Cutting Edge Microbiology Research for Today’s Learners

The 13th Edition of Tortora, Funke, and Case’s *Microbiology: An Introduction* brings a 21st-century lens to this trusted market-leading introductory textbook. New and updated features, such as *Exploring the Microbiome* boxes and *Big Picture* spreads, emphasize how our understanding of microbiology is constantly expanding. New *In the Clinic Video Tutors* in *Mastering™ Microbiology* illustrate how students can apply their learning to their future careers. *Mastering Microbiology* also includes new *Ready-to-Go Teaching Modules* that guide you through the most effective teaching tools available.
Do your students struggle to make connections between course topics?

**NEW! Exploring the Microbiome** boxes illustrate how research in microbiology is revolutionizing our understanding of health and disease. These boxes highlight the possibilities in this exciting field and present insights into some of the newly identified ways that microbes influence human health. In addition, they provide examples of how research in this field is done—building on existing information, designing fair testing, drawing conclusions, and raising new questions.

**Exploring the Microbiome: Do Artificial Sweeteners (and the Intestinal Microbiota That Love Them) Promote Diabetes?**

For years, beverages made with artificial sweeteners were endorsed by diabetics and weight watchers because, unlike sugar, artificial sweeteners don’t impact blood glucose levels and don’t provide calories. However, recent research indicates artificial sweeteners may actually increase the risk of cardiovascular disease and diabetes. One study, published in 2015 in the American Diabetes Association, found that daily consumption of diet soda was associated with a 67% greater relative risk of developing type 2 diabetes. Unregulated by bacteria, artificial sweeteners provide zero calories to us when we consume them. But they are a food source for bacteria, allowing them to grow and multiply by over twenty-fold. As bacteria grow, they consume and increase in numbers, other types of microbiota simultaneously decline. Among these are Lactobacillus bacteria. Studies indicate that high sucrose levels in the intestine are associated with decreased blood sugar levels. The exact mechanism remains unclear, but it is hypothesized that decreases in the population of lactobacilli bacteria lead to higher blood glucose levels, thereby forcing the body to produce more insulin to control the rising blood glucose. Probiotics—high in insulin—may help to resist insulin resistance, a condition whereby the body stops responding normally to the hormone. Insulin resistance is the hallmark sign of type 2 diabetes. Recent and current research are exploring whether ingesting probiotics with lactobacillus acidophilus and bifidobacteria strains may be a useful treatment for type 2 diabetes. Initial studies show a decrease in blood sugar levels and a reduction in glycated hemoglobin levels. Further research is required to fully understand the role of probiotics in managing type 2 diabetes.

**Exploring the Microbiome: Antimicrobial Soaps: Doing More Harm Than Good?**

Staphylococcus aureus is a normal member of the human microbiome, found on the skin and in the nose. S. aureus is also a significant cause of healthcare-associated infections in patients. The bacterium can switch from harmless commensal of the skin community to a disease-causing pathogen if it gains entry to the body through a wound. Some methicillin-resistant S. aureus infections are nosocomial—that is, caused by bacteria that have colonized on or on the body before someone became a patient. Hospitals have long used a disinfectant called trichloroethylene to prevent methicillin-resistant infections. However, this chemical has been shown to be harmful to many household products, such as food-degrading enzymes, toothpaste, and body washes. However, using these antimicrobial products only seems to be a “wise choice of a good thing.”

Trichloroethylene irritates the skin and is excreted in urine. Therefore, trichloroethylene can be found in many areas of the body, including the nasal mucosa, of people who use these products. One note is the potential threat of S. aureus in an example of unintended consequences, prevention of trichloroethylene from blood is also associated with nasal colonization of the S. aureus. S. aureus is more likely to bind to nasopharyngeal membranes in the presence of trichloroethylene. Moreover, constant exposure to trichloroethylene selects for trichloroethylene-resistant mutants over generations of bacterial growth. Trichloroethylene-resistant bacteria avoid death by removing the chemical from dead cells using transport proteins. These transporters can also remove some antibiotics from the bacterial cells. However, methicillin-resistant S. aureus can also inhibit their own replication by increasing the methicillin-resistant strain.

Starting in late 2015, the American Drug Association found that trichloroethylene is a common cause of drug resistance. The American Medical Association recommends using a mild soap and water and proper handwashing techniques instead—"Handwashing matters."
New! **In the Clinic Video Tutors** bring to life the scenarios in the chapter-opening In the Clinic features. Concepts related to infection control, principles of disease, and antimicrobial therapies are integrated throughout the chapters, providing a platform for instructors to introduce clinically relevant topics throughout the term. Each Video Tutor has a series of assessments assignable in Mastering Microbiology that are tied to learning outcomes.

NEW! **Ready-to-Go Teaching Modules** in the Instructor Resources of Mastering Microbiology help instructors efficiently make use of the available teaching tools for the toughest topics in microbiology. Pre-class assignments, in-class activities, and post-class assessments are provided for ease of use. Within the Ready-to-Go Teaching Modules, **Adopt a Microbe** modules enable instructors to select specific pathogens for additional focus throughout the text.
**Interactive Microbiology** is a dynamic suite of interactive tutorials and animations that teach key microbiology concepts. Students actively engage with each topic and learn from manipulating variables, predicting outcomes, and answering assessment questions that test their understanding of basic concepts and their ability to integrate and build on these concepts. These are available in Mastering Microbiology.

**NEW! Even more Interactive Microbiology** modules are available for Fall 2018. Additional titles include:
- Antimicrobial Resistance: Mechanisms
- Antimicrobial Resistance: Selection
- Aerobic Respiration in Prokaryotes
- The Human Microbiome
MicroBoosters are a suite of brief video tutorials that cover key concepts some students may need to review or relearn. Titles include Study Skills, Math, Scientific Terminology, Basic Chemistry, Cell Biology, and Basic Biology.

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

NEW! Instructors can now remove questions from Dynamic Study Modules to better fit their course.
Do your students have trouble organizing and synthesizing

**Big Picture** spreads integrate text and illustrations to help students gain a broad, “big picture” understanding of important course topics.

Each **Big Picture spread** includes an overview that breaks down important concepts into manageable steps and gives students a clear learning framework for related chapters. Each spread includes Key Concepts that help students make the connection between the presented topic and previously learned microbiology principles. Each spread is paired with a coaching activity and assessment questions in Mastering Microbiology.

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**Bioterrorism**

**Biological agents were first tapped by armies, and now by terrorists. Today, technology and ease of travel increase the potential damage.**

**History of Bioweapons**

Biological weapons (bioweapons)—pathogens intentionally used for hostile purposes—are not new. The “ideal” bioweapon is one that disseminates by aerosol, spreads efficiently from human to human, causes debilitating disease, and has no readily available treatment. The earliest recorded use of a bioweapon occurred in 1346 during the Siege of Kaffa, in what is now known as Feodosia, Ukraine. There the Tartar army catapulted their own dead soldiers’ plague-ridden bodies over city walls to infect opposing troops. Survivors from that attack went on to introduce the “Black Death” to the rest of Europe, sparking the plague pandemic of 1348–1350.

In the eighteenth century, blankets contaminated with smallpox were intentionally introduced into Native American populations by the British during the French and Indian War. And during the Sino-Japanese War (1937–1945), Japanese planes dropped canisters of fleas carrying Yersinia pestis bacteria, the causative agent of plague, on China. In 1975, Bacillus anthracis endospores were accidentally released from a bioweapon production facility in Sverdlovsk.

**Selected Diseases Identified as Potential Bioweapons**

<table>
<thead>
<tr>
<th>Bacterial</th>
<th>Viral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthrax (Bacillus anthracis)</td>
<td>Nonbacterial meningitis (Neisseria)</td>
</tr>
<tr>
<td>Pneumococcal (Streptococcus pneumoniae)</td>
<td>Neumotoric fever (Staph, Meningitis, Lyme)</td>
</tr>
<tr>
<td>Botulism (Clostridium botulinum tetani)</td>
<td>Neumotoric fever (Staph, Meningitis, Lyme)</td>
</tr>
<tr>
<td>Tularemia (Francisella tularensis)</td>
<td>Monkeypox</td>
</tr>
<tr>
<td>Cholera (Vibrio cholerae)</td>
<td>Nipah virus infection</td>
</tr>
<tr>
<td>Plague (Yersinia pestis)</td>
<td>Smallpox</td>
</tr>
</tbody>
</table>

**Biological Weapons Banned in the Twentieth Century**

The Geneva Conventions are internationally agreed upon standards for conducting war. Written in the 1920s, they prohibited deploying bioweapons—but did not specify that possessing or creating them was illegal. As such, most powerful nations in the twentieth century continued to create bioweapons, and the growing stockpiles posed an ever-growing threat. In 1975, the Biological Weapons Convention banned both possession and development of biological weapons. The majority of the world’s nations ratified the treaty, which stipulated that any existing bioweapons be destroyed and related research halted.

**Emergence of Bioterrorism**

Unfortunately, the history of bioweapons doesn’t end with the ratification of the Biological Weapons Convention. Since then, the main actors engaging in bioweapons have not been nations but rather radical groups and individuals. One of the most publicized bioterrorism incidents occurred in 2001, when five people died from, and many more were infected with, anthrax that an army researcher sent through the mail in letters.
Public Health Authorities Try to Meet the Threat of Bioterrorism

One of the problems with bioweapons is that they contain living organisms, so their impact is difficult to control or even predict. However, public health authorities have created some protocols to deal with potential bioterrorism incidents.

Vaccination: A Key Defense

When the use of biological agents is considered a possibility, military personnel and first responders (health care personnel and others) are vaccinated—if a vaccine for the suspected agent exists. New vaccines are being developed, and existing vaccines are being stockpiled for use where needed.

The current plan to protect civilians in the event of an attack with a microbe is illustrated by the smallpox preparedness plan. This killer disease has been eradicated from the population, but unfortunately, a cache of the virus remains preserved in research facilities, meaning that it might one day be weaponized. It’s not practical to vaccinate all people against the disease. Instead, the U.S. government’s strategy following a confirmed smallpox outbreak includes “ring containment and voluntary vaccination.” A “ring” of vaccinated/protected individuals is built around the bioterrorism infection case and their contacts to prevent further transmission.

New Technologies and Techniques to Identify Bioweapons

Monitoring public health, and reporting incidence of diseases of note, is the first step in any bioterrorism defense plan. The faster a potential incident is uncovered, the greater the chance for containment. Rapid tests are being investigated to detect genetic changes in hosts due to bioweapons even before symptoms develop. Early-warning systems, such as DNA chips or recombinant cells that fluoresce in the presence of a bioweapon, are also being developed.

Biological hazard symbol.

Examining mail for B. anthracis.

Pro Strips Rapid Screening System, developed by ADVNT Biotechnologies LLC, is the first advanced multi-agent biowarfare detection kit that tests for anthrax, ricin toxin, botulinum toxin, plague, and SEB (staphylococcal enterotoxin B).

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Additional Instructor and Student Resources

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

**Instructor Resource Materials for Microbiology: An Introduction**
The Instructor Resource Materials organize all instructor media resources by chapter into one convenient and easy-to-use package containing:
- All figures, photos, and tables from the textbook in both labeled and unlabeled formats
- TestGen Test Bank
- MicroFlix animations
- Instructor’s Guide

A wealth of additional classroom resources can be downloaded from the Instructor Resources area of Mastering Microbiology.

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To all my children, the most important gift I have: Lynne, Gerard Jr., Kenneth, Anthony, and Drew, whose love and support have been such an important part of my personal life and professional career.

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I owe my deepest gratitude to Don Biederman and our three children, Daniel, Jonathan, and Andrea, for their unconditional love and unwavering support.
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Preface

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

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

- **An appropriate balance between microbiological fundamentals and applications, and between medical applications and other applied areas of microbiology.** Basic microbiological principles are given greater emphasis, and health-related applications are featured.

- **Straightforward presentation of complex topics.** Each section of the text is written with the student in mind.

- **Clear, accurate, and pedagogically effective illustrations and photos.** Step-by-step diagrams that closely coordinate with narrative descriptions aid student comprehension of concepts.

- **Flexible organization.** We have organized the book in a clear learning framework for the related chapters. Each refers the student to a related MicroFlix video accessible through MasteringMicrobiology.

- **Big Picture core topic features.** These two-page spreads focus on the most challenging topics for students to master: metabolism (Chapter 5), genetics (Chapter 8), and immunology (Chapter 16). Each spread breaks down these important concepts into manageable steps and gives students a clear learning framework for the related chapters. Each refers the student to a related MicroFlix video accessible through MasteringMicrobiology.

- **Big Picture disease features.** These two-page spreads appear within each chapter in Part Four, Microorganisms and Human Disease (Chapters 21–26), as well as Chapters 18 (Practical Applications of Immunology) and 19 (Disorders of the Immune System). Each spread focuses on one significant public health aspect of microbiology.

- **ASM guidelines.** The American Society for Microbiology has released six underlying concepts and 27 related topics to provide a framework for key microbiological topics deemed to be of lasting importance beyond the classroom. The thirteenth edition explains the themes and competencies at the beginning of the book and incorporates callouts when chapter content matches one of these 27 topics. Doing so addresses two key challenges: it helps students and instructors focus on the enduring principles of the course, and it provides another pedagogical tool for instructors to assess students’ understanding and encourage critical thinking.

- **Cutting-edge media integration.** MasteringMicrobiology (www.masteringmicrobiology.com) provides unprecedented, cutting-edge assessment resources for instructors as well as self-study tools for students. Big Picture Coaching Activities are paired with the book’s Core Topics and Clinical Features. Interactive Microbiology is a dynamic suite of interactive tutorials and animations that teach key concepts in microbiology; and MicroBoosters are brief video tutorials that cover key concepts that some students may need to review or relearn.

New to the Thirteenth Edition

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

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

- **Exploring the Microbiome.** Each chapter has a new box featuring an aspect of microbiome study related to the chapter. Most feature the human microbiome. The boxes are designed to show the importance of microorganisms in health, their importance to life on Earth, and how research on the microbiome is being done.

- **In the Clinic videos accompanying each chapter opener.** In the Clinic scenarios that appear at the start of every chapter include critical-thinking questions that encourage students to think as health care professionals would in various clinical scenarios and spark student interest in the forthcoming chapter content. For the thirteenth edition, videos have been produced for the In the Clinic features for Chapters 1 through 20 and are accessible through MasteringMicrobiology.
• New Big Picture disease features. New Big Picture features include Vaccine-Preventable Diseases (Chapter 18), Vertical Transmission: Mother to Child (Chapter 22), and Bioterrorism (Chapter 24).
• Reworked immunology coverage in Chapters 17, 18, and 19. New art and more straightforward discussions make this challenging and critical material easier for students to understand and retain.

Chapter-by-Chapter Revisions

Data in text, tables, and figures have been updated. Other key changes to each chapter are summarized below.

Chapter 1
• The resurgence in microbiology is highlighted in sections on the Second and Third Golden Ages of Microbiology.
• The Emerging Infectious Diseases section has been updated.
• A discussion of normal microbiota and the human microbiome has been added.

Chapter 2
• A discussion of the relationship between starch and normal microbiota has been added.

Chapter 3
• Coverage of super-resolution light microscopy has been added.

Chapter 4
• The description of the Gram stain method of action has been revised.
• Archaella are now covered.

Chapter 5
• The potential for probiotic therapy using lactic acid bacteria is introduced.
• Reoxidation of NADH in fermentation is now shown in Figure 5.18.

Chapter 6
• Discussion has been added regarding the influence of carrying capacity on the stationary phase of microbial growth.
• Discussion of quorum sensing in biofilms is included.
• The plate-streaking figure is revised.

Chapter 7
• A new section on plant essential oils has been added.

Chapter 8
• The discussion of operons, induction, and repression has been revised.

Chapter 9
• Riboswitches are defined.
• A new box about tracking Zika virus is included.

Chapter 10
• Discussion of gene editing using CRISPR technology has been added.

Chapter 11
• The genus Prochlorococcus is now included.
• The phylum Tenericutes has been added.

Chapter 12
• The classification of algae and protozoa is updated.

Chapter 13
• Baltimore classification is included.
• Virusoids are defined.

Chapter 14
• Discussions of herd immunity and the control of healthcare-associated infections are expanded.
• Clinical trials are defined.
• Congenital transmission of infection is included.
• Discussion of the emerging HAI pathogen Elizabethkingia is now included.
• Epidemiological data have been updated.

Chapter 15
• Genotoxin information is updated.

Chapter 16
• The discussion of the role of normal microbiota in innate immunity is expanded.
• A table of chemical mediators of inflammation is included.

Chapter 17
• A new table listing cytokines and their functions has been added.
• Cells involved in cell-mediated immunity are summarized in a table.

Chapter 18
• Vaccine-preventable diseases are discussed in a new Big Picture.
• Coverage of recombinant vector vaccines has been added.

Chapter 19
• The discussion of autoimmune diseases has been updated.
• The discussion of HIV/AIDS has been updated.
• The Big Picture box has been revised to expand discussion of dysbiosis-linked disorders.
Chapter 20
- Tables have been reorganized.
- Coverage regarding the mechanisms of action of antimicrobial drugs has been updated.
- In the Clinical Focus box, data on antibiotics in animal feed have been updated.

Chapter 21
- All data are updated.
- The Big Picture on Neglected Tropical Diseases has been revised to include river blindness.

Chapter 22
- All data are updated.
- Coverage of Zika virus disease has been added.
- Discussion of Bell's palsy has been added.
- A new Big Picture covering vertical transmission of congenital infections has been added.

Chapter 23
- All data are updated.
- The new species of *Borrelia* are included.
- Maps showing local transmission of vector-borne diseases have been updated.

Chapter 24
- All data, laboratory tests, and drug treatments have been updated.
- The emerging pathogen *Enterovirus* D68 is included.
- A new Big Picture covering bioterrorism has been added.

Chapter 25
- All data, laboratory tests, and drug treatments are updated.
- *Salmonella* nomenclature has been revised to reflect CDC usage.
- Images of protozoan oocysts and helminth eggs have been added to illustrate laboratory identification.

Chapter 26
- All data, laboratory tests, and drug treatments have been updated.
- STIs that do not affect the genitourinary system are cross-referenced to the organ system affected.
- Discussion of ocular syphilis is now included.

Chapter 27
- The concept of the Earth microbiome is introduced.
- Discussion of hydrothermal vent communities has been added.
- The discussions of bioremediation of oil and wastewater have been updated.

Chapter 28
- The discussion of industrial fermentation has been updated.
- The definition of *biotechnology* is included.
- A discussion of the iChip has been added.
- A table listing fermented foods has been added.
- Discussion of microbial fuels cells is now included.
Acknowledgments

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Michele Mangelli, Mangelli Productions, LLC, managed the book from beginning to end. She expertly guided the team through the editorial phase, managed the new design, and then oversaw the production team and process. Karen Gulliver expertly guided the text through the production process and managed the day-to-day workflow. Sally Peyrefitte’s careful attention to continuity and detail in her copyedit of both text and art served to keep concepts and information clear throughout. The talented staff at Imagineering gracefully managed the high volume and complex updates of our art and photo program. Jean Lake coordinated the many complex stages of the art and photo processing and kept the entire art team organized and on-track. Our photo researcher, Kristin Piljay, made sure we had clear and striking images throughout the book. Gary Hespenheide created the elegant interior design and cover. The skilled team at iEnergizer Aptara®, Ltd moved this book through the composition process. Maureen Johnson prepared the index, Betsy Dietrich carefully proofread the art, while Martha Ghent proofread pages. Stacey Weinberger guided the book through the manufacturing process. A special thanks goes to Amy Siegesmund for her detailed review of the pages. Lucinda Bingham, Amanda Kaufmann, and Tod Regan managed this book’s robust media program. Courtney Towson managed the print ancillaries through the complex production stages.

Allison Rona, Kelly Galli, and the entire Pearson sales force did a stellar job presenting this book to instructors and students and ensuring its unwavering status as the best-selling microbiology textbook.

We would like to acknowledge our spouses and families, who have provided invaluable support throughout the writing process.

Finally, we have an enduring appreciation for our students, whose comments and suggestions provide insight and remind us of their needs. This text is for them.

Gerard J. Tortora  Berdoll R. Funke  Christine Case
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**FEATURES**
ASM Recommended Curriculum Guidelines for Undergraduate Microbiology

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

ASM Guideline Concepts and Statements

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

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

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

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

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

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