric

Cotton production requires large tracts of land, pesticides, and fertilizer, and the crop yield depends on the weather. However, bacteria can produce both cotton and polyester with less environmental impact. *Gluconacetobacter xylinus* bacteria make cellulose by attaching glucose units to simple chains in the outer membrane of the bacterial cell wall. The cellulose microfibrils are extruded through pores in the outer membrane, and bundles of microfibrils then twist into ribbons.

Bleaching

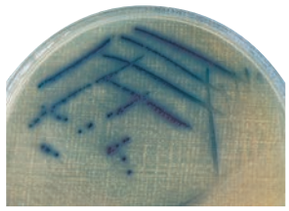
Peroxide is a safer bleaching agent than chlorine and can be easily removed from fabric and wastewater by enzymes. Researchers at Novo Nordisk Biotech cloned a mushroom peroxidase gene in yeast and grew the yeasts in washing machine conditions. The yeast that survived the washing machine were selected as the peroxidase producers.

Indigo

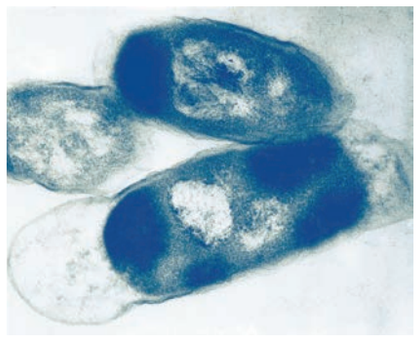
Chemical synthesis of indigo requires a high pH and produces waste that explodes on contact with air. However, a California biotechnology company, Genencor, has developed a method to produce indigo by using bacteria. Researchers identified a gene from a soil bacterium, *Pseudomonas putida*, that converts the bacterial by-product indole to indigo. This gene was put into *Escherichia coli* bacteria, which then turned blue.

Bioplastic

Microbes can even make plastic zippers and packaging material for the jeans. Over 25 bacteria make polyhydroxyalkanoate (PHA) inclusion granules as a food reserve. PHAs are similar to common plastics, and because they are made by bacteria, they are also readily degraded by many bacteria. PHAs could provide a biodegradable alternative to conventional plastic, which is made from petroleum.



***E. coli* bacteria produce indigo from tryptophan.**



Indigo-producing *E. coli* bacteria.

0.3 μm

TEM

the color of many colonies of this bacterium. The genus of the bacterium *Escherichia coli* (esh′er-IK-ē-ah KŌ-lī, or KŌ-lē) is named for a scientist, Theodor Escherich, whereas its specific epithet, *coli,* reminds us that *E. coli* live in the colon, or large intestine. Table 1.1 contains more examples.

CHECK YOUR UNDERSTANDING

Distinguish a genus from a specific epithet. 1-2

Types of Microorganisms

Here is an overview of the main types of microorganisms. (The classification and identification of microorganisms are discussed in Chapter 10.)

Bacteria

Bacteria (singular: **bacterium**) are relatively simple, single-celled (unicellular) organisms. Because their genetic material is not enclosed in a special nuclear membrane, bacterial cells are called **prokaryotes** (prō-KAR-e-ōts), from Greek words meaning pre-nucleus. Prokaryotes include both bacteria and archaea.

Clinical Case: A Simple Spider Bite?

Andrea is a normally healthy 22-year-old college student who lives at home with her mother and younger sister, a high school gymnast. She is trying to work on a paper for her psychology class but is having a hard time because a red, swollen sore on her right wrist is making typing difficult. "Why won't this spider bite heal?" she wonders. "It's been there for days!" She makes an appointment with her doctor so she can show him the painful lesion. Although Andrea does not have a fever, she does have an elevated white blood cell count that indicates a bacterial infection. Andrea's doctor suspects that this isn't a spider bite at all, but a staph infection. He prescribes a β-lactam antibiotic, cephalosporin. Learn more about the development of Andrea's illness on the following pages.

What is staph? Read on to find out.

TABLE 1.1 Making Scientific Names Familiar

Use the word roots guide to find out what the name means. The name will not seem so strange if you translate it. When you encounter a new name, practice saying it out loud (guidelines for pronunciation are given in Appendix D). The exact pronunciation is not as important as the familiarity you will gain.

Following are some examples of microbial names you may encounter in the popular press as well as in the lab.

	Pronunciation	Source of Genus Name	Source of Specific Epithet
Salmonella enterica (bacterium)	sal'mōn-EL-lah en-TER-i-kah	Honors public health microbiologist Daniel Salmon	Found in the intestines (*entero-*)
Streptococcus pyogenes (bacterium)	strep'tō-KOK-kus pī-AH-jen-ēz	Appearance of cells in chains (*strepto-*)	Forms pus (*pyo-*)
Saccharomyces cerevisiae (yeast)	sak'kar-ō-MĪ-sēz se-ri-VIS-ē-ī	Fungus (*-myces*) that uses sugar (*saccharo-*)	Makes beer (*cerevisia*)
Penicillium chrysogenum (fungus)	pen'i-SIL-lē-um krī-SO-jen-um	Tuftlike or paintbrush (*penicill-*) appearance microscopically	Produces a yellow (*chryso-*) pigment
Trypanosoma cruzi (protozoan)	TRI-pa-nō-sō-mah KROOZ-ē	Corkscrew- (*trypano-*, borer; *soma-*, body)	Honors epidemiologist Oswaldo Cruz

Bacterial cells generally appear in one of several shapes. *Bacillus* (bah-SIL-lus) (rodlike), illustrated in **Figure 1.1a**, *coccus* (KOK-kus) (spherical or ovoid), and *spiral* (corkscrew or curved) are among the most common shapes, but some bacteria are star-shaped or square (see Figures 4.1 through 4.5, pages 74–75). Individual bacteria may form pairs, chains, clusters, or other groupings; such formations are usually characteristic of a particular genus or species of bacteria.

Bacteria are enclosed in cell walls that are largely composed of a carbohydrate and protein complex called *peptidoglycan.* (By contrast, cellulose is the main substance of plant and algal cell walls.) Bacteria generally reproduce by dividing into two equal cells; this process is called *binary fission.* For nutrition, most bacteria use organic chemicals, which in nature can be derived from either dead or living organisms. Some bacteria can manufacture their own food by photosynthesis, and some can derive nutrition from inorganic substances. Many bacteria can "swim" by using moving appendages called *flagella.* (For a complete discussion of bacteria, see Chapter 11.)

Archaea

Like bacteria, **archaea** (AR-kē-ah) consist of prokaryotic cells, but if they have cell walls, the walls lack peptidoglycan. Archaea, often found in extreme environments, are divided into three main groups. The *methanogens* produce methane as a waste product from respiration. The *extreme halophiles* (*halo* = salt; *philic* = loving) live in extremely salty environments such as the Great Salt Lake and the Dead Sea. The *extreme thermophiles* (*therm* = heat) live in hot sulfurous water, such as hot springs at Yellowstone National Park. Archaea are not known to cause disease in humans.

Fungi

Fungi (singular: **fungus**) are **eukaryotes** (ū-KAR-ē-ōts), organisms whose cells have a distinct nucleus containing the cell's genetic material (DNA), surrounded by a special envelope called the nuclear membrane. Organisms in the Kingdom Fungi may be unicellular or multicellular (see Chapter 12, page 320). Large multicellular fungi, such as mushrooms, may look somewhat like plants, but unlike most plants, fungi cannot carry out photosynthesis. True fungi have cell walls composed primarily of a substance called *chitin.* The unicellular forms of fungi, *yeasts,* are oval microorganisms that are larger than bacteria. The most typical fungi are *molds* (Figure 1.1b). Molds form visible masses called *mycelia,* which are composed of long filaments (*hyphae*) that branch and intertwine. The cottony growths sometimes found on bread and fruit are mold mycelia. Fungi can reproduce sexually or asexually. They obtain nourishment by absorbing solutions of organic material from their environment—whether soil, seawater, freshwater, or an animal or plant host. Organisms called *slime molds* have characteristics of both fungi and amebae (see Chapter 12).

Protozoa

Protozoa (singular: **protozoan**) are unicellular eukaryotic microbes (see Chapter 12, page 337). Protozoa move by pseudopods, flagella, or cilia. Amebae (Figure 1.1c) move by using extensions of their cytoplasm called *pseudopods* (false feet). Other protozoa have long *flagella* or numerous shorter appendages for locomotion called *cilia.* Protozoa have a variety of shapes and live either as free entities or as *parasites* (organisms that derive nutrients from living hosts) that absorb or ingest organic compounds from their environment. Some protozoa, such as *Euglena* (ū-GLĒ-nah), are photosynthetic. They use light as a source of energy and carbon

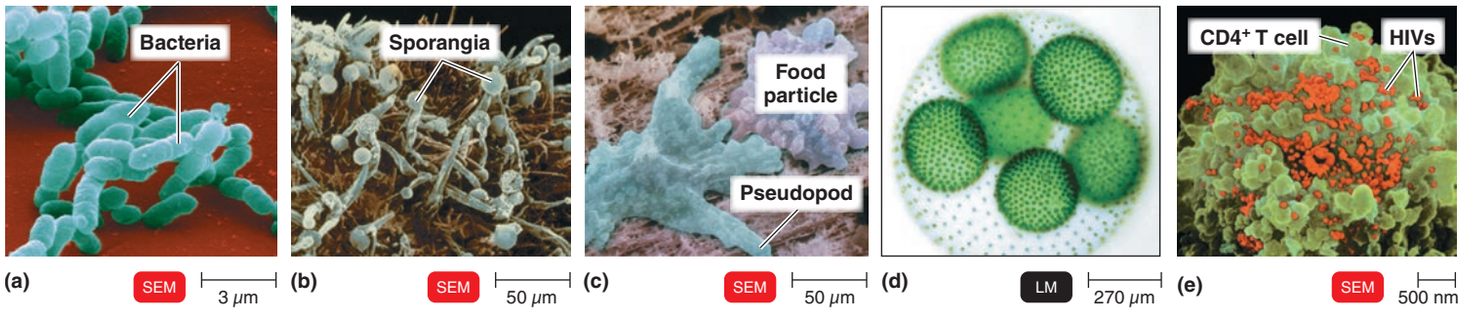


Figure 1.1 Types of microorganisms. **(a)** The rod-shaped bacterium *Haemophilus influenzae,* one of the bacterial causes of pneumonia. **(b)** *Mucor,* a common bread mold, is a type of fungus. When released from sporangia, spores that land on a favorable surface germinate into a network of hyphae (filaments) that absorb nutrients. **(c)** An ameba, a protozoan, approaching a food particle. **(d)** The pond alga *Volvox.* **(e)** Human immunodeficiency viruses (HIVs), the causative agent of AIDS, budding from a $CD4^+$ T cell.

Q How are bacteria, archaea, fungi, protozoa, algae, and viruses distinguished on the basis of cellular structure?

NOTE: Throughout the book, a red icon under a micrograph indicates that the micrograph has been artificially colored. SEM (scanning electron microscope) and LM (light microscope) scales are discussed in detail in Chapter 3.

dioxide as their chief source of carbon to produce sugars. Protozoa can reproduce sexually or asexually.

Algae

Algae (singular: **alga**) are photosynthetic eukaryotes with a wide variety of shapes and both sexual and asexual reproductive forms (Figure 1.1d). The algae of interest to microbiologists are usually unicellular (see Chapter 12, page 332). The cell walls of many algae are composed of a carbohydrate called *cellulose.* Algae are abundant in freshwater and saltwater, in soil, and in association with plants. As photosynthesizers, algae need light, water, and carbon dioxide for food production and growth, but they do not generally require organic compounds from the environment. As a result of photosynthesis, algae produce oxygen and carbohydrates that are then utilized by other organisms, including animals. Thus, they play an important role in the balance of nature.

Viruses

Viruses (Figure 1.1e) are very different from the other microbial groups mentioned here. They are so small that most can be seen only with an electron microscope, and they are acellular (not cellular). Structurally very simple, a virus particle contains a core made of only one type of nucleic acid, either DNA or RNA. This core is surrounded by a protein coat, which is sometimes encased by a lipid membrane called an envelope. All living cells have RNA *and* DNA, can carry out chemical reactions, and can reproduce as self-sufficient units. Viruses can reproduce only by using the cellular machinery of other organisms. Thus, on the one hand, viruses are considered to be living only when they multiply within host cells they infect. In this sense, viruses are parasites of other forms of life. On the other hand, viruses are not considered to be living because they are inert outside living hosts. (Viruses will be discussed in detail in Chapter 13.)

Multicellular Animal Parasites

Although multicellular animal parasites are not strictly microorganisms, they are of medical importance and therefore will be discussed in this text. Animal parasites are eukaryotes. The two major groups of parasitic worms are the flatworms and the roundworms, collectively called **helminths** (see Chapter 12, page 343). During some stages of their life cycle, helminths are microscopic in size. Laboratory identification of these organisms includes many of the same techniques used for identifying microbes.

CHECK YOUR UNDERSTANDING

Which groups of microbes are prokaryotes? Which are eukaryotes? **1-3**

Classification of Microorganisms

Before the existence of microbes was known, all organisms were grouped into either the animal kingdom or the plant kingdom. When microscopic organisms with characteristics of animals and plants were discovered late in the seventeenth century, a new system of classification was needed. Still, biologists couldn't agree on the criteria for classifying these new organisms until the late 1970s.

In 1978, Carl Woese devised a system of classification based on the cellular organization of organisms. It groups all organisms in three domains as follows:

1. Bacteria (cell walls contain a protein–carbohydrate complex called peptidoglycan)
2. Archaea (cell walls, if present, lack peptidoglycan)
3. Eukarya, which includes the following:
   - Protists (slime molds, protozoa, and algae)
   - Fungi (unicellular yeasts, multicellular molds, and mushrooms)

- Plants (mosses, ferns, conifers, and flowering plants)
- Animals (sponges, worms, insects, and vertebrates)

Classification will be discussed in more detail in Chapters 10 through 12.

CHECK YOUR UNDERSTANDING

What are the three domains? **1-4**

A Brief History of Microbiology

LEARNING OBJECTIVES

1-5 Explain the importance of observations made by Hooke and van Leeuwenhoek.
1-6 Compare spontaneous generation and biogenesis.
1-7 Identify the contributions to microbiology made by Needham, Spallanzani, Virchow, and Pasteur.
1-8 Explain how Pasteur's work influenced Lister and Koch.
1-9 Identify the importance of Koch's postulates.
1-10 Identify the importance of Jenner's work.
1-11 Identify the contributions to microbiology made by Ehrlich and Fleming.
1-12 Define *bacteriology, mycology, parasitology, immunology,* and *virology*.
1-13 Explain the importance of microbial genetics and molecular biology.

Bacterial ancestors were the first living cells to appear on Earth. For most of human history, people knew little about the true causes, transmission, and effective treatment of disease. Let's look now at some key developments in microbiology that have spurred the field to its current technological state.

The First Observations

In 1665, after observing a thin slice of cork through a crude microscope, Englishman Robert Hooke reported that life's smallest structural units were "little boxes," or "cells." Using his improved microscope, Hooke later saw individual cells. Hooke's discovery marked the beginning of the **cell theory**—the theory that *all living things are composed of cells.*

Though Hooke's microscope was capable of showing large cells, it lacked the resolution that would have allowed him to see microbes clearly. Dutch merchant and amateur scientist Anton van Leeuwenhoek was probably the first to observe live microorganisms through the magnifying lenses of the more than 400 microscopes he constructed. Between 1673 and 1723, he wrote about the "animalcules" he saw through his simple, single-lens microscopes. Van Leeuwenhoek made detailed drawings of organisms he found in rainwater, feces, and material scraped from teeth. These drawings have since been identified as representations of bacteria and protozoa (**Figure 1.2**).

CHECK YOUR UNDERSTANDING

What is the cell theory? **1-5**

The Debate over Spontaneous Generation

After van Leeuwenhoek discovered the previously "invisible" world of microorganisms, the scientific community became interested in the origins of these tiny living things. Until the second half of the nineteenth century, many scientists and philosophers believed that some forms of life could arise spontaneously from nonliving matter; they called this hypothetical process **spontaneous generation.** Not much more than 100 years ago, people commonly believed that toads, snakes, and mice could be born of moist soil; that flies could emerge from manure; and that maggots (which we now know are the larvae of flies) could arise from decaying corpses.

Physician Francesco Redi set out in 1668 to demonstrate that maggots did not generate spontaneously. Redi filled two jars with decaying meat. The first was left unsealed, allowing flies to lay eggs on the meat, which developed into larvae. The second jar was sealed, and because the flies could not get inside, no maggots appeared. Still, Redi's antagonists were not convinced; they claimed that fresh air was needed for spontaneous generation. So Redi set up a second experiment, in which he covered a jar with a fine net instead of sealing it. No larvae appeared in the gauze-covered jar, even though air was present.

Redi's results were a serious blow to the long-held belief that large forms of life could arise from nonlife. However, many scientists still believed that small organisms, such as van Leeuwenhoek's "animalcules," were simple enough to generate from nonliving materials.

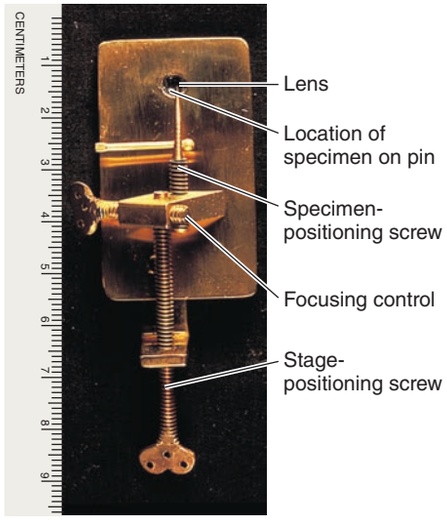
The case for spontaneous generation of microorganisms seemed to be strengthened in 1745, when John Needham found that even after he heated chicken broth and corn broth before pouring them into covered flasks, the cooled solutions were soon teeming with microorganisms. Needham claimed that microbes developed spontaneously from the fluids. Twenty years later, Lazzaro Spallanzani suggested that microorganisms from the air probably entered Needham's solutions after they were boiled. Spallanzani showed that nutrient fluids heated *after* being sealed in a flask did not develop microbial growth. Needham responded by claiming the "vital force" necessary for spontaneous generation had been destroyed by the heat and was kept out of the flasks by the seals.

Spallanzani's observations were also criticized on the grounds that there was not enough oxygen in the sealed flasks to support microbial life.

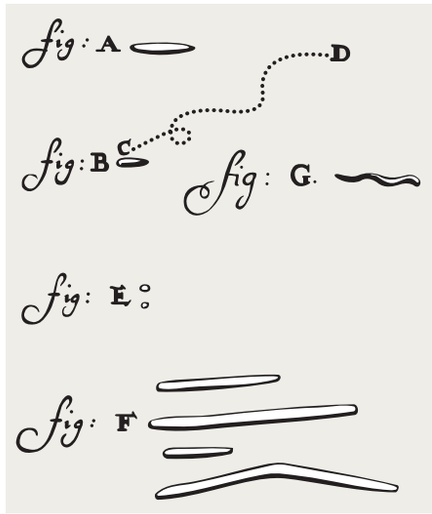
The Theory of Biogenesis

In 1858 Rudolf Virchow challenged the case for spontaneous generation with the concept of **biogenesis,** hypothesizing that living cells arise only from preexisting living cells. Because he could offer no scientific proof, arguments about spontaneous generation

(a) Van Leeuwenhoek using his microscope



(b) Microscope replica



(c) Drawings of bacteria

Figure 1.2 Anton van Leeuwenhoek's microscopic observations. **(a)** By holding his brass microscope toward a source of light, van Leeuwenhoek was able to observe living organisms too small to be seen with the unaided eye. **(b)** The specimen was placed on the tip of the adjustable point and viewed from the other side through the tiny, nearly spherical lens. The highest magnification possible with his microscopes was about 300× (times). **(c)** Some of van Leeuwenhoek's drawings of bacteria, made in 1683. The letters represent various shapes of bacteria. C–D represents a path of motion he observed.

Q Why was van Leeuwenhoek's discovery so important?

continued until 1861, when the issue was finally resolved by the French scientist Louis Pasteur.

Pasteur demonstrated that microorganisms are present in the air and can contaminate sterile solutions, but that air itself does not create microbes. He filled several short-necked flasks with beef broth and then boiled their contents. Some were then left open and allowed to cool. In a few days, these flasks were found to be contaminated with microbes. The other flasks, sealed after boiling, were free of microorganisms. From these results, Pasteur reasoned that microbes in the air were the agents responsible for contaminating nonliving matter.

Pasteur next placed broth in open-ended, long-necked flasks and bent the necks into S-shaped curves (**Figure 1.3**). The contents of these flasks were then boiled and cooled. The broth in the flasks did not decay and showed no signs of life, even after months. Pasteur's unique design allowed air to pass into the flask, but the curved neck trapped any airborne microorganisms that might contaminate the broth. (Some of these original vessels are still on display at the Pasteur Institute in Paris. They have been sealed but, like the flask in Figure 1.3, show no sign of contamination more than 100 years later.)

Pasteur showed that microorganisms can be present in nonliving matter—on solids, in liquids, and in the air. Furthermore, he demonstrated conclusively that microbial life can be destroyed by heat and that methods can be devised to block the access of airborne microorganisms to nutrient environments. These discoveries form the basis of **aseptic techniques,** procedures that prevent contamination by unwanted microorganisms, which are now the standard practice in laboratory and many medical procedures. Modern aseptic techniques are among the first and most important concepts that a beginning microbiologist learns.

Pasteur's work provided evidence that microorganisms cannot originate from mystical forces present in nonliving materials. Rather, any appearance of "spontaneous" life in nonliving solutions can be attributed to microorganisms that were already present in the air or in the fluids themselves. Scientists now believe that a form of spontaneous generation probably did occur on the primitive Earth when life first began, but they agree that this does not happen under today's environmental conditions.

CHECK YOUR UNDERSTANDING

- What evidence supported spontaneous generation? **1-6**
- How was spontaneous generation disproved? **1-7**

The Golden Age of Microbiology

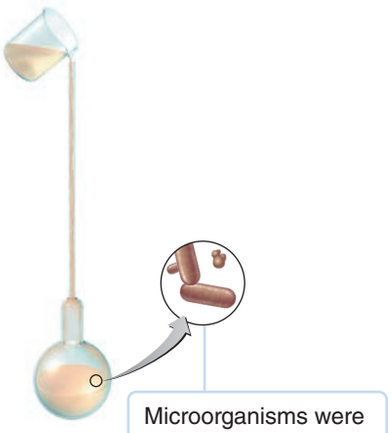
The period from 1857 to 1914 has been appropriately named the Golden Age of Microbiology. Rapid advances, spearheaded mainly by Pasteur and Robert Koch, led to the establishment of microbiology. Discoveries included both the agents of many diseases and the role of immunity in preventing and curing disease. During this

FOUNDATION FIGURE 1.3

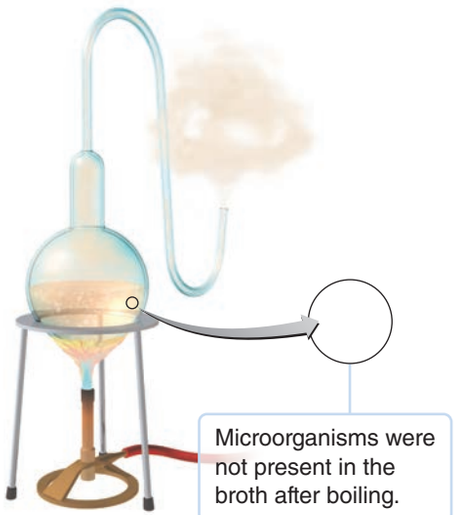
Disproving the Theory of Spontaneous Generation

According to the theory of spontaneous generation, life can arise spontaneously from nonliving matter, such as dead corpses and soil. Pasteur's experiment, described below, demonstrated that microbes are present in nonliving matter—air, liquids, and solids.

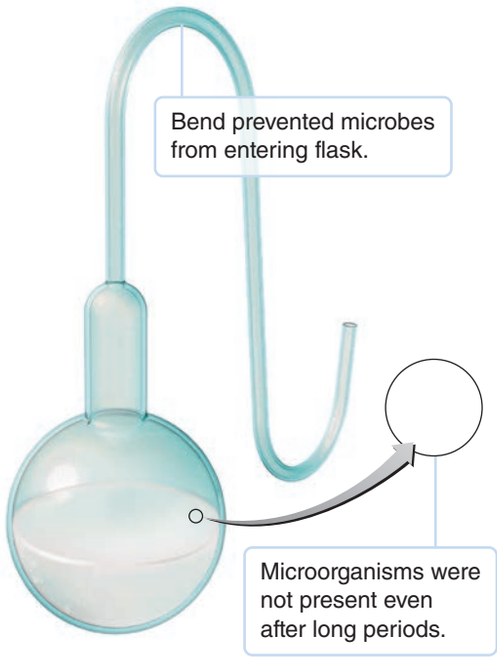
1 Pasteur first poured beef broth into a long-necked flask.



2 Next he heated the neck of the flask and bent it into an S-shape; then he boiled the broth for several minutes.



3 Microorganisms did not appear in the cooled solution, even after long periods.



Some of these original vessels are still on display at the Pasteur Institute in Paris. They have been sealed but show no sign of contamination more than 100 years later.

KEY CONCEPTS

- Pasteur demonstrated that microbes are responsible for food spoilage, leading researchers to the connection between microbes and disease.
- His experiments and observations provided the basis of aseptic techniques, which are used to prevent microbial contamination, as shown in the photo at right.

productive period, microbiologists studied the chemical activities of microorganisms, improved the techniques for performing microscopy and culturing microorganisms, and developed vaccines and surgical techniques. Some of the major events that occurred during the Golden Age of Microbiology are listed in Figure 1.4.

Fermentation and Pasteurization

One of the key steps that established the relationship between microorganisms and disease occurred when a group of French merchants asked Pasteur to find out why wine and beer soured. They hoped to develop a method that would prevent spoilage when those beverages were shipped long distances. At the time, many scientists believed that air converted the sugars in these fluids into alcohol. Pasteur found instead that microorganisms called yeasts convert the sugars to alcohol in the absence of air. This process, called **fermentation** (see Chapter 5, page 127), is used to make wine and beer. Souring and spoilage are caused by different microorganisms, called bacteria. In the presence of air, bacteria change the alcohol into vinegar (acetic acid).

Pasteur's solution to the spoilage problem was to heat the beer and wine just enough to kill most of the bacteria that caused the spoilage. The process, called **pasteurization,** is now commonly used to reduce spoilage and kill potentially harmful bacteria in milk as well as in some alcoholic drinks.

The Germ Theory of Disease

Before the time of Pasteur, effective treatments for many diseases were discovered by trial and error, but the causes of the diseases were unknown. The realization that yeasts play a crucial role in fermentation was the first link between the activity of a microorganism and

Golden Age of MICROBIOLOGY

1857	**Pasteur**—Fermentation
1861	**Pasteur**—Disproved spontaneous generation
1864	**Pasteur**—Pasteurization
1867	**Lister**—Aseptic surgery
1876	**Koch***—Germ theory of disease
1879	**Neisser**—*Neisseria gonorrhoeae*
1881	**Koch***—Pure cultures
	Finlay—Yellow fever
1882	**Koch***—*Mycobacterium tuberculosis*
	Hess—Agar (solid) media
1883	**Koch***—*Vibrio cholerae*
1884	**Metchnikoff***—Phagocytosis
	Gram—Gram-staining procedure
	Escherich—*Escherichia coli*
1887	**Petri**—Petri dish
1889	**Kitasato**—*Clostridium tetani*
1890	**von Bering***—Diphtheria antitoxin
	Ehrlich*—Theory of immunity
1892	**Winogradsky**—Sulfur cycle
1898	**Shiga**—*Shigella dysenteriae*
1908	**Ehrlich***—Syphilis treatment
1910	**Chagas**—*Trypanosoma cruzi*
1911	**Rous***—Tumor-causing virus (1966 Nobel Prize)

Louis Pasteur (1822–1895)
Demonstrated that life did not arise spontaneously from nonliving matter.

Joseph Lister (1827–1912)
Performed surgery under aseptic conditions using phenol. Proved that microbes caused surgical wound infections.

Robert Koch (1843–1910)
Established experimental steps for directly linking a specific microbe to a specific disease.

Figure 1.4 Milestones in the Golden Age of Microbiology. An asterisk (*) indicates a Nobel laureate.

Q Why do you think the Golden Age of Microbiology occurred when it did?

physical and chemical changes in organic materials. This discovery alerted scientists to the possibility that microorganisms might have similar relationships with plants and animals—specifically, that microorganisms might cause disease. This idea was known as the **germ theory of disease.**

The germ theory met great resistance at first because for centuries disease was believed to be punishment for an individual's crimes or misdeeds. When the inhabitants of an entire village became ill, people often blamed the disease on demons appearing as foul odors from sewage or on poisonous vapors from swamps. Most people born in Pasteur's time found it inconceivable that "invisible" microbes could travel through the air to infect plants and animals or remain on clothing and bedding to be transmitted from one person to another. Despite these doubts, scientists gradually accumulated the information needed to support the new germ theory.

In 1865, Pasteur was called upon to help fight silkworm disease, which was ruining the silk industry in Europe. Decades earlier amateur microscopist Agostino Bassi had proved that another silkworm disease was caused by a fungus. Using data provided by Bassi, Pasteur found that the more recent infection was caused by a protozoan, and he developed a method for recognizing afflicted silkworm moths.

In the 1860s, Joseph Lister, an English surgeon, applied the germ theory to medical procedures. Lister was aware that in the 1840s, the Hungarian physician Ignaz Semmelweis had demonstrated that physicians, who at the time did not disinfect their hands, routinely transmitted infections (puerperal, or childbirth, fever) from one obstetrical patient to another. Lister had also heard of Pasteur's work connecting microbes to animal diseases. Disinfectants were not used at the time, but Lister knew that phenol (carbolic acid) kills bacteria, so he began treating surgical wounds with a phenol solution. The practice so reduced the incidence of infections and deaths that other surgeons quickly adopted it. His findings proved that microorganisms cause surgical wound infections.

The first proof that bacteria actually cause disease came from Robert Koch (kōk) in 1876. Koch, a German physician, was Pasteur's rival in the race to discover the cause of anthrax, a disease that was destroying cattle and sheep in Europe. Koch discovered