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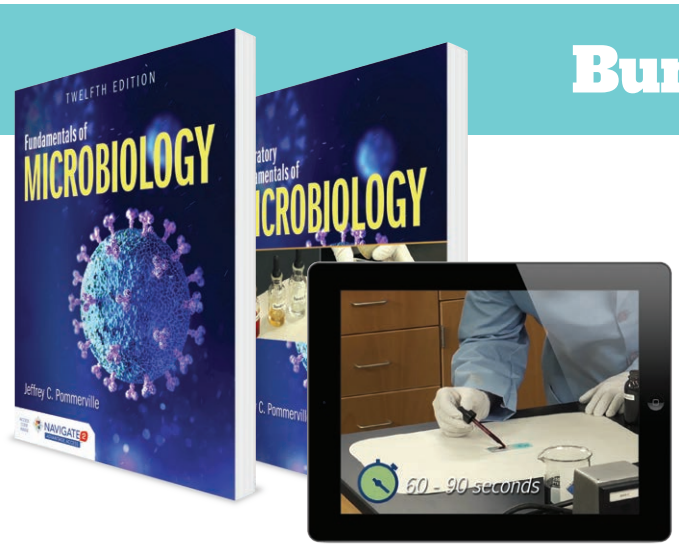

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TWELFTH EDITION

Fundamentals of MICROBIOLOGY

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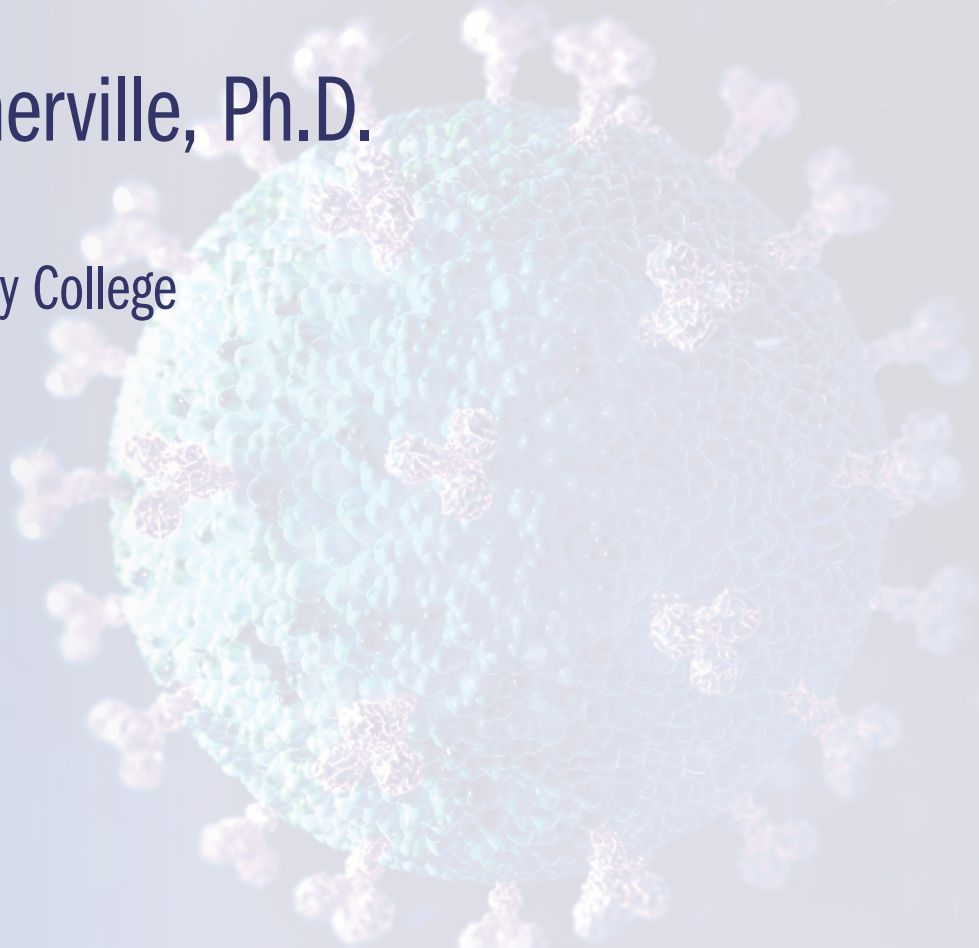
Professor Emeritus
Glendale Community College



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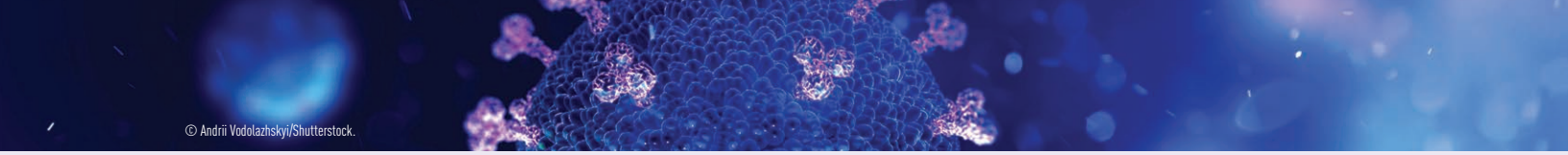

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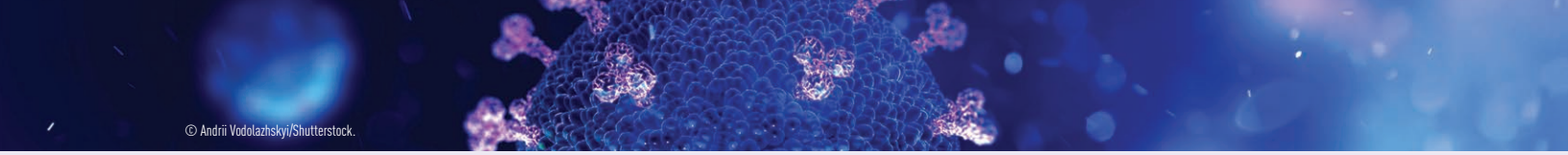

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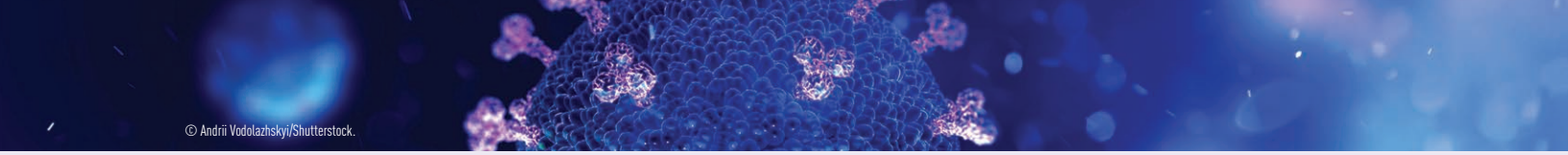

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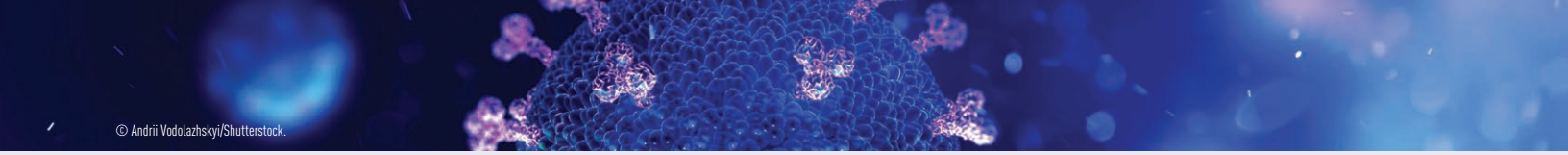

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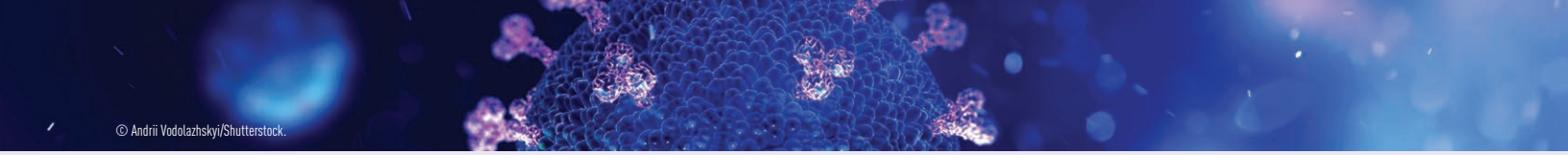


Preface

Teaching and Learning in the Time of COVID-19

What a difference an edition makes. In the preface to the previous edition of *Fundamentals of Microbiology*, I remarked that

> "Today … despite extraordinary advances to eliminate or lessen the development and spread of infectious disease, their appearance continues—and indeed, it is inevitable." I went on to say that "more than 60% percent of new human infections originate in, or are transmitted by, wild animals, [including] AIDS (apes and monkeys to humans), SARS and Ebola (bats [to other animals] to humans), and Zika (monkeys to mosquitoes to humans). Consequently … unknown infectious microbes in wild animals will 'jump' to humans as these interacting species make contact … adding to these factors is the globalized world we live in today. Airline travel makes an infectious disease outbreak in one corner of the world only a day's plane ride from almost any other destination on the globe. Accordingly, infectious diseases can 'pop up' from seemingly nowhere."

Many disease experts around the world for decades have said that it is not *if* a disease pandemic will happen, but rather *when* it will happen. And, so it has in the form of coronavirus disease 2019 (COVID-19).

I went on to echo the thoughts of numerous health experts that

> "Each new emerging disease brings unique challenges, forcing the medical community to continually adapt to these ever-shifting threats. The battle against emerging infectious diseases is a continual process in trying to get ahead and stay ahead of the next infectious agent before it can explode on the world scene."

Unfortunately, that next infectious agent has exploded on the world in the form of the SARS-CoV-2 virus, the infectious agent for COVID-19. It certainly has brought many new challenges to every aspect of work, school, economics, health care, and societal behaviors (social distancing, wearing masks, etc.). All of us have and will continue to be impacted in every aspect of our lives by this disease.

Another major change in these pandemic times has affected higher education. Community colleges, four-year colleges, and universities have scrambled to get courses online, and many students have experienced this new paradigm to higher education by finishing and taking classes and labs online. I suspect the traditional format for higher education might never be quite what it was in the past. An important aspect of this change is flexibility, a characteristic that both students and instructors must have, as all struggle to deal with ensuing educational changes.

In the process of teaching and learning, our age of social media has brought many instances of misinformation/disinformation about many aspects of science. In microbiology, this includes COVID-19, its origin and spread, and value of vaccination in general as well as to COVID-19 specifically. Therefore, one key to the new era of learning and teaching in this "infodemic" world will be sources of trusted and accurate information outside the classroom. I believe that beyond the instructor, the college textbook remains the best, most authoritative source of information to provide the flexibility and foundation for the new education experience involving distance learning.

Fundamentals of Microbiology, Twelfth Edition provides that essential role and need. Besides the fundamental microbiological and disease aspects of COVID-19, which are discussed throughout the pages of this current edition, the textbook is an important tool for student learning in microbiology. It consolidates the important concepts and ideas necessary for mastery by students entering the health care field as a nurse or other allied health professional. Over many editions of *Fundamentals of Microbiology*, the textbook

has reflected flexibility by evolving in response to the rapidly changing field of microbiology and the changing learning needs of students. I hope that you will find *Fundamentals of Microbiology*, *Twelfth Edition* welcoming and informative as you explore the amazing world of microbiology.

A Concept-Based Curriculum

Fundamentals of Microbiology, Twelfth Edition is written for introductory microbiology courses having an emphasis in the health sciences. It is geared toward students in health and allied health science curricula such as nursing, dental hygiene, medical assistance, sanitary science, and medical laboratory technology. It also will be an asset to students studying food science, agriculture, environmental science, and health administration. In addition, the text provides a firm foundation for advanced programs in biological sciences, as well as medicine, pharmacy, dentistry, and other health professions.

The textbook is divided into six parts. Each part reflects the *Overarching Concepts and Fundamental Statements* found in the American Society for Microbiology **Recommended Curriculum Guidelines for Undergraduate Microbiology Education** as published in the *Journal of Microbiology and Biology Education* (Merkel, *JMBE* May 2012, pp 32-38).

Overarching Concepts and Fundamental Statements[1]	
Evolution	1. Cells, organelles (e.g., mitochondria and chloroplasts), and all major metabolic pathways evolved from early prokaryotic cells. 2. Mutations and horizontal gene transfer, with the immense variety of microenvironments, have selected for a huge diversity of microorganisms. 3. Human impact on the environment influences the evolution of microorganisms (e.g., emerging diseases and the selection of antibiotic resistance). 4. The traditional concept of species is not readily applicable to microbes due to asexual reproduction and the frequent occurrence of horizontal gene transfer. 5. Evolutionary relatedness of organisms is best reflected in phylogenetic trees.
Cell Structure and Function	6. The structure and function of microorganisms have been revealed by the use of microscopy (including bright field, phase contrast, fluorescent, and electron). 7. Bacteria have unique cell structures that can be targets for antibiotics, immunity, and phage infection. 8. Bacteria and Archaea have specialized structures e.g., flagella, endospores, and pili) that often confer critical capabilities. 9. 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. 10. The replication cycles of viruses (lytic and lysogenic) differ among viruses and are determined by their unique structures and genomes.
Metabolic Pathways	11. Bacteria and Archaea exhibit extensive, and often unique, metabolic diversity (e.g., nitrogen fixation, methane production, anoxygenic photosynthesis). 12. The interactions of microorganisms among themselves and with their environment are determined by their metabolic abilities (e.g., quorum sensing, oxygen consumption, nitrogen transformations). 13. The survival and growth of any microorganism in a given environment depends on its metabolic characteristics. 14. The growth of microorganisms can be controlled by physical, chemical, mechanical, or biological means.
Information Flow and Genetics	15. Genetic variations can impact microbial functions (e.g., in biofilm formation, pathogenicity and drug resistance). 16. Although the central dogma is universal in all cells, the processes of replication, transcription, and translation differ in Bacteria, Archaea, and Eukaryotes. 17. The regulation of gene expression is influenced by external and internal molecular cues and/or signals. 18. The synthesis of viral genetic material and proteins is dependent on host cells. 19. Cell genomes can be manipulated to alter cell function.

Microbial Systems	20. Microorganisms are ubiquitous and live in diverse and dynamic ecosystems. 21. Most bacteria in nature live in biofilm communities. 22. Microorganisms and their environment interact with and modify each other. 23. Microorganisms, cellular and viral, can interact with both human and nonhuman hosts in beneficial, neutral, or detrimental ways.
Impact of Microorganisms	24. 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). 25. Microorganisms provide essential models that give us fundamental knowledge about life processes. 26. Humans utilize and harness microorganisms and their products. 27. Because the true diversity of microbial life is largely unknown, its effects and potential benefits have not been fully explored.

[1]Reproduced from Curriculum Guidelines for Undergraduate Microbiology (September 2014) https://www.asm.org/getattachment/1b074b9e-8522-4d9d-bbc3-c0ca9b9abf1a/FINAL_Curriculum_Guidelines_w_title_page.pdf.

What's New in This Edition

When you read this text, you get a global perspective on microbiology and infectious disease as found in no other similar textbook. The current edition has been updated with the latest scientific and education research and has incorporated many suggestions made by my colleagues, by emails received from microbiology instructors, and by my students and other students around the world. Along with these revisions, the visual aspects of the text have been improved to make the understanding of complex concepts more approachable and the figures more engaging. Each chapter now includes several **SEEING THE CONCEPT** figures that highlight important microbiological concepts. The new **COVID-19 pandemic material** (see table for COVID-19 topics and material) is the single, most extensive addition to the current edition. All the basic and fundamental information is present in context with chapter key concepts.

COVID-19 Topics and Material (by chapter)	
Chapter 1	COVID-19 as an emerging disease.
Chapter 6	SARS-CoV-2 as part of virosphere; structure; classification; replication.
Chapter 9	Clinical case.
Chapter 10	SARS-CoV-2 and mutations.
Chapter 13	COVID-19 diagnostic testing.
Chapter 14	Chapter opener; COVID-19 disease description.
Chapter 20	Chapter opener; airborne transmission; zoonotic disease; reservoir and superspreaders; portal of entry; infectious dose; as a primary infection; course of infection; epidemiology; basic reproductive number (R_0); community spread; emerging disease.
Chapters 21 & 22	Cytokine storm; clonal selection; antibody production; as a subclinical disease; vaccine development; active/passive acquired immunity; herd immunity.
Chapter 23	Association with multisystem inflammatory syndrome in children (MIS-C).

New Chapter Content

Each chapter of *Fundamentals of Microbiology, Twelfth Edition* has been carefully and thoroughly edited and revised. New information pertinent to nursing and allied health has been included, while many figures and tables have been updated, revised, and/or reorganized for clarity. Here are the other major changes.

- **Chapter 1** has been reorganized and revised to reflect the role microbes play on a daily basis around the globe as well as within the human body. The emphasis here is to show how important microbes are to daily life beyond the infectious diseases that a limited number of species might cause. In addition, a more concise section on the important pioneers to microbiology is presented

along with the place of microbiology today in helping solve many problems of scientific and medical importance.

Part I: Microbial Cell Biology

This part introduces students to the world of microbial cells and viruses, both chemically, globally, and as individual units of life.

- **Chapter 2** still contains the basic chemistry, as much as microbial growth, metabolism, and control are grounded in molecules and macromolecules and in the biological processes these substances undergo.
- **Chapter 3** has revised material on the naming of microbes and the tools (microscopes) needed to observe the tiny organisms. The chapter also has update material on the cataloging of organisms and the organization of these living cells into the tree of life. **Chapter 4** continues to concentrate on the bacterial organisms, where we survey their structural frameworks.

  Previously, the eukaryotic microbes and viruses were covered in later chapters (Chapters 15, 18, and 19 in the previous edition of *Fundamentals*). Now, these organisms and viruses have been brought forward to be covered along with and compared to the bacterial organisms. In **Chapter 5**, a discussion similar to that in Chapter 4 focuses on the protists, fungi, and the multicellular animal parasites, the helminths. Part I concludes with **Chapter 6**, which describes the viruses, those microbial agents that are of great significance to all organisms, including humans.

  Together, Chapters 3 through 6 now provide an integrated set of chapters describing the agents comprising the microbial world. The information of infectious diseases caused by these microbes, worms, and viruses has been moved to the appropriate chapter in Part IV (Microbial and Viral Diseases of Humans).

Part II: Microbial Growth, Metabolism, and Genetics

Part II covers an important aspect of microbiology that some students might find more difficult in comprehending its importance, especially to the nursing and allied health fields. Practicing nurses often lack the understating and skill using genetics and genomic technologies when dealing with patient care. Therefore, these chapters have been revised to enhance the integration of genetic and genomic content that future nurses and allied health students will need in their careers and health care practices.

- Chapters 7 through 10 cover the important material on the growth and metabolism of microorganisms, as well as information on genetics, genetic engineering, and microbial genomics and biotechnology. In **Chapter 7**, the frameworks used to examine microbial growth patterns and nutritional requirements have been simplified. **Chapter 8** describes the metabolism of microbial cells, including those chemical reactions that produce energy and use energy. Again, the figures and narrative have been clarified and simplified.
- The contributions of microbial genetics have been numerous, diverse, and far-reaching. Today, genomic analyses of microorganisms have broad significance not only for microbiology, human health, industry, and the environment, but also in our daily lives.

  Chapter 9 is devoted to the basics of microbial genetics. We examine how microbial DNA is replicated and how this information codes for and directs protein synthesis. Added attention has been given to visualizing concepts, which make the material easier to understand and learn. **Chapter 10** introduces the fields of genetic engineering, biotechnology, and microbial genomics, areas that today are playing a bigger part in health care. Again, making concepts, such as horizontal gene transfer and unique techniques of genetic engineering, more visual has been a major emphasis in the revision of this chapter.

Part III: Control of Microorganisms

Part III covers the physical methods and chemical agents used to control microbial growth and the antimicrobial drugs used to cure or control infectious diseases.

- **Chapter 11** considers the physical methods and chemical agents. Other than reviewing these pages, there were no major changes in content in this chapter. **Chapter 12** is an important chapter on antimicrobial drugs and antimicrobial resistance. The material has been updated with the current understanding of antimicrobial resistance, especially with regard to antibiotic resistance. Figures have been revised to illustrate clearly how

resistance develops and the discussion of origins of resistance have been reorganized.

Part IV: Microbial and Viral Diseases of Humans

In Part IV, the infectious diseases of the human body are surveyed.

- *NEW* **Chapter 13** focuses on how diseases are diagnosed. It includes new material on the methods used to identify and diagnose an infection and the need for clinical specimens that are of high quality for testing. The rest of the chapter examines methods and tests for diagnosis. This includes phenotypic methods (microscopy, staining, and biochemical testing), nucleic acid–based methods involving nucleic acid sequencing, and serological tests. The latter is the material that was in Chapter 23 of the previous edition.
- In these following six chapters (**Chapters 14 through 19**), the various infectious diseases are discussed according to the body system typically colonized by the infectious agent. In each of the body system chapters, the infectious diseases have been reorganized and the pertinent information presented in the following sequence:
  - Epidemiology
  - Infectious Agent and Transmission
  - Clinical Presentation and Diagnosis
  - Treatment and Prevention

Part V: Interactions and Impact of Microorganisms with Humans

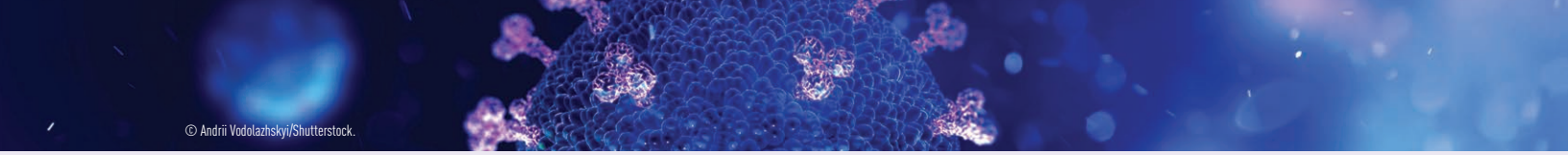
In Part V of this text, we explore the infectious disease process and the mechanisms by which the body responds to disease. The decision was made to place immunology after the discussion of infectious diseases, although the chapters on immunology could certainly be discussed in class prior to the diseases. The rational for discussing the immune response to infection after infectious diseases is that knowing the behaviors and virulence factors of microbes makes it clear how the immune system works to control and hopefully defeat these infectious agents.

- **Chapter 20** is an overview of the host–microbe relationship and the factors contributing to the establishment of disease. Within this chapter, the material on epidemiology has been completely revised, based on the recent events with COVID-19. This portion of the chapter emphasizes descriptive epidemiology, how epidemiologists track infectious diseases, how epidemic curves are generated, and the basics for carrying out an epidemiological investigation. Much of the information uses COVID-19 as the example disease.
- **Chapter 21** now is organized into surface barriers and nonspecific (innate) immunity. **Chapter 22** continues the discussion with specific (adaptive) immunity methods by which the body develops resistance to a particular pathogen. Added to this chapter is the material on vaccinations and immunizations. This was previously in Chapter 23 along with serology, the latter now moved to Chapter 13. In **Chapter 23** the discussion centers on immune disorders and immune deficiencies leading to serious problems in humans. The material on AIDS can now be found much earlier in the text in the chapter on Systemic Infectious Diseases.

Part VI: Applied and Environmental Microbiology

The last part of the text turns to the more applied (industrial) and environmental aspects of microbiology. These chapters, only available online, remain essentially the same (with some figure changes) from the previous edition.

- **Chapter 24** on applied and industrial microbiology is organized around food spoilage, food preservation, and industrial uses of microbes in food production (fermentation).
- **Chapter 25** covers important aspects of environmental microbiology, including the biogeochemical cycles.

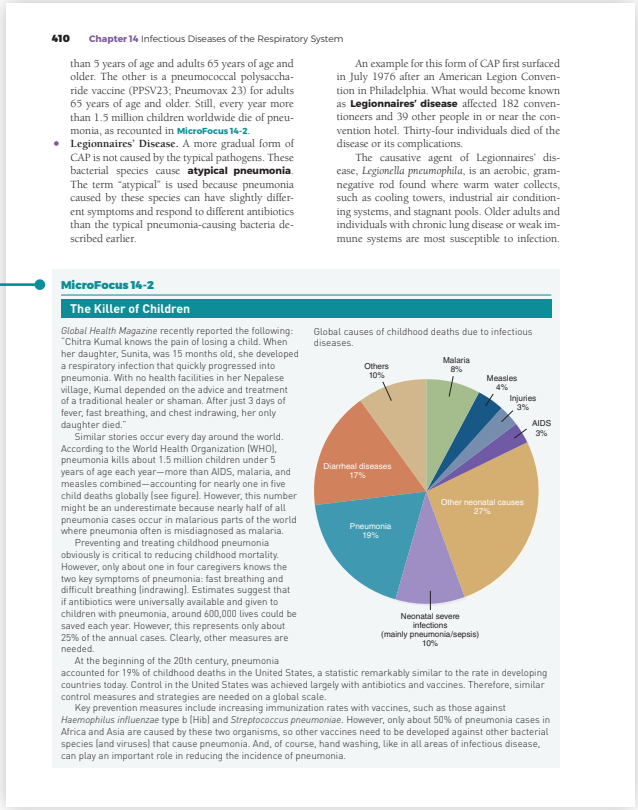


The Student Experience

A Global Perspective

Many decades ago, nursing and allied health students studying microbiology only needed to be concerned about infectious diseases as related to their community or geographic region. Today, with global travel, diseases from halfway around the world can be at our doorstep almost overnight. COVID-19 is an excellent example. Therefore, students need a more global perspective of infectious disease and an understanding and familiarity with these diseases, which are presented no better than in this text.

MICROFOCUS features provide students with the information and understanding they need. Each article, such as the one about childhood pneumonia, provides the background and significance needed for students to be informed and conversant.



410 Chapter 14 Infectious Diseases of the Respiratory System

than 5 years of age and adults 65 years of age and older. The other is a pneumococcal polysaccharide vaccine (PPSV23; Pneumovax 23) for adults 65 years of age and older. Still, every year more than 1.5 million children worldwide die of pneumonia, as recounted in MicroFocus 14-2.

- **Legionnaires' Disease.** A more gradual form of CAP is not caused by the typical pathogens. These bacterial species cause **atypical pneumonia**. The term "atypical" is used because pneumonia caused by these species can have slightly different symptoms and respond to different antibiotics than the typical pneumonia-causing bacteria described earlier.

An example for this form of CAP first surfaced in July 1976 after an American Legion Convention in Philadelphia. What would become known as **Legionnaires' disease** affected 182 conventioneers and 39 other people in or near the convention hotel. Thirty-four individuals died of the disease or its complications.

The causative agent of Legionnaires' disease, *Legionella pneumophila*, is an aerobic, gram-negative rod found where warm water collects, such as cooling towers, industrial air conditioning systems, and stagnant pools. Older adults and individuals with chronic lung disease or weak immune systems are most susceptible to infection.

MicroFocus 14-2

The Killer of Children

Global Health Magazine recently reported the following: "Chitra Kumal knows the pain of losing a child. When her daughter, Sunita, was 15 months old, she developed a respiratory infection that quickly progressed into pneumonia. With no health facilities in her Nepalese village, Kumal depended on the advice and treatment of a traditional healer or shaman. After just 3 days of fever, fast breathing, and chest indrawing, her only daughter died."

Similar stories occur every day around the world. According to the World Health Organization (WHO), pneumonia kills about 1.5 million children under 5 years of age each year—more than AIDS, malaria, and measles combined—accounting for nearly one in five child deaths globally (see figure). However, this number might be an underestimate because nearly half of all pneumonia cases occur in malarious parts of the world where pneumonia often is misdiagnosed as malaria.

Preventing and treating childhood pneumonia obviously is critical to reducing childhood mortality. However, only about one in four caregivers knows the two key symptoms of pneumonia: fast breathing and difficult breathing (indrawing). Estimates suggest that if antibiotics were universally available and given to children with pneumonia, around 600,000 lives could be saved each year. However, this represents only about 25% of the annual cases. Clearly, other measures are needed.

Global causes of childhood deaths due to infectious diseases.

At the beginning of the 20th century, pneumonia accounted for 19% of childhood deaths in the United States, a statistic remarkably similar to the rate in developing countries today. Control in the United States was achieved largely with antibiotics and vaccines. Therefore, similar control measures and strategies are needed on a global scale.

Key prevention measures include increasing immunization rates with vaccines, such as those against *Haemophilus influenzae* type b (Hib) and *Streptococcus pneumoniae*. However, only about 50% of pneumonia cases in Africa and Asia are caused by these two organisms, so other vaccines need to be developed against other bacterial species (and viruses) that cause pneumonia. And, of course, hand washing, like in all areas of infectious disease, can play an important role in reducing the incidence of pneumonia.

KEY CONCEPT 20-5 Epidemiology Is Key to Fighting Infectious Diseases 615

Clinical Case 20

Community Spread of COVID-19

This case study is adapted from an article in the CDC's *Morbidity and Mortality Weekly Report*. Fictitious names have been added, and some events have been edited or modified for clarity.

In February 2020, Walt, who had just returned from a trip out of state, made plans to attend the funeral for a relative of a close friend, Greg. Although Walt was experiencing a mild respiratory illness, he accepted an invitation for dinner at Greg's home. Over a 3-hour dinner, Walt, Greg, and Greg's wife Nancy, all shared a takeout dinner served from common serving dishes.

The next day, Walt went to the funeral, which lasted for 2 hours. He then attended a potluck-style meal back at the home of Greg and Nancy. The meal lasted 2 hours, and then Walt embraced Greg and Nancy and another relative, Sophia, to express his condolences before departing.

Two and 4 days later, respectively, Greg and Nancy developed symptoms that would be diagnosed as confirmed COVID-19, while Sophia develop symptoms that would be diagnosed as probable COVID-19 6 days after the funeral. Greg was hospitalized 7 days after symptom onset, requiring intubation and ventilation for acute respiratory failure, and died 17 days after admission. Both Nancy and Sophia recovered.

Meanwhile, 3 days after the funeral for Walt and Nancy's relative, Walt, who was still experiencing mild respiratory illness, attended a family birthday party with nine other family members. The party was at the home of Walt's brother Jerry. Walt had close contact with all the attendees, embraced others, and shared food during the 3-hour party.

Three days later, Jerry developed symptoms that would be diagnosed as confirmed COVID-19. Five days later, two other family members also developed symptoms that would be diagnosed as confirmed COVID-19, and a day later another four family members diagnosed with probable COVID-19. Jerry was hospitalized 6 days after symptom onset and died 5 days later. Another family member was hospitalized 8 days after symptom onset and died 9 days later. Prior to death, both patients had been intubated and put on a ventilator for acute respiratory failure.

Three of the probable COVID-19 family members attended church 6 days after symptom onset. All had close contact with another church attendee (direct conversations, sitting within one row of the attendee, and passing the offering plate). That attendee developed symptoms that would be diagnosed as confirmed COVID-19 just 1 day after the church service.

The four family members with probable cases all recovered, as did the church attendee. The other two family members never developed symptoms within 14 days of the birthday party. When Walt was finally tested as part of the epidemiological investigation, he received a diagnosis of confirmed COVID-19.

Questions

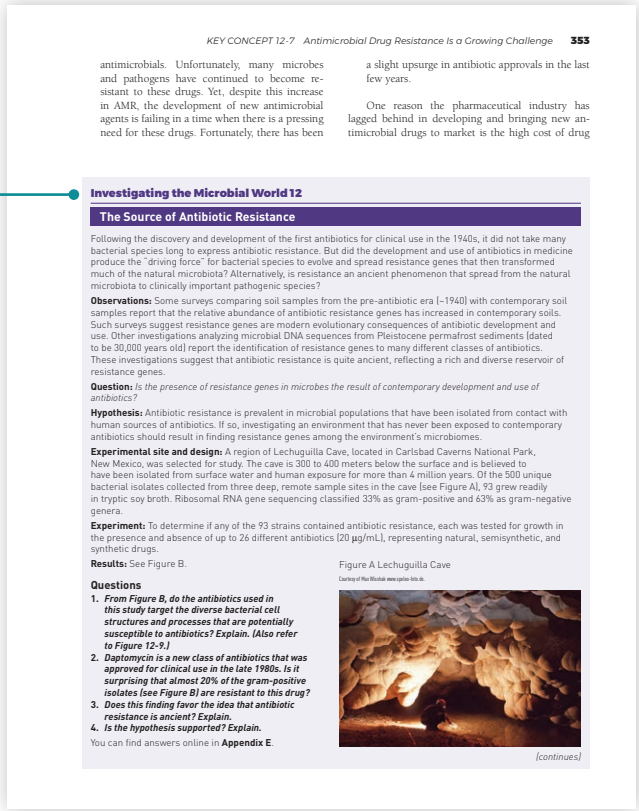
1. Although Walt only had a mild respiratory illness that was eventually confirmed as COVID-19, how sure can we be that he was the source for the community spread of COVID-19 in the two groups (funeral and birthday party)? Explain.
2. Calculate the mean incubation period (time of contact to development of symptoms) in this case study.
3. Assuming that Walt did transmit SARS-CoV-2 to contacts, how many people became ill directly from him?
4. Based on your answer to question (3), does the spread from Walt follow the basic reproduction number (R_0) assigned to COVID-19 [see Table 20-6]?
5. Would Walt be considered a superspreader and what factors would make such a superspreader event likely?

You can find answers online in **Appendix E**.
For additional information, see www.cdc.gov/mmwr/volumes/69/wr/mm6915e1.htm?s_cid=mm6915e1_w.

CLINICAL CASES also provide the opportunity to develop a working knowledge of microbial infections that is essential for student achievement and career success. These cases often are presented as a series of disease observations that are accompanied by several questions to develop the student's thinking skills.

INVESTIGATING THE MICROBIAL WORLD (IMW) introduces students to real world science. Although most students will not be entering the research field, the nursing and allied health arenas require that they have a familiarity with how science is done. The examples in each chapter vary from basic to applied science experiments and, as in the IMW on antibiotic resistance, often have real world (and personal) implications.

One of the best ways to ensure mastery of a topic is through further thought and conversation. Again, the application to what a student has read will not only indicate if she or he has mastered the material, but also strengthen her or his critical-thinking skills.



KEY CONCEPT 12-7 Antimicrobial Drug Resistance Is a Growing Challenge 353

antimicrobials. Unfortunately, many microbes and pathogens have continued to become resistant to these drugs. Yet, despite this increase in AMR, the development of new antimicrobial agents is failing in a time when there is a pressing need for these drugs. Fortunately, there has been a slight upsurge in antibiotic approvals in the last few years.

One reason the pharmaceutical industry has lagged behind in developing and bringing new antimicrobial drugs to market is the high cost of drug

Investigating the Microbial World 12

The Source of Antibiotic Resistance

Following the discovery and development of the first antibiotics for clinical use in the 1940s, it did not take many bacterial species long to express antibiotic resistance. But did the development and use of antibiotics in medicine produce the "driving force" for bacterial species to evolve and spread resistance genes that then transformed much of the natural microbiota? Alternatively, is resistance an ancient phenomenon that spread from the natural microbiota to clinically important pathogenic species?

Observations: Some surveys comparing soil samples from the pre-antibiotic era (~1940) with contemporary soil samples report that the relative abundance of antibiotic resistance genes has increased in contemporary soils. Such surveys suggest resistance genes are modern evolutionary consequences of antibiotic development and use. Other investigations analyzing microbial DNA sequences from Pleistocene permafrost sediments (dated to be 30,000 years old) report the identification of resistance genes to many different classes of antibiotics. These investigations suggest that antibiotic resistance is quite ancient, reflecting a rich and diverse reservoir of resistance genes.

Question: *Is the presence of resistance genes in microbes the result of contemporary development and use of antibiotics?*

Hypothesis: Antibiotic resistance is prevalent in microbial populations that have been isolated from contact with human sources of antibiotics. If so, investigating an environment that has never been exposed to contemporary antibiotics should result in finding resistance genes among the environment's microbiomes.

Experimental site and design: A region of Lechuguilla Cave, located in Carlsbad Caverns National Park, New Mexico, was selected for study. The cave is 300 to 400 meters below the surface and is believed to have been isolated from surface water and human exposure for more than 4 million years. Of the 500 unique bacterial isolates collected from three deep, remote sample sites in the cave (see Figure A), 93 grew readily in tryptic soy broth. Ribosomal RNA gene sequencing classified 33% as gram-positive and 63% as gram-negative genera.

Experiment: To determine if any of the 93 strains contained antibiotic resistance, each was tested for growth in the presence and absence of up to 26 different antibiotics (20 μg/mL), representing natural, semisynthetic, and synthetic drugs.

Results: See Figure B.

Figure A Lechuguilla Cave

Courtesy of Max Mitchell: www.speleo-foto.de.

Questions

1. ***From Figure B, do the antibiotics used in this study target the diverse bacterial cell structures and processes that are potentially susceptible to antibiotics? Explain. (Also refer to Figure 12-9.)***
2. ***Daptomycin is a new class of antibiotics that was approved for clinical use in the late 1980s. Is it surprising that almost 20% of the gram-positive isolates (see Figure B) are resistant to this drug?***
3. ***Does this finding favor the idea that antibiotic resistance is ancient? Explain.***
4. ***Is the hypothesis supported? Explain.***

You can find answers online in **Appendix E**.

[continues]

4 Chapter 1 Introduction to Microbiology: Then and Now

KEY CONCEPT 1-1 Microbial Communities Support and Affect All Life on Earth

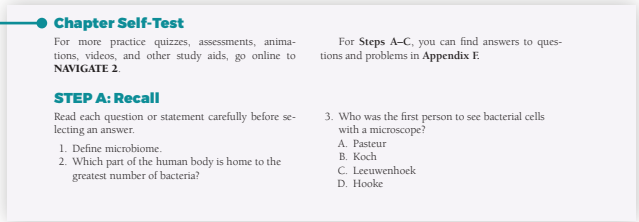
Almost 4 billion years ago, Earth was a microbial planet. The diverse and numerous microorganisms populating the planet were beginning the processes that would create the environment that sustains and shapes our planet and that has made Earth habitable

no less impressive in its daily activities than that of its marine counterparts. In fact, every time you walk on the soil, you step on billions of microbes (**Figure 1-3**). Moreover, like their cousins in the oceans, they are found in every imaginable environment, from the tops

KEY CONCEPT organization presents section statements identifying the important concepts in the upcoming section and alerts you to the significance of that written material.

CHAPTER SELF-TEST organization outlines the important concepts in the chapters through Bloom's Taxonomy, which is a classification of levels of intellectual skills important in learning. The three steps for the self-tests are:

- **STEP A: Recall** are multiple-choice, matching, and true–false questions focusing on concrete "facts" learned in the chapter. Let's face it; there is information that needs to be memorized in order to reason critically.
- **STEP B: Application and Analysis** are questions requiring students to analyze and reason critically through a problem of practical significance.
- **STEP C: Evaluation and Discussion** encourage students to use the text to resolve thought-provoking problems with contemporary relevance.



Chapter Self-Test

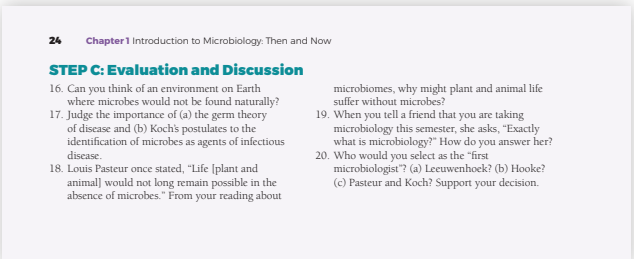
For more practice quizzes, assessments, animations, videos, and other study aids, go online to **NAVIGATE 2**.

For **Steps A–C**, you can find answers to questions and problems in **Appendix F**.

STEP A: Recall

Read each question or statement carefully before selecting an answer.

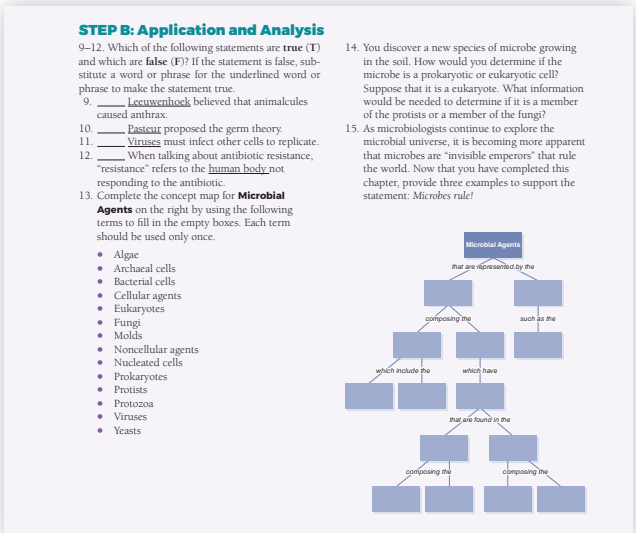
1. Define microbiome.
2. Which part of the human body is home to the greatest number of bacteria?
3. Who was the first person to see bacterial cells with a microscope?
   A. Pasteur
   B. Koch
   C. Leeuwenhoek
   D. Hooke



24 Chapter 1 Introduction to Microbiology: Then and Now

STEP C: Evaluation and Discussion

16. Can you think of an environment on Earth where microbes would not be found naturally?
17. Judge the importance of (a) the germ theory of disease and (b) Koch's postulates to the identification of microbes as agents of infectious disease.
18. Louis Pasteur once stated, "Life [plant and animal] would not long remain possible in the absence of microbes." From your reading about microbiomes, why might plant and animal life suffer without microbes?
19. When you tell a friend that you are taking microbiology this semester, she asks, "Exactly what is microbiology?" How do you answer her?
20. Who would you select as the "first microbiologist"? (a) Leeuwenhoek? (b) Hooke? (c) Pasteur and Koch? Support your decision.



STEP B: Application and Analysis

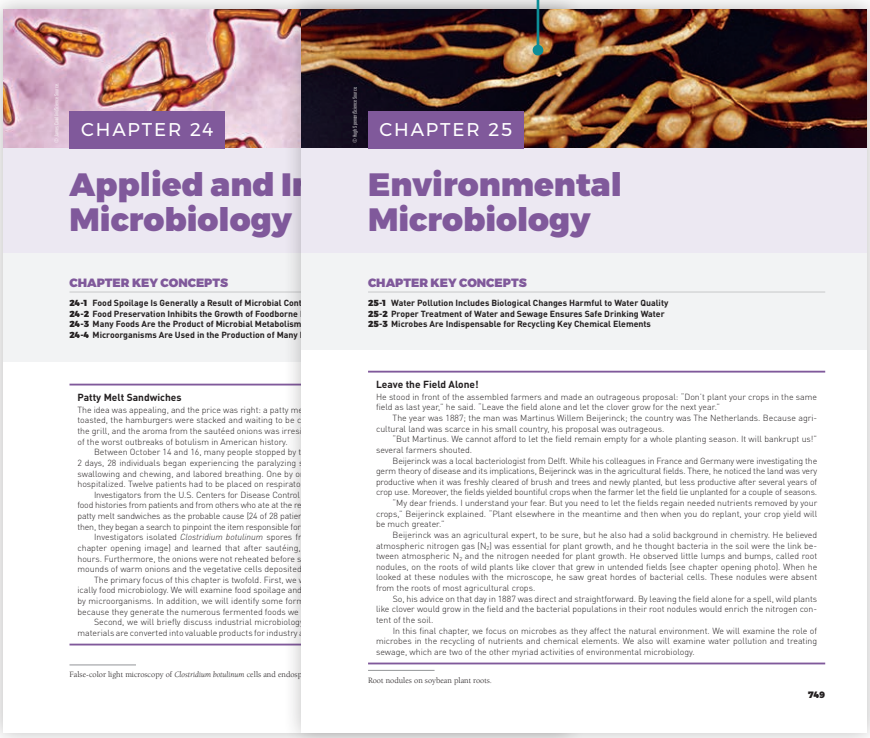
9–12. Which of the following statements are **true** (T) and which are **false** (F)? If the statement is false, substitute a word or phrase for the underlined word or phrase to make the statement true.

9. ____ Leeuwenhoek believed that animalcules caused anthrax.
10. ____ Pasteur proposed the germ theory.
11. ____ Viruses must infect other cells to replicate.
12. ____ When talking about antibiotic resistance, "resistance" refers to the human body not responding to the antibiotic.
13. Complete the concept map for **Microbial Agents** on the right by using the following terms to fill in the empty boxes. Each term should be used only once.
    - Algae
    - Archaeal cells
    - Bacterial cells
    - Cellular agents
    - Eukaryotes
    - Fungi
    - Molds
    - Noncellular agents
    - Nucleated cells
    - Prokaryotes
    - Protists
    - Protozoa
    - Viruses
    - Yeasts
14. You discover a new species of microbe growing in the soil. How would you determine if the microbe is a prokaryotic or eukaryotic cell? Suppose that it is a eukaryote. What information would be needed to determine if it is a member of the protists or a member of the fungi?
15. As microbiologists continue to explore the microbial universe, it is becoming more apparent that microbes are "invisible emperors" that rule the world. Now that you have completed this chapter, provide three examples to support the statement: *Microbes rule!*

Jones & Bartlett Learning offers an assortment of supplements to assist students in mastering the concepts in this text.

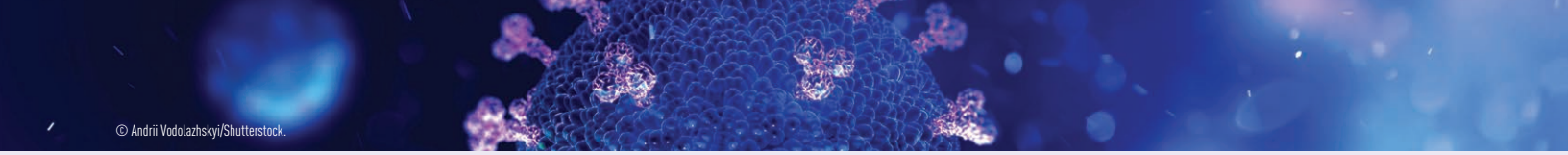
Animations: Engaging animations bring fascinating microbiology phenomena to life! Each animation guides students through microbiology processes and gauges students' progress and understanding with exercises and assessment questions introduced throughout each narrated animation.

Bonus eBook content: Two bonus chapters, "Applied and Industrial Microbiology" and "Environmental Microbiology," are available online.



Web Links: A variety of weblinks are available that present external website resources to continue your study of microbiology and keep up to date on what is happening in the field today.

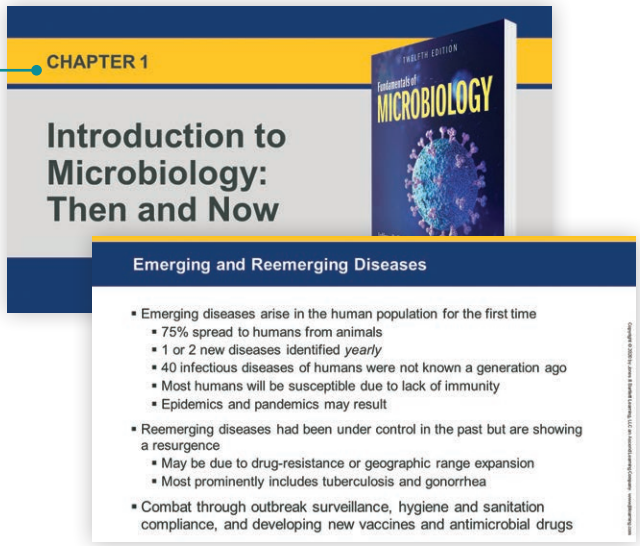
Answer Key: Answers for the end-of-chapter Questions, as well as the questions in the MicroFocus, Chapter Challenge, Clinical Case, and Investigating the Microbial World feature boxes are available in the online Appendices D, E, and F (accessible with access card).



Teaching Tools

Jones & Bartlett Learning also has an array of supportive materials for instructors. Additional information and review copies of any of the following items are available through your Jones & Bartlett Learning sales representative or by going to http://www.jblearning.com.

The **PowerPoint Lecture Outline** presentation package provides lecture notes and images for each chapter of the text. Instructors with Microsoft PowerPoint software can customize the outlines, art, and order of presentation.



The **Image Bank in PowerPoint format** provides images of the illustrations, photographs, and tables (to which Jones & Bartlett Learning holds the copyright or has permission to reproduce digitally). These images are not for sale or distribution, but you can copy individual images or tables into your existing lecture presentations, test and quizzes, or other classroom materials.

An **Unlabeled Art Image Bank in PowerPoint format** provides selected images from the text with the labels removed so you can easily integrate them into your lectures, assignments, or exams.

The **Instructor's Manual**, provided as a text file, includes an Instructional Overview, Instructional Objectives, Key Terms and Concepts, Chapter Teaching Points and Tips, and Essay Questions.

A robust **Test Bank**, including hundreds of assessment questions, is available.

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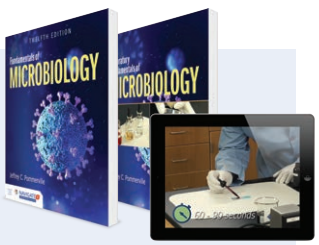

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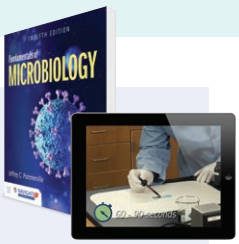

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Preparing the Acid-Fast Stain
Oxidase Test
IMViC: Indole Test
IMViC: Methyl Red Test
IMViC: Voges-Proskauer Test
IMViC: Citrate Test
Section: Identification of a Bacterial Unknown
Biochemical Tests: Carbohydrate Fermentation
Starch Hydrolysis Test
Catalase Test
Hydrogen Sulfate
Urease Test

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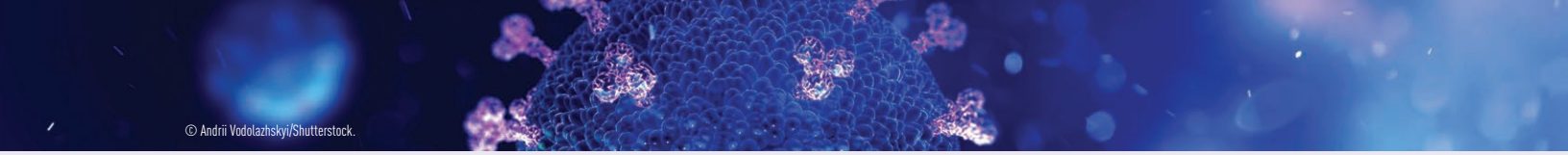
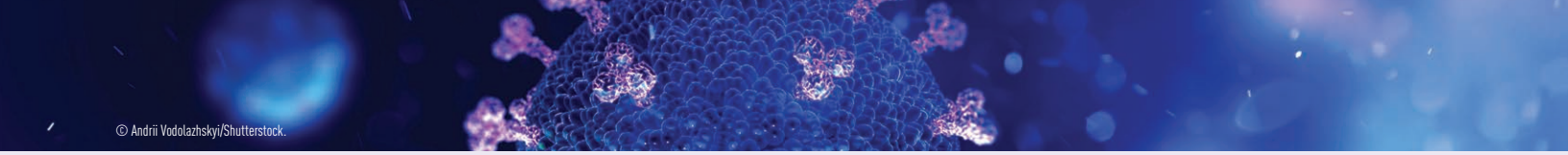


Acknowledgments

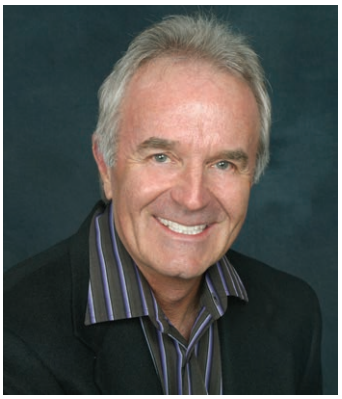
Textbook revisions are always a major project and a team effort. The new edition of *Fundamentals of Microbiology* is no exception. Moreover, when the team members at Jones & Bartlett Learning are exceptionally talented professionals, my work is made easier. That is especially true as this edition was done more remotely than any previous edition. I wish to thank Melissa Duffy, Content Strategist, who coordinated the textbook revision with skill and direction. I also want to thank Alex Schab for all his help and guidance during the production process.

Throughout all my years of teaching at universities and colleges, I have had great fortune of working with great colleagues and outstanding students. My students kept me on my toes in the classroom, required me to always be prepared, and let me know when a topic or concept was not conveyed in as clear and understandable a way as it could (or should) be. Their suggestions and evaluations encouraged me to continually assess my instruction and make it the best it could be. I salute all my former students—and I hope those of you who read this text will let me know what works and what still needs improvement to make your learning effective, enjoyable, and most of all—successful.

Jeff Pommerville, PhD
Professor Emeritus
Glendale Community College
Glendale, AZ



About the Author



Today, I am a microbiologist, researcher, and science educator. My plans did not start with that intent. While in high school in Santa Barbara, California, I wanted to play professional baseball, study the stars, and own a '66 Corvette. None of those desires would come true—as a high school baseball player my batting average was miserable (but I was a good defensive fielder), I hated the astronomy correspondence course I took in high school, and I never bought that Corvette.

I found an interest in biology at Santa Barbara City College. After squeaking through college calculus, I transferred to the University of California at Santa Barbara (UCSB) where I received a B.S. in biology and stayed on to pursue a Ph.D. in the lab of the late Ian Ross studying cell communication and sexual pheromones in a water mold. After receiving my doctorate in cell and organismal biology, my graduation was written up in the local newspaper as a native son who was a fungal sex biologist—an image that was not lost on my three older brothers!

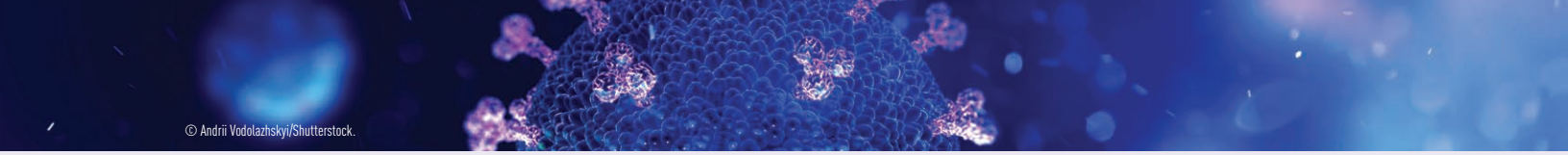
While in graduate school at UCSB, I rescued a secretary in distress from being licked to death by a German shepherd. Within a year, we were married (the secretary and I). When I finished my doctoral thesis, I spent several years as a postdoctoral fellow at the University of Georgia. Worried that I was involved in too many research projects, a faculty member told me something I will never forget. He said, "Jeff, it's when you can't think of a project or what to do that you need to worry." Well, I have never had to worry!

Moving to Texas A&M University, I spent 8 years in teaching and research—and telling Aggie jokes. Toward the end of this time, I realized I had a real interest in teaching and education. Leaving the sex biologist nomen behind, I headed farther west to Arizona to join the biology faculty at Glendale Community College, where I continued to teach introductory biology and microbiology until my retirement in 2018.

I have been lucky to be part of several educational research projects. I was project director and lead principal investigator for a National Science Foundation grant to improve student outcomes in science through changes in curriculum and pedagogy. This culminated in my being honored with the Gustav Ohaus Award (College Division) for Innovations in Science Teaching from the National Science Teachers Association.

For 6 years I was the Perspectives Editor for the *Journal of Microbiology and Biology Education*, the education research journal of the American Society for Microbiology (ASM). I have been cochair for the ASM Conference for Undergraduate Educators and chair of the Undergraduate Education Division of ASM. My dedication to teaching and mentoring students has been recognized by an Outstanding Instructor Award at Glendale Community College and, nationally, the Carski Foundation Distinguished Undergraduate Teaching Award for distinguished teaching of microbiology to undergraduate students and encouraging them to subsequent achievement.

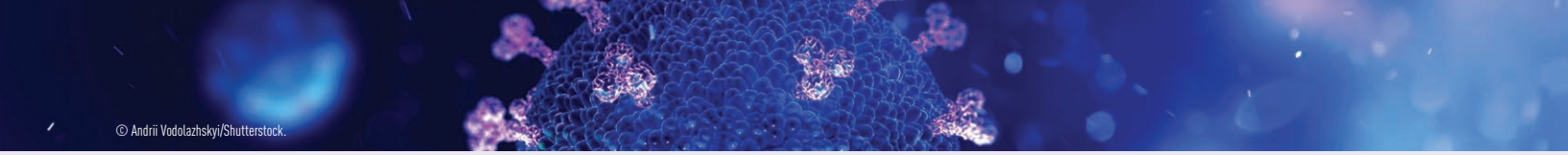
I mention all this not to impress, but to show how the road of life sometimes offers opportunities in unexpected and unplanned ways. The key though is keeping your "hands on the wheel and your eyes on the prize;" then unlimited opportunities will come your way. And, hey, who knows—maybe that '66 Corvette could be in my garage yet.



Dedication

I dedicate this *Twelfth Edition* of the textbook to the two people who most influenced my life in science. My thesis advisor, Ian K. Ross passed away in 2019. He was my mentor and thesis advisor in the early 1970s and in whose lab I was a graduate student for 5 years. He provided the foundation for my scientific thought and excited my interest in the biological sciences that I carried throughout my career.

This is the sixth edition of *Fundamentals of Microbiology* that I have authored. Over these 20 years, I have spent countless months (years?) revising and updating the various editions, often unintentionally neglecting time that should be spent with my wife, Yvonne. She always has supported my passion for teaching and has encouraged me to push forward throughout the textbook revisions, often providing valuable and constructive suggestions. Thanks for your support and encouragement, and enduring love through the years.



Reviewers for the Twelfth Edition

As always, it is the input, suggestions, and comments from instructors and students alike, that evolve a textbook and make each edition an improvement on its predecessor. I thank everyone from previous editions as well as the reviewers for this edition for their time and effort with the review.

Mari Aanenson, MS
Western Illinois University

Vasanta Lakshmi Chivukula, PhD
Atlanta Metropolitan State College

Heather M. Craig, PhD
Monterey Peninsula College

Eric DeAngelo, BA, MS
Lehigh Carbon Community College

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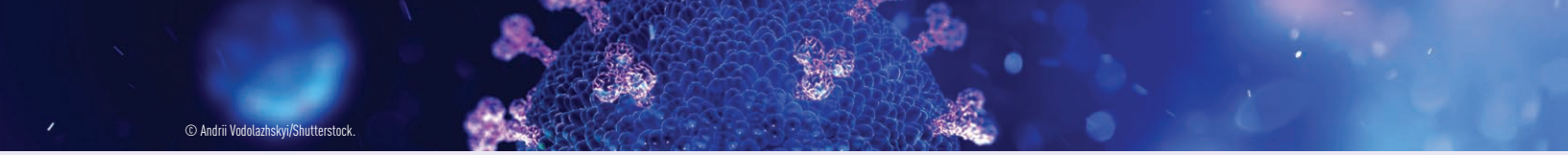


To the Student—Study Smart

Your success in microbiology and any college or university course will depend on your ability to study effectively and efficiently, especially in these times of online learning where more of the responsibility for learning is placed on the student. Therefore, this textbook was designed with you, the student, in mind. The text's organization will help you improve your learning and understanding and, ultimately, your grades. The learning design concept described in the Preface and illustrated below reflects this organization. Study it carefully, and, if you adopt the flow of study shown, you should be a big step ahead in your preparation and understanding of microbiology—and for that matter any subject you are taking.

When I was an undergraduate student, I hardly ever read the "To the Student" section (if indeed one existed) in my textbooks because the section rarely contained any information of importance. This one does, so please read on.

In college, I was a mediocre student until my junior year. Why? Mainly because I did not know how to study properly, and, important here, I did not know how to read a textbook effectively. My textbooks were filled with underlined sentences (highlighters hadn't been invented yet!) without any plan on how I would use this "emphasized" information. In fact, most textbooks assume you know how to read a textbook properly. I didn't, and you might not, either.

Reading a textbook is difficult if you are not properly prepared. So that you can take advantage of what I learned as a student and have learned from instructing thousands of students, I have worked hard to make this text user friendly with a reading style that is not threatening or complicated. Still, there is a substantial amount of information to learn and understand, so having the appropriate reading and comprehension skills is critical. Therefore, I encourage you to spend 30 minutes reading this section, as I am going to give you several tips and suggestions for acquiring those skills. Let me show you how to be an active reader. Note: the Student Study Guide also contains similar information on how to take notes from the text, how to study, how to take class (lecture) notes, how to prepare for and take exams, and perhaps most important for you, how to manage your time effectively. It all is part of this "learning design," my wish to make you a better student.

Be a Prepared Reader

Before you jump into reading a section of a chapter in this text, prepare yourself by finding the place and time and having the tools for study.

Place. Where are you right now as you read these lines? Are you in a quiet library or at home? If at home, are there any distractions, such as loud music, a blaring television, or screaming kids? Is the lighting adequate to read? Are you sitting at a desk or lounging on the living room sofa? Get where I am going? When you read for an educational purpose—that is, to learn and understand something—you need to maximize the environment for reading. Yes, it should be comfortable but not to the point that you will doze off.

Time. All of us have different times during the day when we perform some skill, be it exercising or reading, the best. The last thing you want to do is read when you are tired or simply not "in tune" for the job that needs to be done. You cannot learn and understand the information if you fall asleep or lack a positive attitude. I have kept the chapters in this text to about the same length so you can estimate the time necessary for each and plan your reading accordingly. If you have done your preliminary survey of the chapter or chapter section, you can determine about how much time you will need. If 40 minutes is needed to read—and comprehend (see below)—a section of a chapter, find the place and time that will give you 40 minutes of uninterrupted study. Brain research suggests that most people's brains cannot spend more than 45 minutes in concentrated, technical reading.

Therefore, I have avoided lengthy presentations and instead have focused on smaller sections, each with its own heading. These should accommodate shorter reading periods.

Reading Tools. Lastly, as you read this, what study tools do you have at your side? Do you have a highlighter or pen for emphasizing or underlining important words or phrases? Notice, the text has wide margins, which allow you to make notes or to indicate something that needs further clarification. Do you have a pencil or pen handy to make these notes? Or, if you do not want to "deface" the text, make your notes in a notebook. Lastly, some students find having a ruler is useful to prevent your eyes from wandering on the page and to read each line without distraction.

Be an Explorer Before You Read

When you sit down to read a section of a chapter, do some preliminary exploring. Look at the section head and subheadings to get an idea of what is discussed. Preview any diagrams, photographs, tables, graphs, or other visuals used. They give you a better idea of what is going to occur. We have used a good deal of space in the text for these features, so use them to your advantage. They will help you learn the written information and comprehend its meaning. Do not try to understand all the visuals but try to generate a mental "big picture" of what is to come. Familiarize yourself with any symbols or technical jargon that might be used in the visuals.

The end of each chapter contains a **Summary of Key Concepts** for that chapter. It is a good idea to read the summary before delving into the chapter. That way you will have a framework for the chapter before filling in the nitty-gritty information.

Be a Detective as You Read

Reading a section of a textbook is not the same as reading a novel. With a textbook, you need to uncover the important information (the terms and concepts) from the forest of words on the page. So, the first thing to do is read the complete paragraph. When you have determined the main ideas, highlight or underline them. However, I have seen students highlighting the entire paragraph in yellow, including every a, the, and and. This is an example of highlighting before knowing what is important. So, I have helped you out somewhat. Important terms and concepts are in **bold face** followed by the definition. So only highlight or underline with a pen essential ideas and key phrases—not complete sentences, if possible. By the way, the important microbiological terms and major concepts are also in the **Glossary** at the back of the text.

What if a paragraph or section has no boldfaced words? How do you find what is important here? From an English course, you may know that often the most important information is mentioned first in the paragraph. If it is followed by one or more examples, then you can backtrack and know what was important in the paragraph. In addition, I have added section "speed bumps" (called **Concept Checks**) to let you test your learning and understanding before getting too far ahead in the material. These checks also are clues to what was important in the section you just read.

Be a Repetitious Student

Brain research has shown that each individual can only hold so much information in short-term memory. If you try to hold more, then something else needs to be removed—sort of like a full computer disk. So that you do not lose any of this important information, you need to transfer it to long-term memory—to the hard drive if you will. In reading and studying, this means retaining the term or concept; so, write it out in your notebook using your own words. Memorizing a term does not mean you have learned the term or that you understand the concept. By actively writing it out in your own words, you are forced to think and actively interact with the information. This repetition reinforces your learning.

Be a Patient Student

In textbooks, you cannot read at the speed that you read your email or a magazine story. There are unfamiliar details to be learned and understood—and this requires being a patient, slower reader. Actually, if you are not a fast reader to begin with, as I am, it may be an advantage in your learning process. Identifying the important information from a textbook chapter requires you to slow down your reading speed. Speed-reading is of no value here.

Know the What, Why, and How

Have you ever read something only to say, "I have no idea what I read!" As I've already mentioned, reading a microbiology text is not the same as reading *Sports Illustrated* or *People* magazine. In these entertainment magazines, you read passively for leisure or perhaps amusement. In *Fundamentals of Microbiology, Twelfth*

Edition you must read actively for learning and understanding—that is, for comprehension. This can quickly lead to boredom unless you engage your brain as you read—that is, be an active reader. Do this by knowing the *what, why*, and *how* of your reading.

- *What* is the general topic or idea being discussed? This often is easy to determine because the section heading might tell you. If not, then it will appear in the first sentence or beginning part of the paragraph.
- *Why* is this information important? If I have done my job, the text section will tell you why it is important, or the examples provided will drive the importance home. These surrounding clues further explain why the main idea was important.
- *How* do I "mine" the information presented? This was discussed under being a detective.

A Marked-Up Reading Example

So let's put words into action. Below is a passage from the text. I have marked up the passage as if I were a student reading it for the first time. It uses many of the hints and suggestions I have provided. Remember, it is important to read the passage slowly and concentrate on the main idea (concept) and the special terms that apply.

Nonenveloped Viruses

The simplest animal viruses, such as the polioviruses, consist of just two components: an indispensable nucleic acid core and a surrounding protein shell. Such viruses represent **nonenveloped viruses** (Figure 6-3A).

The protein shell, called the **capsid**, surrounds the viral genome while providing shape or symmetry to the particle. The capsid is built from individual protein subunits called **capsomeres** that self-assemble into the virus's shape. On the virus either special capsid proteins called **spikes** or other protein fibers protrude from the surface. These external proteins help attach the virus to protein receptors on, and facilitate entry into, host cells. The capsid also protects the viral nucleic acid against chemical and physical agents and other environmental fluctuations (e.g., temperature and pH changes).

The nucleic acid core, called the **viral genome**, contains one or more molecules of DNA or RNA that have the instructions to make more viruses. The genome can be a double-stranded or a single-stranded form, depending on the specific virus type. Usually the tightly packed nucleic acid is a linear or circular

Have a Debriefing Strategy

After reading the material, be ready to debrief. Verbally summarize what you have learned. This will start moving the short-term information into the long-term memory storage—that is, retention. Any notes you made concerning confusing material should be discussed as soon as possible with your instructor. For microbiology, allow time to draw out diagrams. Again, repetition makes for easier learning and better retention.

In many professions, such as sports or the theater, the name of the game is practice, practice, practice. The hints and suggestions I have given you form a skill that requires practice to perfect and use efficiently. Be patient, things will not happen overnight; perseverance and willingness though will pay off with practice. You might also check with your college or university academic (or learning) resource center. These folks will have more ways to help you to read a textbook better and to study well overall.

Concept Maps

In science as well as in other subjects you take at the college or university, there often are concepts that appear abstract or simply so complex that they are difficult to understand. A concept map is one tool to help you enhance your abilities to think and learn. Critical reasoning and the ability to make connections between complex, nonlinear information are essential to your studies and career.

Concept maps are a learning tool designed to represent complex or abstract information visually. Neurobiologists and psychologists tell us that the brain's primary function is to take incoming information and interpret it in a meaningful or practical way. They also have found that the brain has an easier time making sense of information when it is presented in a visual format. Importantly, concept maps not only present the information in "visual sentences" but also take paragraphs of material and present it in an "at-a-glance" format. Therefore, you can use concept maps to:

- Communicate and organize complex ideas in a meaningful way
- Aid your learning by seeing connections within or between concepts and knowledge
- Assess your understanding or diagnose misunderstanding

- There are many different types of concept maps. The two most used in this textbook are the process map or flow chart and the hierarchical map. The hierarchical map starts with a general concept (the most inclusive word or phrase) at the top of the map and descends downward using more specific, less general words or terms. In several chapters in this textbook process or hierarchical maps are drawn—and you have the opportunity to construct your own hierarchical maps as well.

Concept mapping is the strategy used to produce a concept map. So, let's see how one makes a hierarchical map.

How to Construct a Concept Map

1. Print the central idea (concept or question to be mapped) in a box at the top center of a blank, unlined piece of paper. Use uppercase letters to identify the central idea.
2. Once the concept has been selected, identify the key terms (words or short phrases) that apply to or stem from the concept. Often these may be given to you as a list. If you have read a section of a text, you can extract the terms from that material, as the words are usually boldfaced or italicized.
3. Now, from this list, try to create a hierarchy for the terms you have identified; that is, list them from the most general, most inclusive to the least general, most specific. This ranking may only be approximate and subject to change as you begin mapping.
4. Construct a preliminary concept map. This can be done by writing all of the terms on sticky notes, which can be moved around easily on a large piece of paper. This is necessary as one begins to struggle with the process of building a good hierarchical organization.
5. The concept map connects terms associated with a concept in the following way:
   - The relationship between the concept and the first term(s), and between terms, is connected by an arrow pointing in the direction of the relationship (usually downward or horizontal if connecting related terms).
   - Each arrow should have a label, a very short phrase that explains the relationship with the next term. In the end, each link with a label reads like a sentence.
6. Once you have your map completed, redraw it in a more permanent form. Box in all terms that were on the sticky notes. Remember there may be more than one way to draw a good concept map, and don't be scared off if at first you have some problems mapping; mapping will become more apparent to you after you have practiced this technique a few times using the opportunities given to you in the early chapters of the textbook.
7. Now look at the map and see if it answers the following. Does it:
   - Clearly define the central idea by positioning it in the center of the page?
   - Place all the terms in a logical hierarchy and clearly indicate the relative importance of each term?
   - Allow you to figure out the relationships among the key ideas more easily?
   - Permit you to see all the information visually on one page?
   - Allow you to visualize complex relationships more easily?
   - Make recall and review more efficient?

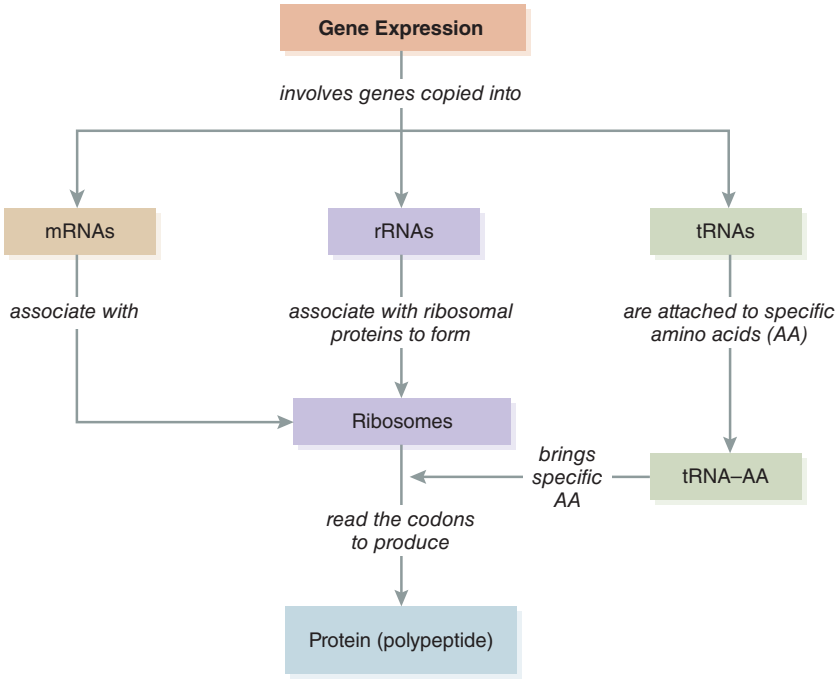
Example

After reading the section on "Gene Expression," a student makes a list of the terms used and maps the concept. Using the steps outlined above, the student produces the following hierarchical map. Does it satisfy all the questions asked in item step 7 above?

Practical Uses for Mapping

- Summarizing textbook readings. Use mapping to summarize a chapter section or a whole chapter in a textbook. This purpose for mapping is used many times in this text.
- Summarizing lectures. Although producing a concept map during the classroom period may not be the best use of the time, making a concept map or maps from the material after class will help you remember the important points and encourage high-level, critical reasoning, which is so important in university and college studies.
- Reviewing for an exam. Having concept maps made ahead of time can be a very useful and productive way to study for an exam, particularly if the emphasis of the course is on understanding and applying abstract, theoretical material, rather than on simply reproducing memorized information.

Figure 9-11 A concept map for gene expression
Gene expression is a combination of the processes of transcription and translation. ***Circle the part of the concept map that represents (a) transcription and (b) translation.***



- Working on an essay. Mapping also is a powerful tool to use during the early stages of writing a course essay or term paper. Making a concept map before you write the first rough draft can help you see and ensure you have the important points and information you will want to make.

Send Me a Note

In closing, I would like to invite you to email me and let me know what is good about this textbook so I can build on it and what may need improvement so I can revise it. Also, I would be pleased to hear about any news of microbiology in your community, and I'd be happy to help you locate any information not covered in the text.

I wish you great success in your microbiology course. Welcome! Let's now plunge into the wonderful and often awesome world of microorganisms.

—Dr. P
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