Lourdes Norman-McKay

Microbiology

Basic and Clinical Principles

Brief Contents

Clinical Cases

Concept Coaches

A S.M.A.R.T. approach to . . .

Lourdes Norman-McKay provides a familiar framework to guide students through critical thinking: the S.M.A.R.T. approach.

The S.M.A.R.T. approach is modeled and described in the Chapter 1 **Concept Coach** video. The simple problem-solving process is utilized in the online **Clinical Cases** and end-of-chapter **Think Clinically: Comprehensive Cases**, giving students opportunities to hone and sharpen their critical thinking skills by applying what they've learned to clinical scenarios.

1) **S**ummarize the known and unknown
2) **M**ake connections
3) **A**void distractors
4) **R**e-read
5) **T**horoughly answer

NCLEX | HESI | TEAS

Think Critically and Clinically

Questions highlighted in **blue** are opportunities to practice NCLEX, HESI, and TEAS-style questions.

NCLEX/HESI/TEAS-style questions at the end of each chapter have multiple correct answers offered, but one is "more correct" than the others. Students are asked to determine the "best solution of several." These questions help students practice critical thinking and build their confidence for licensing and entrance exams.

2. A patient has developed a type III reaction to a drug. Which of the following is the most immediate action required?
   a. Lower the patient's fever.
   b. Stop administration of the drug.
   c. Treat the patient's skin rash to avoid possible infections.
   d. Hook the patient up to an IV for rehydration therapy.
   e. Administer antihistamines to limit the response.

critical thinking and application

Think Clinically: Comprehensive Cases provide an opportunity for students to delve deeper into a case. Students flex their critical thinking skills, analyze data, and apply what they've learned throughout each chapter. Assignable in Mastering Microbiology, these are also tagged to the ASM's Microbiology in Nursing and Allied Health Undergraduate Curriculum Guidelines.

THINK CLINICALLY: Be S.M.A.R.T. About Cases

COMPREHENSIVE CASE

The following case integrates basic principles from the chapter. Try to answer the case questions on your own. Don't forget to be **S.M.A.R.T.*** about your case study to help you interlink the scientific concepts you have just learned and apply your new understanding of metabolism principles to a case study.

*The five-step method is shown in detail in the Chapter 1 Comprehensive Case on cholera. See pages 32–33. Refer back to this example to help you apply a SMART approach to other critical thinking questions and cases throughout the book.

• • •

A 40-year-old male called 911 stating that he was having difficulty breathing and felt too nauseous to drive himself to the hospital. He said he had type I diabetes and had not been able to afford insulin on a consistent basis, especially over the past week, since he lost his job. Fortunately, the emergency medical team promptly got to the patient and took him to the hospital. His blood work revealed an exceedingly high blood glucose level, a finding consistent with the fact that the body relies on insulin to get glucose into cells. The patient was diagnosed as suffering from ketoacidosis. This is a metabolic state in which the body perceives that it is starving for glucose and so switches to mainly catabolizing fats. In ketoacidosis, ketones, which are by-products of fat catabolism, rapidly build up in the body and dangerously lower the blood's pH level. After stabilizing the patient, a thorough physical examination was performed.

Upon physical examination, the physician noticed the man had an infected ulcer on his foot. A bacterial specimen was collected and analysis showed Gram-positive rods that form endospores. The doctor said it was fortunate that the man sought medical assistance, because he could have gone into a coma and died from ketoacidosis. Also, he told the patient that if ketoacidosis had not killed him, the foot wound could have. The ulcer was infected with an anaerobic bacterium, *Clostridium perfringens*, which causes gas gangrene.

The patient stated that he often had slow-healing sores on his feet and asked if it was something to be concerned about. The doctor explained that people who have diabetes and do not consistently regulate their blood glucose often suffer from a number of complications, including circulatory system vessel damage. When blood vessels are damaged, blood delivery to the tissues is decreased, which can affect healing. This pathology is particularly common in the extremities, and especially the feet. Follow-up care for all wounds is important to prevent future infections with dangerous bacteria like *C. perfringens*. Fortunately the patient's infection was localized and readily responded to basic wound care and a regimen of clindamycin and penicillin.

• • •

CASE-BASED QUESTIONS

1. Blood work revealed that the patient had high blood glucose levels. However, ketoacidosis results when the body is "starving" for glucose. Why can these two conditions simultaneously exist in a diabetic patient?
2. Why would the body preferentially metabolize fats before metabolizing proteins?
3. Explain why low blood pH, like that seen in ketoacidosis, is potentially deadly.
4. Why are diabetics at risk for wound infections by anaerobic bacteria like *Clostridium perfringens*?
5. Name two biochemical tests that were discussed in this chapter that would most likely be *negative* for *Clostridium perfringens*. Explain why.

Art informed by principles of learning design

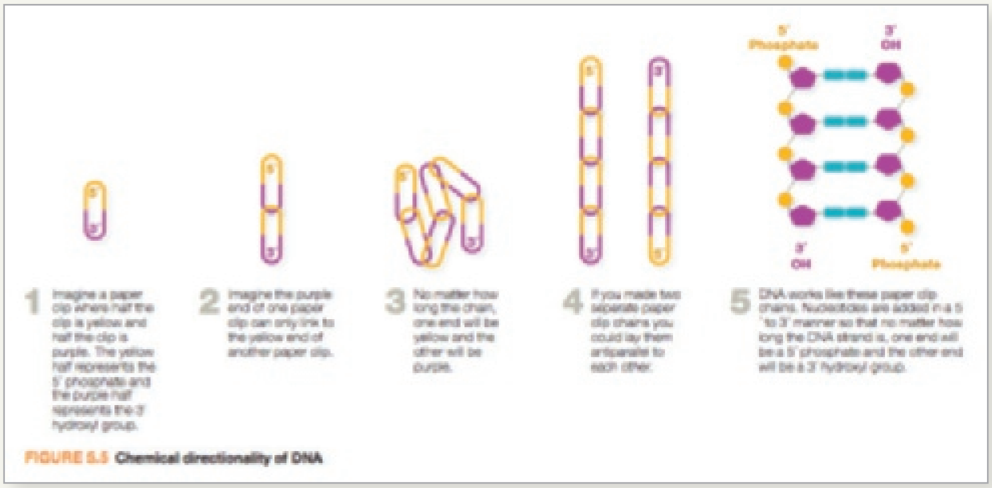
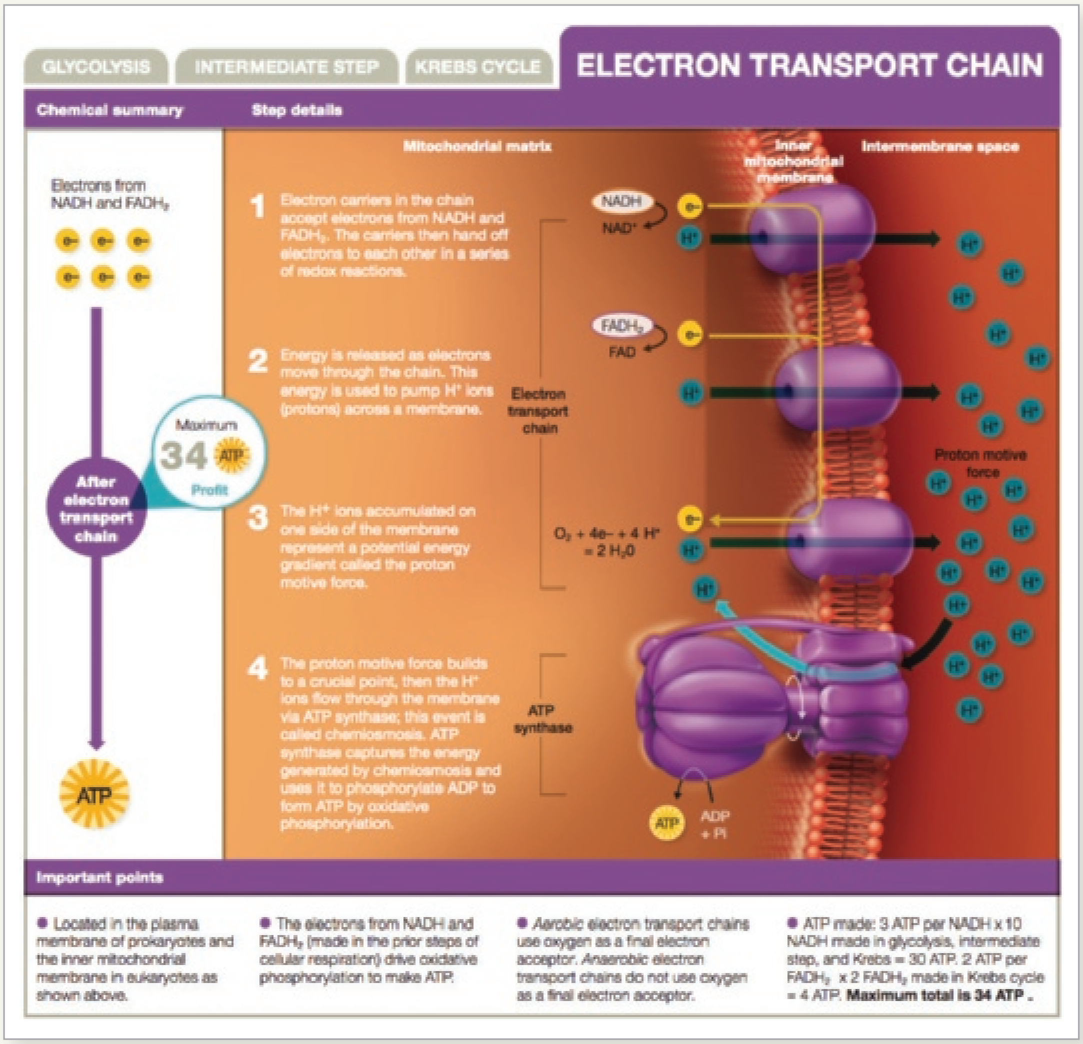


FIGURE 5.5 Chemical directionality of DNA

Norman-McKay's art program employs step-by-step process figures, easy-to-navigate layouts, intuitive orientation diagrams, humor, and analogies to help students master microbiology fundamentals. By employing a consistent aesthetic and deliberately focusing students on the truly important content details, cognitive load is reduced and student understanding is enhanced.



S.M.A.R.T. tips and tricks to succeed in microbiology

CHEM • NOTE

Phosphorylation and dephosphorylation reactions The element phosphorus (P) is important in cells. When phosphorus is bonded to three oxygen atoms it is called a phosphoryl group (PO_3^{2-}). When it is bonded to four oxygen atoms it is a phosphate group (PO_4^{3-}). Phosphoryl groups are added in phosphorylation reactions. They are removed by dephosphorylation reactions. When a phosphoryl group is added to a molecule by bonding to another oxygen, it becomes a phosphate group (as occurs when ADP is recharged to ATP).

CHEM NOTES are included in the narrative to remove learning barriers for students who lack a chemistry background. For students who have taken a chemistry course, the CHEM NOTES provide an opportunity to revisit essential information before moving on.

Mnemonic devices throughout the text help students unpack and remember challenging microbiology concepts.

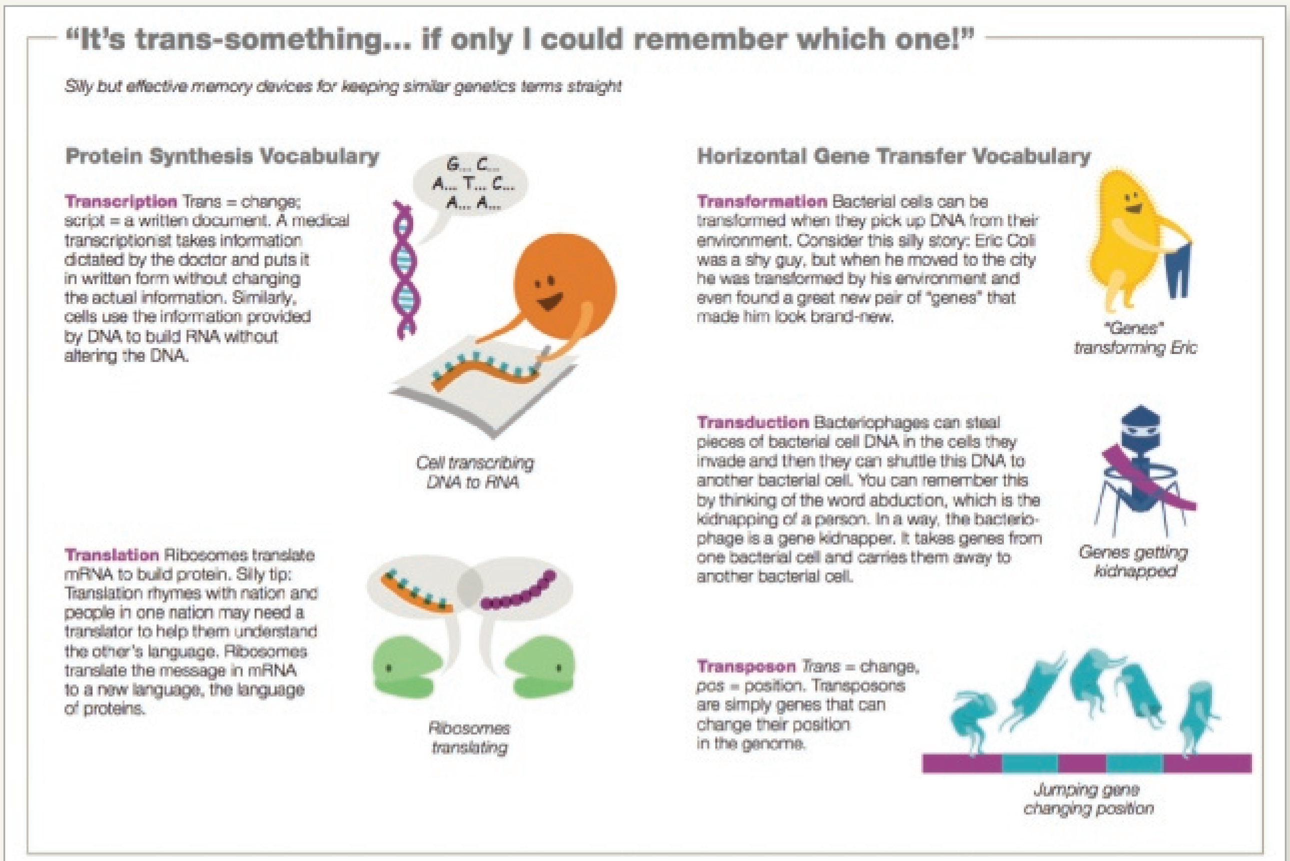
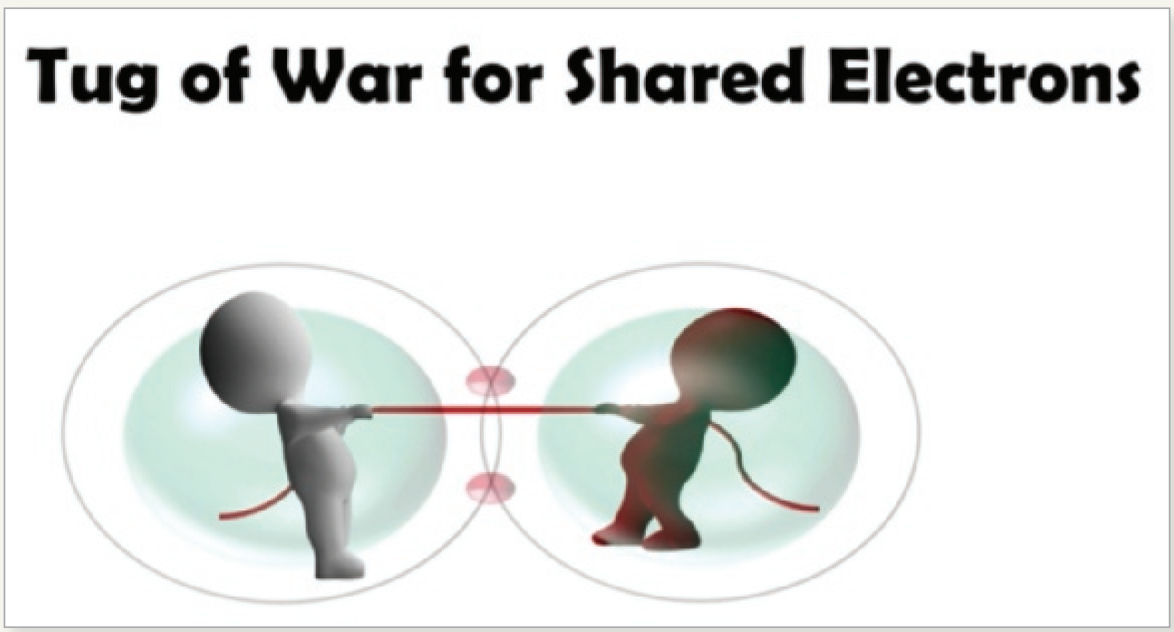


FIGURE 5.25 **Keeping genetics terminology straight**

Bringing the art to life through rich media

MicroFlix 3D-quality video animations with self-paced coaching activities and gradable quizzes help students master the three toughest topics in microbiology: metabolism, DNA replication, and immunology.

MicroBoosters are a suite of brief video tutorials that cover key concepts that students may need to review or relearn. MicroBooster topics include Study Skills, Math, Scientific Terminology, Basic Chemistry, Cell Biology, and Basic Biology. MicroBoosters can be assigned in the Mastering Microbiology Item Library or as Dynamic Study Modules, and are also available for self-study in the Mastering Microbiology Study Area.



in www.MasteringMicrobiology.com

Glycolysis

For most organisms, **glycolysis** (also called the *Embden-Meyerhof-Parnas pathway*) is the first stage in aerobic *and* anaerobic carbohydrate catabolism (FIG. 8.18). It extracts energy from complex carbohydrates such as starches, from disaccharides like sucrose and lactose, and from simple sugars such as mannose, fructose, and of course, glucose. The word *glycolysis* means splitting of sugar.

Glycolysis consists of ten reactions that occur in two basic stages: an energy investment stage and a payoff stage. This pathway, which occurs in the cytoplasm of prokaryotic and eukaryotic cells, does not require oxygen.

CONCEPT COACH

Bring the art to life! Watch the Concept Coach animation and master glycolysis.

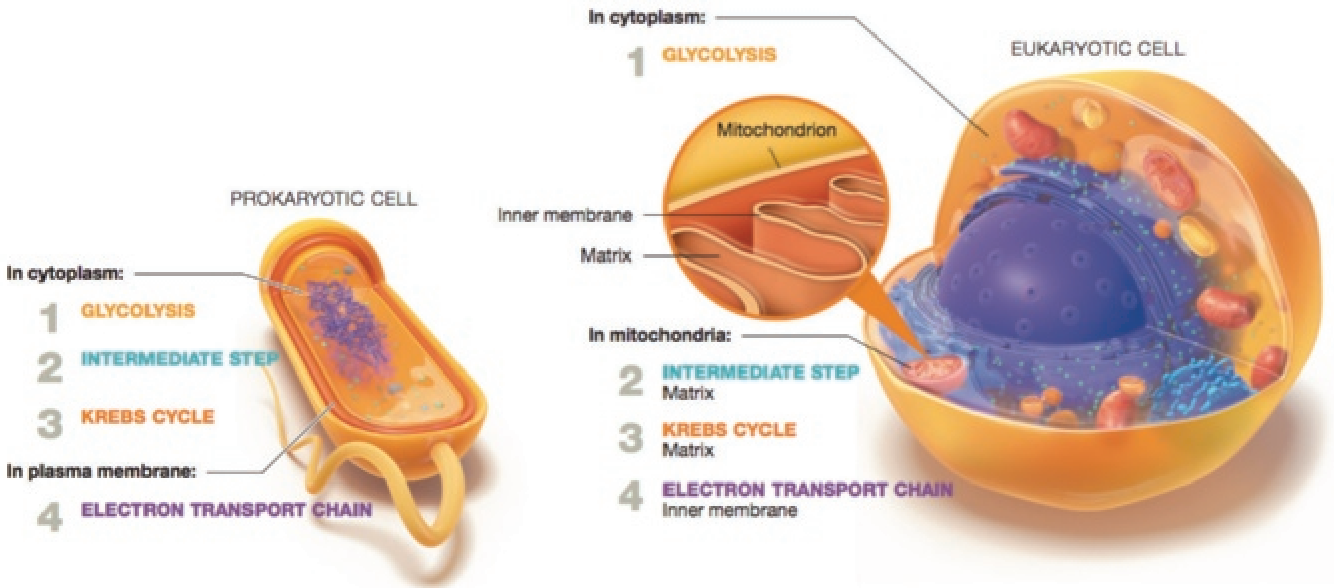


FIGURE 8.17 Where cellular respiration occurs

Concept Coach animations bring the art to life for students. These author-introduced tutorials provide just-in-time coaching on the most difficult concepts in microbiology with interactive, assignable media in **Mastering Microbiology**. These can also be accessed via QR codes embedded in the text.

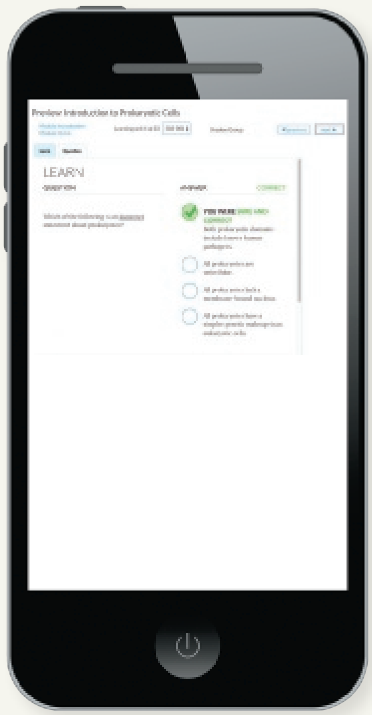
CONCEPT COACH

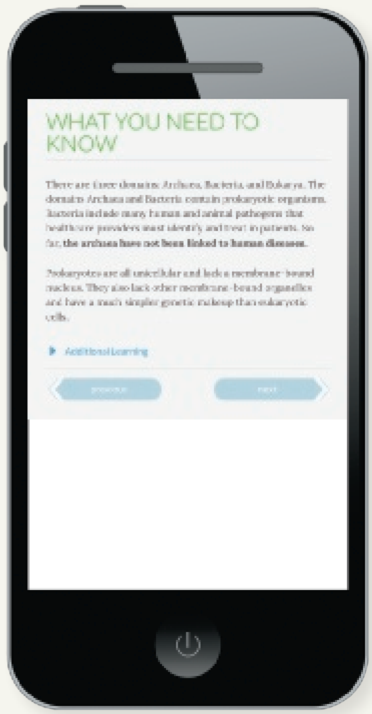
Bring the art to life! Watch the Concept Coach animation and master glycolysis.

Helping students tackle

Succeed with Mastering Microbiology: S.M.A.R.T. on the go!

Mastering Microbiology improves results by engaging students before, during, and after class.





Before class

Dynamic Study Modules provide students with multiple sets of questions with extensive feedback so that they can **test, learn, and retest** until they achieve mastery of the textbook material.

Pre-Class Reading Quizzes help students pinpoint concepts that they understand and concepts that they need to review.

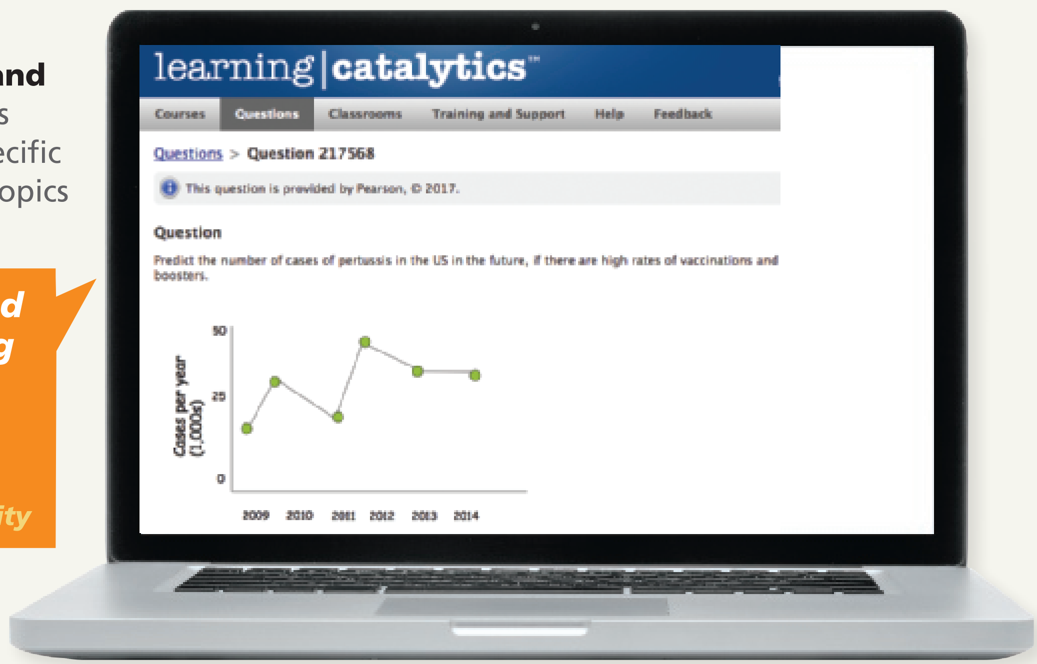
During class

Learning Catalytics allow students to use a smartphone, tablet, or laptop to respond individually or in groups to questions in class. Visit **learningcatalytics.com** to learn more.

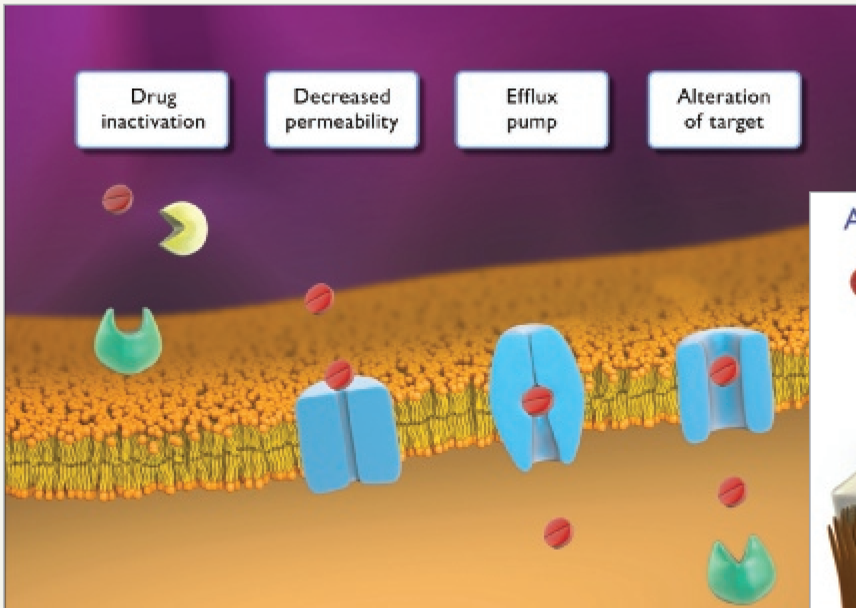
After class

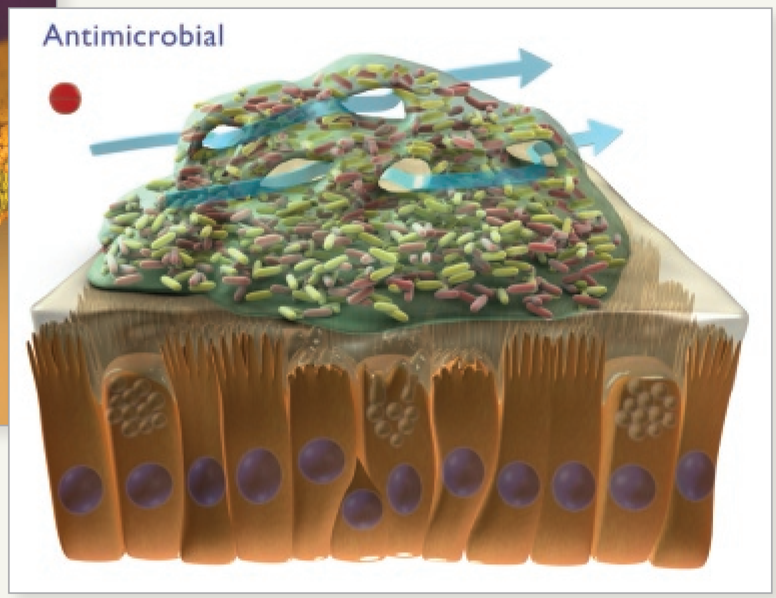
Hundreds of self-paced tutorials and coaching activities provide students with individualized coaching with specific hints and feedback on the toughest topics in the course.

> ***"My students are so busy and engaged answering Learning Catalytics questions during lecture that they don't have time for Facebook."***
>
> **Decian De Paor, *Old Dominion University***



tough topics in microbiology





interactivemicrobiology is a dynamic suite of interactive tutorials and animations that teach key microbiology concepts, including Operons, Biofilms and Quorum Sensing, Complement, and Antibiotic Resistance. Interactive Microbiology actively engages students with each topic, enabling them to learn from manipulating variables, predicting outcomes, and answering formative and summative assessment questions. Each tutorial presents the concepts within a real healthcare scenario in order to emphasize problem solving and interest students from the beginning.

BUILD YOUR FOUNDATION

1. Give a general description of metabolism.
2. Describe how anabolic and catabolic reactions are interconnected, yet different.
3. Describe how ATP acts as a go-between, or intermediate, in catabolic and anabolic reactions.
4. Even though ATP is not very high energy, why is it an ideal molecule for fueling cellular processes?

QUICK QUIZ

Build your foundation by answering the Quick Quiz: scan this code or visit the Mastering Microbiology Study Area to quiz yourself.

Build Your Foundation Quick Quizzes offer formative self-assessment with wrong answer–specific feedback at every Build Your Foundation checkpoint. Accessible on mobile devices via QR codes embedded in the text, these quick quizzes are also available in the Mastering Microbiology Study Area.

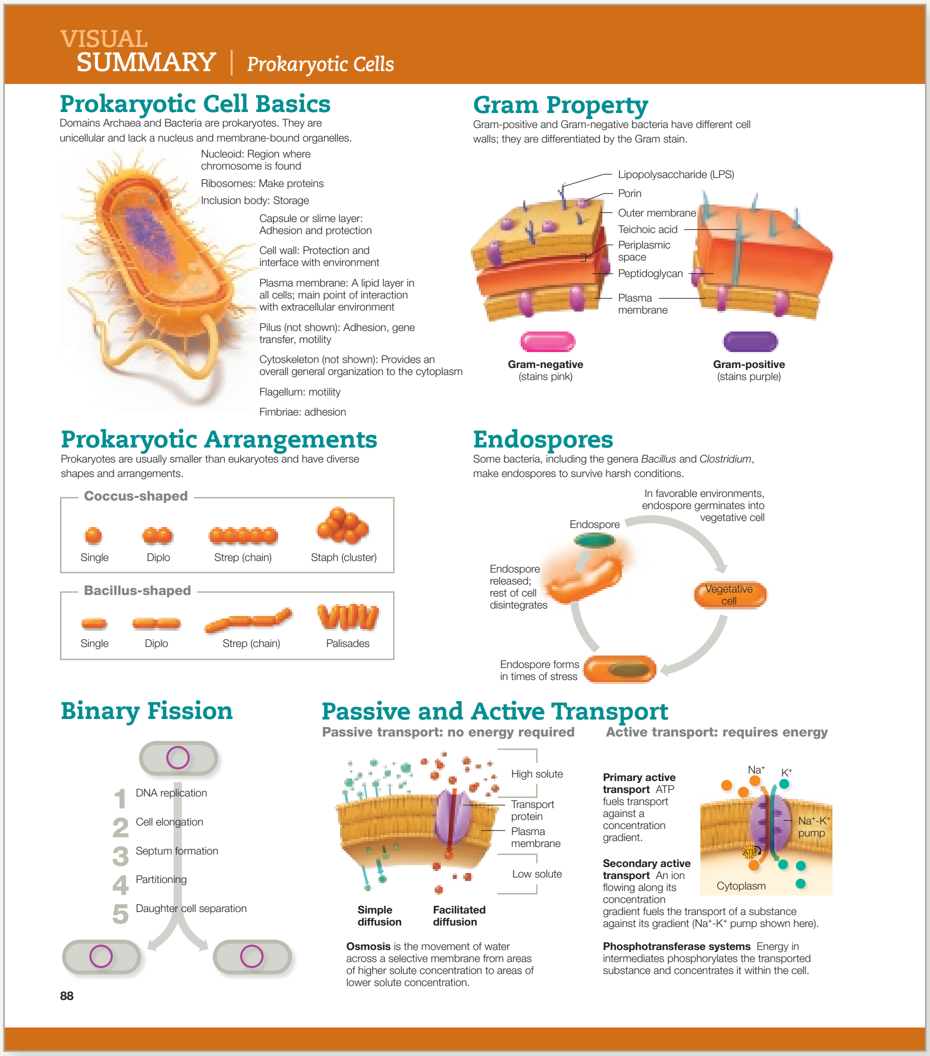
Bridging the gap between class and career

Clinical Cases are presented in an engaging mystery storyline throughout each chapter. Students are asked to use the **S.M.A.R.T.** approach and apply learned chapter content to solve the Clinical Case. Brought to life on mobile devices via QR codes, these items are also assignable in Mastering Microbiology.

Visual Summaries provide an illustrative representation of key chapter concepts using clear, engaging art from the text. Students are encouraged to visualize and reflect on everything they've learned in the chapter in one succinct, easy-to-understand page.

"The Visual Summary at the end of the chapter is genius! Why haven't textbooks done this before?"

-Student, Lansing Community College

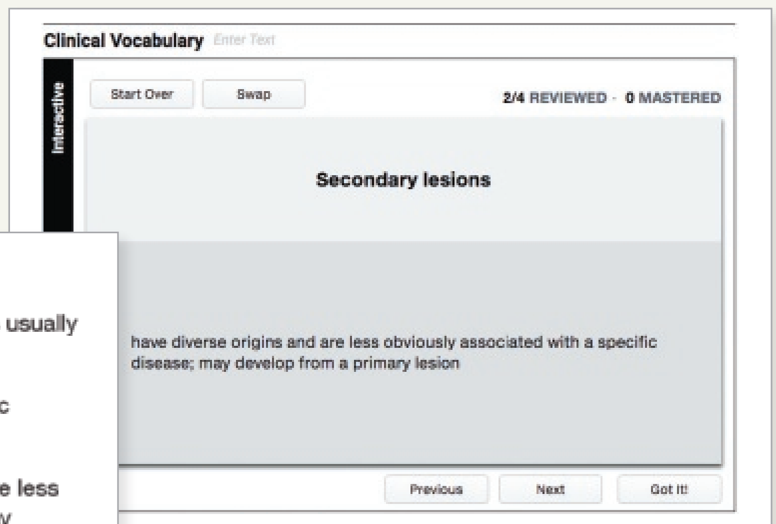


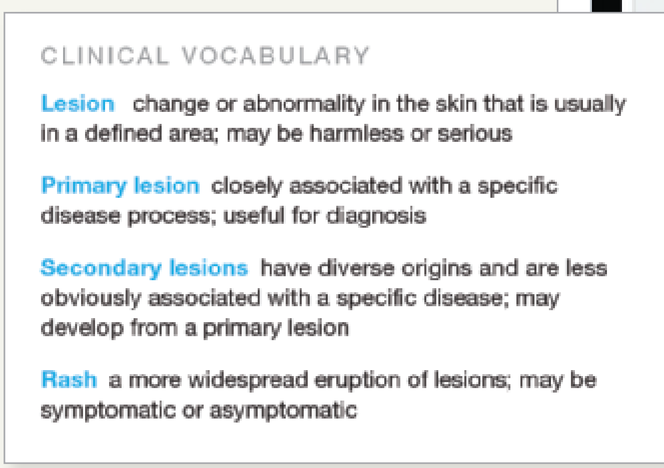
Access the complete textbook online or offline with Pearson eText

The first edition of Norman-McKay is available in Pearson's fully accessible Pearson eText platform.

The Pearson eText mobile app offers offline access and can be downloaded for most iOS and Android phones and tablets from the Apple app or Google Play stores.

Powerful interactive and customization functions The Norman-McKay eText also includes embedded videos and flashcards that help students right when they need it.





CLINICAL VOCABULARY

Lesion change or abnormality in the skin that is usually in a defined area; may be harmless or serious

Primary lesion closely associated with a specific disease process; useful for diagnosis

Secondary lesions have diverse origins and are less obviously associated with a specific disease; may develop from a primary lesion

Rash a more widespread eruption of lesions; may be symptomatic or asymptomatic

Student and Instructor Resources

Instructor Resource Materials with PowerPoint Lecture Outlines

by Lourdes Norman-McKay

0-13-481846-6 / 978-0-13-481846-7

Features all the art, photos, and tables from the book, in both JPEG and PowerPoint format. Additional resources include PowerPoint lecture outlines, select figures in step-edit and label-edit format, PowerPoint art organized into chapter-specific folders, and Test Bank Microsoft Word files. Also included are MicroFlix 3D animations with quizzes (PRS-enabled, clicker questions) that focus on hard-to-teach concepts.

Instructor's Manual

by Lourdes Norman-McKay

0-13-483786-x / 978-0-13-483786-4

Written by the author, this Instructor's Manual contains strategies to implement S.M.A.R.T. in your classroom, whether you have 5 or 50 minutes. She guides instructors on using S.M.A.R.T. for in-class activities, in Mastering Microbiology assignments, or on exams. A detailed guide to interactive media accompanies every chapter, helping instructors to easily integrate Norman-McKay's media into their course.

TestGen Test Bank for Microbiology: Basic and Clinical Principles

0-13-481400-2 / 978-0-13-481400-1

Contains thousands of test questions including multiple-choice, true/false, short answer, and essay.

Microbiology

Basic and Clinical Principles

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Welcome to microbiology!

I dedicate this book to my students, who every day teach me how to be a better teacher; and also to my family, who have been a constant support in this endeavor.

In this course you'll explore **foundational knowledge about microbes**, which is central to your future **healthcare-related career**. However, science facts aren't the only thing you'll need to be successful as you progress in your chosen field. What I mean is this: Five or ten years into your career, you'll need to understand many facts that aren't featured in this textbook or in your lecture—because they aren't known today! Diseases emerge, drugs sometimes lose effectiveness, and new vaccines come to market. In this rapidly shifting world, it's as essential to know how to assess facts as it is to know the facts themselves. You need to learn how to think critically, and to apply that process clinically, so patients benefit.

Every component of this learning package is designed to help you master microbiology as well as fine-tune your ability to think clinically and critically. Down-to-earth language and art are designed to break the content into digestible bites, so you can more easily grasp key concepts. An important part of all learning is active practice, so each chapter opens with a **Clinical Case**, accessible via QR code using your mobile device, or via **https://goo.gl/qK9ep9**. Clinical Cases describe interesting patient scenarios and include questions that allow you to apply your understanding of chapter material. Additionally, each Build Your Foundation section has an associated **Quick Quiz**, again available via your mobile device or the above URL. Sometimes the clearest way to learn a molecular process is through an animation, so we created those, too. Scan the **Concept Coach** QR code to bring the art to life!

Assessing facts is not always a black-and-white process outside the classroom. Both Clinical Cases and end-of-chapter assessments include **NCLEX/HESI/TEAS-STYLE** questions, which require you to consider gray areas and weigh options. While the NCLEX is a licensure exam for nurses, the critical thinking skills these question types employ are useful regardless of your next program or chosen profession. Similarly, each chapter concludes with the **Think Clinically: Comprehensive Case** that introduces you to "**S.M.A.R.T.**," a problem-solving framework for clinical scenarios that stands for **s**ummarize known and unknown; **m**ake connections; **a**void distractors; **r**eread the questions; and **t**horoughly answer them. (For more on S.M.A.R.T., see pages 32–33 of Chapter 1, or the Chapter 1 Concept Coach.)

As you make your way through this course and your future career, I hope you'll "think S.M.A.R.T." and appreciate the process of solving higher-order problems. Because one day, you will be called upon to answer questions that aren't explicitly defined in a book. You will need to integrate information quickly and accurately, with a lot more than a grade at stake. We want you to practice this skill now, before a life is on the line, so that you'll become an integral part of tomorrow's healthcare team.

Enjoy the journey,

Dr. Lourdes Norman-McKay

CLINICAL CASE

QUICK QUIZ

CONCEPT COACH

NCLEX
HESI
TEAS

About the Author

DR. LOURDES NORMAN-MCKAY earned her B.S. in microbiology and cell science from the University of Florida and her Ph.D. in biochemistry and molecular biology from the Pennsylvania State University College of Medicine. She completed a postdoctoral fellowship in microbiology and immunology at Penn State College of Medicine, where she was awarded a National Institutes of Health Fellowship to study the role of viruses in cancer. She has 15 years of experience teaching allied health students at the associate, baccalaureate, and postbaccalaureate levels. She is currently a full-time professor at Florida State College at Jacksonville, where she primarily teaches microbiology and anatomy and physiology. She is also an adjunct faculty for Nova Southeastern University, where she teaches clinical genetics to physician assistant students.

While she was an associate dean at her college, she was directly involved in STEM program development for a biomedical sciences baccalaureate program, as well as STEM career and workforce certificates. Dr. Norman-McKay has extensive experience with building online and hybrid course curriculum; this includes technical training through the Florida Space Research Institute and Workforce Florida.

Her dedication to students is clearly marked by her work as a co-principle investigator on an NSF grant that provided over half a million dollars in scholarship funds for STEM education at her institution. And, in 2016, her peers and students recognized her with the Outstanding Faculty Award at Florida State College at Jacksonville. Lastly, she has been an active participant in the American Society for Microbiology's (ASM's) Microbiology in Nursing Task Force Committee, which recently drafted and disseminated learning outcomes focused on microbiology curriculum as it applies to nursing/prenursing students.

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Preface

Most of my students are training to become allied health professionals, so I wanted a textbook that was specifically built from the ground up for their chosen careers. But it didn't exist! The books available have either been retrofitted with features that target these students or they were built by pulling art and wording from existing non–allied health texts. This is the *very first* microbiology text *completely* designed from scratch to train allied health students—art, media ancillaries, wording, assessments, *everything* you see is just for them.

The First Microbiology Textbook Aligned with ASM's *New* Microbiology Nursing Learning Outcomes

In 2012 the American Society for Microbiology (ASM) drafted a document called "Recommended Curriculum Guidelines for Undergraduate Microbiology Education." Today, most microbiology textbooks are aligned to these guidelines. Unfortunately, the guidelines are not at all clinical—you won't find the words "pathogen" or "infection" *anywhere* in them. Based on this, it's no wonder that anyone looking from the outside in would conclude that microbiology courses are for science majors, not allied health students. That's exactly why some nursing programs are removing microbiology courses from their curriculum and prerequisites. Most microbiology faculty would agree that this is a tremendous disservice to students and patients. Preventable medical errors are the third leading cause of death in the United States, and healthcare-acquired infections affect over 1.7 million U.S. patients annually and cost $35 billion dollars per year in the United States alone. Clearly, allied health students need microbiology. However, their training in microbiology is not the same as general microbiology. Allied health students need microbiology from an allied health perspective every bit as much as science majors need training from a research perspective.

To address the issue, ASM convened a task force, of which I was one of many faculty participants. The task force drafted nursing-centric microbiology learning outcomes and showed how they align with NCLEX learning outcomes. This textbook is the first on the market that directly aligns with ASM's nursing–centric learning outcomes and NCLEX learning outcomes. And this textbook is the first to have assignable, auto-graded content specifically tagged with these outcomes. Faculty can review this content in Mastering Microbiology and track student progress on theses outcomes—along with ASM's original outcomes.

The First Microbiology Textbook that Overtly Teaches Critical Thinking

Allied healthcare workers have the potential to either save lives or end them based on how they perform in their careers. Our students are studying for more than a grade; there are lives at stake. This means that they need to learn the course content, but they also must be able to think clinically and critically. Knowing this, faculty may infuse case studies and other critical thinking exercises into their courses. But, there are challenges to this. Many students lack prerequisite knowledge and struggle with critical thinking; class time is limited and there is so much to cover. Also, most microbiology case studies require students to be diagnosticians—an arguably unreasonable expectation to have for an introductory microbiology student. Most books include critical thinking exercises and case studies, but none overtly provide a framework for students to approach higher order questions. This book does, and here's why . . .

I used to believe that students would pick up on how to think critically if I assigned them readings, gave them critical thinking questions, and modeled critical thinking for them. But time after time I had students come to me in a daze of frustration. They'd routinely say things like, "The answer's not in the book," or "I don't even know where to begin." I eventually realized I had to *overtly* teach critical thinking—not just model it and assign it as a task. It has to be expressly taught, just like the course content. But I don't have unlimited time with my students and I can't hold their hands through all of their course work or into their next program. This is how the S.M.A.R.T. framework was born.

I thought about how trained clinicians and scientists approach problems. I also followed the literature on the neurological aspects of how we learn and how we develop critical thinking skills. Years of teaching and experimenting with thousands of my own students led me to distill the process into the five formulaic steps in S.M.A.R.T. (**S**ummarize, **M**ake connections, **A**void distractors, **R**eread, and **T**horoughly answer). These steps are easy to teach, model, and evaluate students on—and students can readily remember them. These steps help students begin to think like the healthcare providers they are seeking to become.

A Book Focused on Students

Learning science is tough enough without introducing a communication barrier into the mix. This is an accessible textbook that breaks away from stuffy "textbook-speak." That does not mean it's "dumbed down"; it means it's conversational, easy to read, focuses on details allied health students need, and uses memorable analogies and learning devices to bring the content to life. When learning a new subject, that last thing anyone needs is to get bogged down in passive voice prose, odd jargon-filled language, and overly busy figures. Having an accessible text is also increasingly important as we shift from traditional face-to-face courses to hybrid and online platforms where students are expected to engage in more independent learning.

Student and Instructor Tested—and Approved

The development process for this book involved substantial numbers of reviews to ensure that my approach works well for allied health instructors and students. Over one hundred professors and 5,000 students participated in product testing. Of these, 1,700 students took part in both class tests and focus groups. Some key student statistics from this research:

- 97% of students felt that the illustrations and photos in this book were more effective in helping them learn the concepts than the illustrations and photos in their current book.
- 86% of students felt this book's writing style was clearer and more engaging than their current book.
- 87% of students said that, if they were a microbiology instructor, they would choose Norman-McKay for their text.
- 91% of the students said that the S.M.A.R.T. case studies helped improve their understanding of the topics and, of those who said they improved their understanding, 54% said that they significantly improved their understanding.

Acknowledgements

In particular I want to thank my daughters, Lourdes Catherine (now 13) and Delia (now 8). For the past six years they shared me with this greedy sibling and never complained. Lourdes Catherine regularly places a cup of coffee by my side and plants a kiss on my head as I work. At age 4, Delia took my hand in hers and stated she was able to write her *own* book, complete with full color illustrations, in just one afternoon. She suggested with her help, we ought to be able to finish Mommy's book "by dinnertime," and play together tomorrow. My husband and best friend Andrew McKay is another hidden hero; without your constant support this book would have never made it to press. My parents, Greg and Lourdes Norman, have always been sources of unwavering encouragement, love, and support. Somehow they always knew when to offer to pick up the kids or take them out on Saturday for some fun. My amazing sisters Evelyn and Amelia are another dear and special source of love and support. My loving parents-in-law Beverly and Daniel McKay, and my dear sister-in-law Molly McKay, also deserve a shout-out. I'm so lucky to count you all as family.

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I'll close by thanking my own students, as well as the many faculty and other students who reviewed chapters. You had an indispensable role in shaping this text!

Lourdes Norman-McKay, Ph.D.

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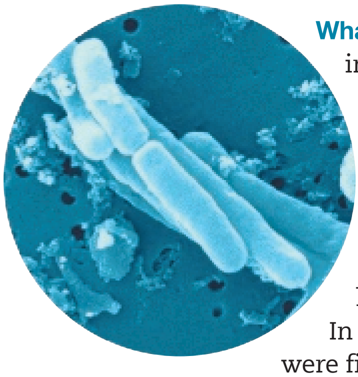
Introduction to Microbiology



What Will We Explore? You are venturing into a new world, one consisting of abundant life forms that can improve or destroy our own way of life. For thousands of years people were unaware of this invisible microbial landscape that is estimated to comprise at least half of the living biomass on Earth.[1] In the late 1600s, when microscopes were first used, our veil of ignorance started to lift as we saw the diversity of what coexisted around us, in us, and on us. In 1665 Robert Hooke first formally described microbial life in his book *Micrographia*, stating, "By the means of telescopes, there is nothing so far distant but may be represented to our view; and by the help of microscopes, there is nothing so small as to escape our inquiry[.]" Since Hooke's time, we continue expanding our knowledge. This chapter introduces a brief history of the field, then explains how we classify microbes and their interactions. Finally, we discuss the modern microscopes and staining techniques essential to the practice of microbiology today.

Why Is It Important? Understanding microbes is central to understanding human health and disease. These days, the smallest of children are taught the connection between microbes and illness. But in recent decades, it's become clearer that our relationship with microbes is more complex than just "microbes make us sick." In a way, we are an ecosystem of many hundreds of species. Despite their small size, microbes also have big roles in sustaining our global environment, producing foods, and even performing everyday functions in our own bodies like making essential vitamins, training our immune system, and helping us digest foods.

The Case of the Mystery Pathogen

How can an infection evade identification?

NCLEX
HESI
TEAS

Scan this code or visit the Mastering Microbiology Study Area to watch the case and find out how microbiology can explain this medical mystery.

[1] Kluyver, A. J., & van Niel, C. B. (1956). *The microbe's contribution to biology.* Cambridge, MA: Harvard University Press, p. 3.

A BRIEF HISTORY OF MICROBIOLOGY

After reading this section, you should be able to:

1. Define the term microorganism and give examples of microbes studied in microbiology.
2. Define the terms pathogen and opportunistic pathogen.
3. Explain biogenesis versus spontaneous generation, and summarize Louis Pasteur's role in proving biogenesis.
4. Describe how Robert Koch helped shape the germ theory of disease and list his postulates of disease.
5. Describe the goals of aseptic technique and why it is important.
6. Discuss how Semmelweis, Lister, and Nightingale contributed to health care.
7. Outline the basic aspects of the scientific method and distinguish an observation from a conclusion and compare a scientific law to a theory.

What is microbiology?

Microbiology is the study of **microbes,** which are often invisible to the naked eye. The term microbe encompasses cellular, living **microorganisms** such as **bacteria, archaea, fungi, protists,** and **helminths,** and nonliving/noncellular entities such as **viruses** and **prions** (infectious proteins) (TABLE 1.1). Some microorganisms are not microscopic. For example, a number of fungi, helminths such as parasitic worms, and protists such as algae are visible to the naked eye.

At least half of Earth's life is microbial. Microbes inhabit almost every region of our planet, from deep-sea trenches to glaciers. And we still have much to discover, as it is estimated that less than 1 percent of the world's microbes are currently identified.

Evolving about 3.5 billion years ago, prokaryotic cells (PRO-care-ee-*ah*-tic) are Earth's earliest life forms. They include unicellular bacteria and archaea (are-KEY-uh), which are structurally and functionally simpler than eukaryotic cells (YOU-care-ee-*ah*-tic). Eukaryotic cells make up all multicellular organisms and a number of unicellular microorganisms such as amoebae and yeast. The **endosymbiotic theory** states that eukaryotic cells evolved from prokaryotic cells. (For more on prokaryotic cells, eukaryotic cells, and endosymbiotic theory, see Chapters 3 and 4.)

Microbiology spans a wide variety of fields, including health care, agriculture, industry, and environmental sciences. Humans rely on microbes for many things such as food production, making medications, and breaking down certain environmental hazards.

Microbes and Disease

While we tend to be most concerned about microbes due to their link with infectious diseases, the majority don't cause disease; the few that do are called **pathogens.** Just over 1,400 pathogens are known to infect humans;[2] overall, less

TABLE 1.1 Living and Nonliving Agents Studied in Microbiology

Microbe	Cell Type	Notes
Bacteria	Prokaryotic	Unicellular*; pathogenic and nonpathogenic
Archaea	Prokaryotic	Unicellular; nonpathogenic; live in extreme environments
Protists	Eukaryotic	Unicellular and multicellular; pathogenic and nonpathogenic (unicellular example: amoebae; multicellular example: algae)
Fungi	Eukaryotic	Unicellular and multicellular; pathogenic and nonpathogenic (unicellular example: yeast; multicellular example: mushrooms)
Helminths	Eukaryotic	Multicellular*; parasitic roundworms and flatworms
Viruses	Not cells; nonliving	Infect animal, plant, or bacterial cells; can have a DNA or RNA genome
Prions	Not cells; nonliving; infectious proteins	Not discovered until the 1980s; transmitted by transplant or ingestion; some prion diseases are inherited

*__Unicellular__ = one-celled organism; **multicellular** = organism made of many cells

Bring the art to life! Watch the Concept Coach video and master how to use this book/media.

[2] Woolhouse, M. E. J., & Gowtage-Sequeria, S. (2005). Host range and emerging and reemerging pathogens. *Emerging Infectious Diseases*, *11*(12), 1842–1847.

than 1 percent of all microbes are likely to be pathogenic. Although some pathogens will always cause disease in humans, given the proper circumstances, others are called **opportunistic pathogens** because they tend to cause disease only in a weakened host. The assistance of a microbiology lab is often required to confirm a diagnosis of infection by a specific pathogen.

Great advances occurred in and around the golden age of microbiology.

The **golden age of microbiology** (approximately 1850–1920) was sparked by innovations in microscopes, the careful documentations made by earlier scientists, and new techniques to isolate and grow microbes (FIG. 1.1). Many of the techniques that spurred this turning point in biology are still used today.

FIGURE 1.1 **Select events in the early history of microbiology**

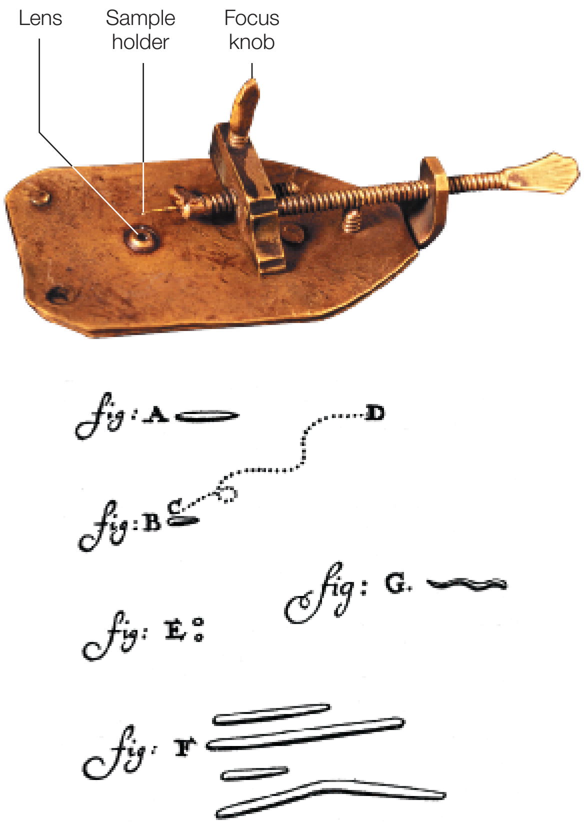


FIGURE 1.2 First views of bacteria Antonie van Leeuwenhoek was the first to report descriptions of bacterial cells. *Top*: Antonie van Leeuwenhoek used a small handheld microscope that had at best a 300× magnification capability. *Bottom*: Leeuwenhoek's drawings of "very little animalcules."

Spontaneous Generation versus Biogenesis

In the 1600s **Robert Hooke** was the first to publish descriptions of cells. **Antonie van Leeuwenhoek,** a contemporary of Hooke, refined earlier versions of the microscope and became the first to see bacteria (FIG. 1.2). Like many of their contemporaries, they participated in the debate about **spontaneous generation,** an idea that life comes from nonliving items, and **biogenesis,** the idea that life emerges from existing life.

Several 17th century scientists, including **Francesco Redi,** performed experiments to test the hypothesis of spontaneous generation. One piece of evidence often cited as proof of spontaneous generation was that rotting meat gave rise to maggots. To further explore this evidence, Redi placed one piece of meat in an uncovered jar and a second piece of meat in a jar with a gauze-covered top. The uncovered meat gave rise to maggots because flies could lay their eggs on it. The meat in the covered jar did not give rise to maggots, since flies were unable to touch the meat.

One would think Redi's experiments would have debunked spontaneous generation, but the theory persisted for another 200 years until the late 1800s, when **Louis Pasteur** showed that biogenesis is responsible for the propagation of life. Pasteur proved that yeast performed fermentation, as opposed to being spontaneously generated by such reactions. He showed that by heating wine to 50–60°C, he could kill off the yeast and prevent stored wine from turning bitter. We now know this heating process as **pasteurization.** It is commonly used to treat milk, juices, and wines to render these foods safe for consumption and slow spoilage.

Convinced that air contained contaminating microbes, Pasteur investigated his hypothesis by performing an experiment with a specialized S-necked flask that was partially filled with broth (FIG. 1.3). He boiled the broth and showed that it remained unspoiled because microbes in the air were trapped in the bent

CHEM • NOTE

Fermentation is a chemical process that often leads to the production of acids and/or alcohols. Fermentation has long been exploited by people who tap microbes to create wine, beer, and vinegar, among other food products.

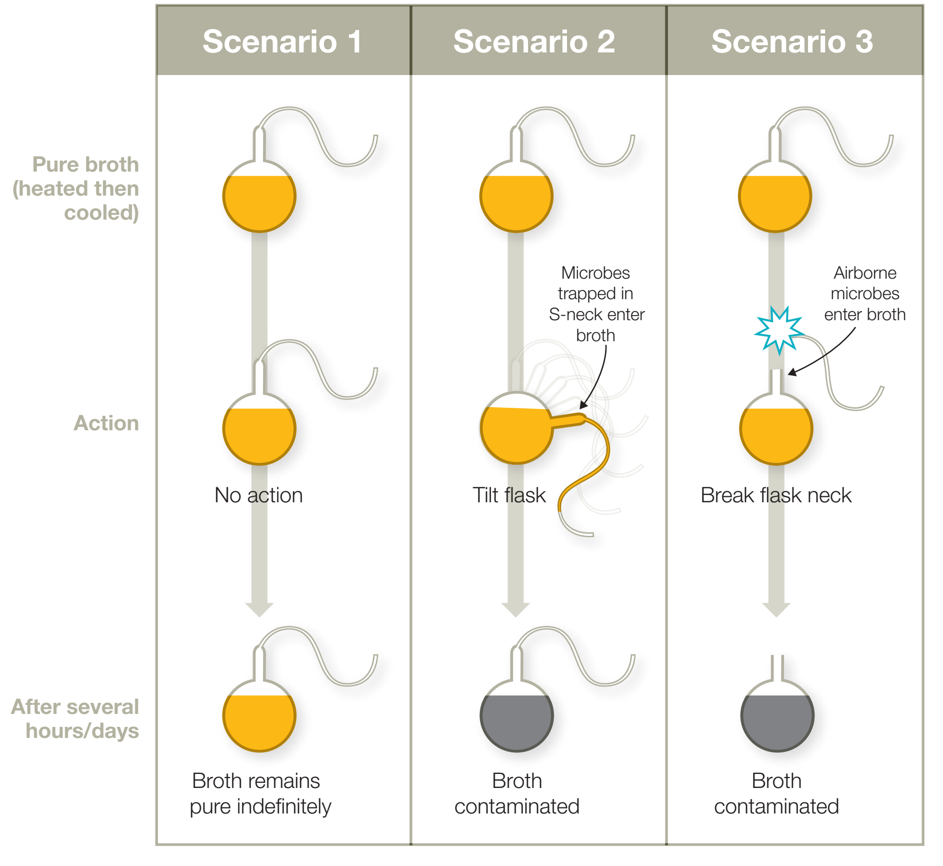


FIGURE 1.3 Pasteur's experiment Louis Pasteur's S-necked flask experiment disproved spontaneous generation.

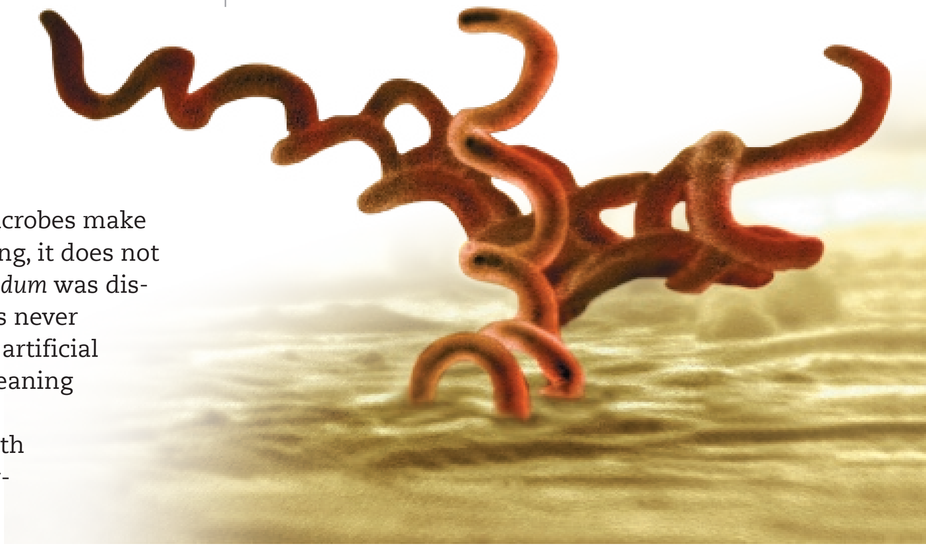
Critical Thinking *Why was it important that the broth was heated in the same flask as it was cooled?*

portion of the flask, unable to reach the liquid below. When the flask was shaken, broth encountered the microbes previously trapped in the curved neck, and the broth would then spoil. Pasteur's work went beyond disproving spontaneous generation. He also developed the first vaccines to protect against anthrax and rabies, and he had a significant role in solidifying the germ theory of disease.

Germ Theory of Disease

The **germ theory of disease** states that microbes cause infectious diseases. From the late 1800s forward, determining the specific **etiological,** or causative, agent of an infectious disease became an important role of microbiology labs. Despite over a century of research, we are still nowhere near discovering the specific etiological agent of every infectious disease. We'll probably never have a complete catalog of every infectious agent, because even as we make progress identifying them, new diseases emerge and previously controlled agents evolve new pathogenic capabilities, such as drug resistance. Further complicating matters is the fact that current laboratory techniques only allow us to grow about 2 percent of the bacterial species found in our environment.

While laboratory limitations and the evolving nature of microbes make characterizing the etiological agents of disease more challenging, it does not make it impossible. For example, the bacterium *Treponema pallidum* was discovered to be the cause of syphilis over 100 years ago, yet it has never been successfully cultured *in vitro* (meaning "in glass," or in an artificial setting). *Treponoma pallidum* has only been sustained *in vivo* (meaning "in the living"—in animal models) using rabbits.[3]



T. pallidum

Louis Pasteur and his contemporary **Robert Koch** (coke) both reinforced the germ theory of disease. Koch was a German physician who developed staining techniques and media for the isolation and cultivation of bacteria. Some of Koch's most groundbreaking work started with the study of anthrax, a disease that primarily infects grazing animals but may infect humans. (For more on anthrax, see Chapter 17.) Koch discovered that anthrax is caused by a bacterium, which he named *Bacillus anthracis*. He was able to isolate these bacteria from diseased animals and introduced the purified bacteria into mice to establish an infection.

Koch's Postulates of Disease

Koch's work on anthrax led to the development of **Koch's postulates of disease** (**FIG. 1.4**). These four principles establish the criteria for determining the causative agent of an infectious disease. (Koch's postulates are briefly listed here, but are reviewed in more detail in Chapter 9.)

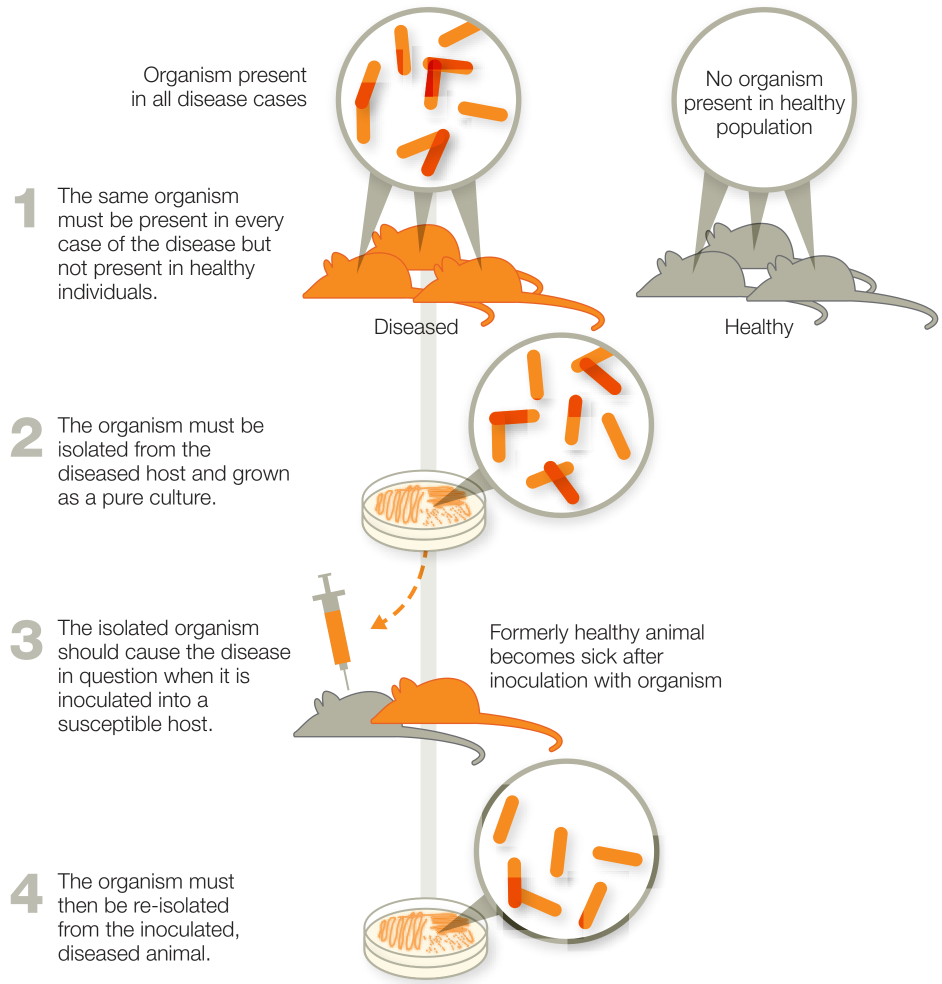
1. The same organism must be present in every case of the disease.
2. The organism must be isolated from the diseased host and grown as a pure culture.
3. The isolated organism should cause the disease in question when it is introduced (inoculated) into a **susceptible host** (a host that can develop the disease).
4. The organism must then be re-isolated from the inoculated, diseased animal.

In his studies, Koch confirmed that not all infections cause evident disease. This is why the third postulate states that disease should result, but avoids the term "must" as is found in his other statements.

[3] Stewart, E. J. (2012). Growing unculturable bacteria. *Journal of Bacteriology*, 194(16), 4151–4160.

FIGURE 1.4 Koch's postulates Koch's postulates can help identify the causative agent of certain infectious diseases.

Critical Thinking *It is not ethical to purposefully expose people to a suspected pathogen to fulfill Koch's third postulate. With this in mind, how could the third step be ethically observed if the disease being studied only occurred in humans and an animal model could not be used?*



Hand Hygiene and Aseptic Techniques

At the same time that the biogenesis theory and the germ theory of disease were being developed and debated, several medical professionals from the 1800s through early 1900s were emphasizing the importance of aseptic techniques in medical settings. In a medical setting, **aseptic technique** entails preventing the introduction of potentially dangerous microbes to a patient; it doesn't mean that everything in the healthcare setting needs to be **sterile** (absent of all microbes). While most surfaces in an operating room or other healthcare setting are disinfected to limit potentially dangerous microbes, they are not sterile. Aseptic processes are central to health care because they prevent **healthcare-acquired infections** or **HAIs** (also called **nosocomial infections**) and limit the spread of diseases.

Aseptic procedures also allow us to safely study microbes in the laboratory. They are also central to helping us keep samples pure so we can study one microbe at a time. The type of aseptic techniques used depends on the situation, but aseptic procedures usually include washing hands, wearing gloves, sterilizing instruments, and decontaminating surfaces. (See Chapter 10 for more on healthcare biosafety precautions.)

A Hungarian physician named **Ignaz Semmelweis** first developed aseptic techniques in the 1840s. He recommended hand washing to decrease mortality rates from childbed fever (puerperal sepsis), an infection that killed many women in childbirth before the antibiotics era.

Semmelweis saved many lives, yet his work was not fully appreciated until about 20 years later, when Pasteur disproved spontaneous generation. Work by

Semmelweis and Pasteur inspired the British surgeon **Joseph Lister** to investigate processes for aseptic surgery. Lister's work in the 1860s proved that sterilizing instruments, and sanitizing wounds with carbolic acid encouraged healing and prevented pus formation. Around the same time, **Florence Nightingale** established the use of aseptic techniques in nursing practices, which, along with other patient-care innovations, earned her the historical distinction of being the founder of modern nursing.

CHEM • NOTE

Carbolic acid (C_6H_6O), also known as phenol, is an organic molecule with antiseptic (degerming) and anesthetic (numbing) properties. It can be found in sore throat sprays, lip balms, and various household cleaners, and is also used for making plastics. Phenol can be commercially produced but also occurs naturally in many foods. Concentrated phenol is toxic to humans and is regulated.

The scientific method is the guiding investigative principle for microbiology.

Before the modern age, illness was often attributed to evil spirits or sinfulness. As such, early medical treatments almost always included some form of penance, pilgrimage, or protective charm. Early physicians thought illness derived from an imbalance of the body's humors that could be relieved by bloodletting or applying leeches to the body (FIG. 1.5).

Today, by contrast, we explore questions about the origins of diseases and potential treatments through the **scientific method.** In its most basic form, the scientific method starts with a question that can be investigated. Next, a **hypothesis,** or prediction based on prior experience or observation, is proposed as a potential answer to the question. The researcher collects and analyzes **observations** (data) and uses them to formulate a **conclusion** that states whether the data supported or contradicted the hypothesis.

Observations versus Conclusions

Failure to recognize the difference between observations and conclusions leads to errors and confusion. An observation is any data collected using our senses or instrumentation, while a conclusion interprets observations. For example, suppose you witnessed a robber driving a getaway car with a Florida license plate. If you tell the detective that the robber is from Florida instead of saying the robber's car had Florida plates, you may mislead the investigation. This scenario is an example of *inference–observation confusion*—more commonly known as "jumping to conclusions." It usually takes a collection of observations and many different methods of testing to draw accurate conclusions. It is essential that healthcare workers avoid inference–observation confusion because it can lead to a wrong assessment of the patient. We should also recognize the limits of experimental design, and what we can truly conclude from our observations.

FIGURE 1.5 **Bloodletting** For about 3,000 years, bloodletting was practiced as a primary medical therapy for practically every ailment.

Law versus Theory

The difference between a scientific law and a scientific theory also confuses many students. A **law** is a precise statement, or mathematical formula, that predicts a specific occurrence. Laws only hold true under carefully defined and limited circumstances. By contrast, a **theory** is a hypothesis that has been proven through many studies with consistent, supporting conclusions. Laws predict *what* happens, while theories explain *how* and *why* something occurs. Unlike a hypothesis, which focuses on a specific problem, theories are comprehensive bodies of work that are useful for making generalized predictions about natural phenomena. Theories unite many different hypotheses and laws.

Sometimes people think that laws must be superior to theories—likely because of the way laws are defined and enforced within governments. But one should not equate the social definition of a law with the scientific one. In science, laws and theories have completely different goals and facilitate discovery in different ways. Thus, the idea that a theory would be "elevated" to a law is inaccurate; to do so would be like turning an apple into an orange. Even a theory or law is not considered a closed case. Scientists continue to retest laws and theories as our technology and knowledge increase.

BUILD YOUR FOUNDATION

Build your foundation by answering the Quick Quiz: scan this code or visit the Mastering Microbiology Study Area to quiz yourself.

QUICK QUIZ

1. Microbiology is the study of living and nonliving microscopic entities. Explain.
2. What is a pathogen and how is it different from an opportunistic pathogen?
3. Describe biogenesis versus spontaneous generation and discuss how Pasteur disproved spontaneous generation.
4. List Koch's postulates of disease and describe how they contributed to the germ theory of disease.
5. The term aseptic does not mean 100 percent sterile. Explain why.
6. How did Lister, Semmelweis, and Nightingale contribute to health care?
7. A student wrote that a red color developed in the test tube being used. Is this an observation or a conclusion? Explain.
8. How is a scientific law different from a theory?

CLASSIFYING MICROBES AND THEIR INTERACTIONS

After reading this section, you should be able to:

8 Describe the binomial nomenclature system and the information it provides about an organism.
9 Summarize the taxonomic hierarchy from domain to species.
10 Define the term strain.
11 Note the genus versus species parts of a microbe's scientific name.
12 Define the term normal microbiota and discuss its establishment and roles.
13 Define parasitism, mutualism, and commensalism.
14 Explain a host–microbe interaction that impacted human evolution.
15 Provide examples of how microbes impact industry and the environment.
16 Describe how a biofilm forms and discuss the healthcare implications of biofilms.

Morphology and physiology are central to bacterial classification.

Classifying or grouping microbes is important both for study and for clear communication among researchers and healthcare providers. Today microbes include bacteria, archaea, protists, helminths, fungi, viruses, and infectious proteins called prions. These categories, and the way we divide various microbes among them, have changed greatly over time. Starting in the 1870s, bacteria were organized into groups based on **morphology** (physical traits such as shape, size, and arrangement) and distinguishing physiological features. These early bacterial classification approaches remain useful. (See Chapter 3 for more on bacterial morphology.)

Between the late 1800s and the mid-1900s most of the major bacterial pathogens known today were characterized. At the same time, numerous bacterial culture and isolation techniques, as well as staining procedures, were being developed. These rapid in-field advancements made microbiologists recognize that they needed some way to organize their findings. So, in the 1920s, the Society of American Bacteriologists (now the American Society for Microbiology, or ASM), worked to unify the classification criteria for bacteria. Their efforts were the foundation of *Bergey's Manual of Determinative Bacteriology*. *Bergey's Manual* evolved through numerous updates, but remains a cornerstone reference for bacterial identification and classification. The ability to sequence genomes is the latest development to have impacted classification systems since the 1950s. Previously unseen links between microbes continue to be uncovered through genetic analysis, leading some microbes to be reclassified.

Prokaryotic and Eukaryotic: A Fundamental Difference in Cells

The smallest unit of life is a cell; all organisms are made of cells. There are two general categories: prokaryotic and eukaryotic. These cell types are reviewed in greater detail later in this text, but it is important to clarify a couple of points here. First, all prokaryotic organisms are **unicellular,** which means they consist of only one cell. Prokaryotic cells also lack a nucleus, and are divided into two main categories: bacteria and archaea. In contrast, eukaryotic cells can exist as unicellular or multicellular organisms. These cells have a distinct nucleus, which houses the cell's genetic material. There are four main types of eukaryotic cells: animal, plant, fungal, and protist. (Chapter 3 further reviews prokaryotic cells; Chapter 4 covers eukaryotic cells.)

Taxonomy groups organisms.

Taxonomy is the study of how organisms can be grouped by shared features. It encompasses identifying, naming, and classifying organisms. Modern classification schemes organize life forms by their shared characteristics, including physical and biochemical features, ecology, and gene sequences.

Scientific Names

In the mid-1700s**, Carl Linnaeus** established criteria for classifying organisms and is recognized as the father of taxonomy. He developed the **binomial nomenclature system,** or two-name system, that includes genus and species designations. Binomial nomenclature is still used today. Organisms have two names: The first is capitalized and reflects the genus, while the second name is lowercase and designates the species. Scientific names are italicized (or underlined, if handwritten) and Latinized, meaning the names are Latin-sounding; in most cases they are nothing near real Latin. For example, in the name *Escherichia coli*, the genus name derives from the discoverer's name, Theodor Escherich; the species name *coli* reflects that the organism is abundant in the colon. Often an organism's name refers to its discoverer, cell shape, cell arrangement, or other distinct traits that the person who coined the name found noteworthy.

Taxonomic Hierarchy

While organism names are based on just two categories, there are actually many rankings within the taxonomic hierarchy. Rankings range from broad overarching domains all the way down to the precise species level. The mnemonic device, "*D*elightful *K*ing *P*hilip *c*ame *o*ver *f*or *g*reat *s*paghetti" may help you remember the individual rankings within the taxonomic hierarchy: *d*omain, *k*ingdom, *p*hylum, *c*lass, *o*rder, *f*amily, *g*enus, *s*pecies.

A **domain** is the broadest grouping of organisms. The three recognized domains include Bacteria, Archaea, and Eukarya. Domain Bacteria and Domain Archaea include single-celled (unicellular) prokaryotic organisms. Most of the prokaryotes you will learn about in this text belong to the Domain Bacteria because this grouping includes potential pathogens. Members of Domain Archaea are best known for living in extreme environments: high-temperature deep-sea vents, areas of bitter cold, or environments with harsh chemical conditions usually devoid of other life forms. However, they can also live in normal environments and according to the Human Microbiome Project, Archaea members are also found in the human gut and on our skin. To date, Archaea members have not been shown to be pathogens. The Domain Eukarya encompasses unicellular and multicellular organisms that are made of eukaryotic cells.

Beneath the umbrella of domains are a variety of **kingdoms.** The number of designated kingdoms has fluctuated from five to eight. The older five-kingdom classification scheme includes Animalia, Plantae, Fungi, Protista, and Monera. The trouble with the five-kingdom scheme is that it fails to assign separate kingdoms for Domain Archaea and Domain Bacteria, instead lumping them together as Kingdom Monera. As an answer to this, a six-kingdom schematic arose, in which Kingdom Monera is replaced by two distinct kingdoms: Eubacteria and Archaebacteria. Even this arrangement has been criticized because the term Archaebacteria implies that the Archaea are a type of bacteria.

The six-kingdom schematic, which is what this text will employ, replaces Kingdom Monera with Kingdom Archaea and Kingdom Bacteria (TABLE 1.2). The discussion is even more elaborate when the proposed new kingdoms for protists are considered. Traditionally, Protista was a sort of miscellaneous catchall kingdom for organisms that couldn't be described as plants, animals, or fungi. Genetics now shows that protists can't logically be lumped into a single kingdom. However, the term "Kingdom Protista" continues to persist, although technically it