How do small things make a big difference?

Microbes, ecology, and the tree of life

Lesson 5: How do microbes interact with humans?

I. Overview

In this lesson, students are introduced to the various microbial communities that live in and on humans. With a video introduction to the human microbiome by microbiologist Bonnie Bassler, students discover the diverse and numerous microbes that call our body "home" and how much there is yet to discover about human-microbe interactions. In the lesson's main activity, students begin by developing initial models of how they think a certain microbial community interacts with a specific body part or process. They then work in "expert" groups to read articles and analyze data pulled from current scientific research that describe that specific human-microbe interaction. After each group analyzes their specific reading and data, students get into "jigsaw" groups, to synthesize information and develop a model that represents their collective knowledge of the human microbiome.

Connections to the driving question

Students address the unit-driving question by investigating how native microbes, those that are part of our microbiome, interact with human body systems. Humans would not survive in the absence of microbes. Human interactions with microbes are essential to proper functioning of human body systems and fending of diseases. The lesson also draws links to ecological concepts by highlighting how the human microbiome is an example of an ecosystem—various microbial populations occupy specific niches to provide protection and nutrients for other microbes and/or human body systems.

Connections to the previous lesson

In the previous lesson, students explore the various microbial populations in a Winogradsky column, an example of an ecosystem whose members work together to provide nutrients for one another. This lesson provides students with another example of how a microbial ecosystem functions, highlighting the various communities that exist in and on the human body and their importance in sustaining the body's normal functions.

II. Standards

National Science Education Standards

- Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years. (Grades 9-12 The Interdependence of Organisms 4.3)

- Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite. This fundamental tension has profound effects on the interactions between organisms. (Grades 9-12 The Interdependence of Organisms 4.4)
- Human beings live within the world's ecosystems. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption. Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors is threatening current global stability, and if not addressed, ecosystems will be irreversibly affected. (Grades 9-12 The Interdependence of Organisms 4.5)
- The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials. (Grades 9-12 Matter, Energy, and Organization in Living Systems)

Benchmarks for Science Literacy

The Living Environment: Interdependence of Life

- Ecosystems can be reasonably stable over hundreds or thousands of years. As any population grows, its size is limited by one or more environmental factors: availability of food, availability of nesting sites, or number of predators. 5D/H1*
- If a disturbance such as flood, fire, or the addition or loss of species occurs, the affected ecosystem may return to a system similar to the original one, or it may take a new direction, leading to a very different type of ecosystem. Changes in climate can produce very large changes in ecosystems. 5D/H2*

III. Learning Objectives

Learning objective	Assessment Criteria	Location in Lesson
Describe why the diversity of microbes in/on the human body is important.	Student descriptions can include a number of examples. There are a variety of microbes from all three domains of life (i.e., bacteria, archaea, and eukaryotes) located in/on the human body. Bacteria, such as *Clostridium*, are known to educate the immune system, preventing autoimmune diseases and allergies. Similarly, the wide array of microbes located on the skin shows that these native microbes carry out important functions, either to help protect us from pathogenic microbes that would like to colonize our skin (by out competing the pathogens for physical space and resources) or to support the local ecosystem by potentially providing nutrients for other microbes that live in/on the skin. The fecal transplant therapy is another example of the	Throughout the lesson

	importance of the diversity of microbes; if certain native microbes are destroyed, pathogenic bacteria have a greater potential to infect those habitats.	
Describe how microbes in and on humans protect them.	Students can describe several different examples. The skin microbiome contains various microbe populations. Some of these microbes, such as *S. epidermidis,* exist in great quantities in healthy people. These microbes outcompete pathogenic bacteria by creating a protective "shield" to block out and outcompete pathogenic microbes. Gut microbes protect us in the same manner. Fecal transplants are a new medical treatment used to repopulate the colons of patients with *C. difficile* infections with native microbes in order to re-establish the natural gut microbiome and keep the *C. difficile population in check*.	Activities 1 & 2
Explain that microbes in the human gut maintain mutualistic relationships with other microbes and humans.	*M. smithii*, *Bacteroidetes*, and the human gut have evolved to exist in mutualistic relationships with one another. When humans consume food, the human gut provides nutrients (in the form of the food they consumed) and a place to live to both *Bacteroidetes* and *M. smithii*. As *Bacteroidetes* metabolize the nutrients, it releases hydrogen as a by-product, while simultaneously providing vitamins and nutrients to the human host. In turn, *M. smithii* removes the excess hydrogen produced by *Bacteroidetes* and uses it in its own metabolism of food from the human host. One of *M. smithii*'s products is short-chain fatty acids (SCFAs), which provide energy (calories) to the human host.	Activities 1 & 2
Illustrate how microbes that are not in their natural habitat can cause human disease.	Non-native microbes can cause disease in the central nervous system (CNS), as they are invading an area in which they do not normally exist. These invasive species (bacteria) harm the CNS ecosystem, as they have not adapted to live in co-existence with the cells of the CNS.	Activities 1 & 2
Discuss how microbes have filled niches to perform necessary functions	Infants are born with a sterile intestine that eventually becomes colonized with various microbes. The number and diversity of these microbes differ depending on several environmental and genetic factors. The microbes	Activities 1 & 2

in the human body.	develop the microbiome and begin to fill specific roles for the developing human. Gut microbes have developed mutualistic relationships with other microbes and the human host to provide protection and nutrients for the human host while securing a stable place to live. Similarly, skin microbes have also adapted to outcompete other non-native microbes and thus protect the human host from unnecessary invasions by other microbes. Finally, gut microbes also play a role in training the immune system, providing the human host with opportunities to recognize "foreign" and "self" cells.	
Analyze and interpret data from recent scientific research in order to draw and support conclusions about the interactions between humans and microbes.	Students will be able to cite specific and relevant information from the data provided in order to support their conclusions about the roles of microbes in and on the human body.	Activities 1 & 2
Develop and use a model to explain and communicate information about human-microbe interactions.	Skin microbes provide protection for the human body by occupying space and using resources more efficiently than pathogenic bacteria. The gut microbes also provide this type of protection but they also have formed mutualistic relationships with one another and the human host to procure resources. Other microbes are responsible for helping develop and train the immune system. More research is being conducted to discover all of the roles of the different microbes; these are some of the roles that scientists know about currently.	Activity 2

IV. Adaptations/Accommodations

All of the readings can be adapted to provide more or less scaffolding for each class. Additionally, the Expert Group and Jigsaw Group questions presented to students can be modified to provide images or textual supports to help students develop their critical thinking and data analysis skills. Pre-teaching certain vocabulary can also be helpful for classes with high numbers of English language learners, particularly the ecology terms such as microbiome, ecosystem, niche, habitat, community, population, commensalism, mutualism, pathogen, metabolism, disturbance, invasive species and native vs. non-native.

Safety

There are no additional safety concerns associated with this lesson.

V. Timeframe for lesson

Opening of Lesson

- Developing initial models and video introduction – 30 minutes

Main Part of Lesson

- Activity 1: What roles do microbes play in/on our bodies? (Expert Groups) – 40 minutes
- Activity 2: Putting the pieces together: How microbes interact with humans (Jigsaw Groups) – 50 minutes

Conclusion of Lesson

- Closing class discussion – 10 minutes

VI. Advance prep and materials

Opening of Lesson

Materials:

- Whiteboards or large poster paper
- Markers
- TED Talk featuring Bonnie Bassler
  - http://www.ted.com/talks/bonnie_bassler_on_how_bacteria_communicate.html
- Powerpoint slide of microbiome phyla (*U9_L5_Image_HumanMicrobiome.ppt)*

Preparation:

- Queue TED Talk video to ensure that it loads properly on the web browser or media player used.

Activity 1: What roles do microbes play in/on our bodies?

Materials:

- 6 readings featuring different topics of the human microbiome (these files include the expert questions that pertain to that reading). A set of these will be needed for each class. To reduce copies, teachers could separate the expert questions from the readings and use the same readings for multiple classes and only print extra expert questions for each student to have their own.

  - Microbes that affect our body weight (*U9_L5_ Reading_Group1.docx*)
  - Our skin microbiome (*U9_L5_ Reading_Group2.docx*)
  - Microbes educate the immune system *(U9_L5_ Reading_Group3.docx)*
  - Intestinal microbiota development in infants *(U9_L5_ Reading_Group4.docx)*
  - Microbes and the blood-brain barrier *(U9_L5_ Reading_Group5.docx)*
  - Using microbes as treatment for bacterial infections *(U9_L4_Reading_Group6.docx)*
  - Additional readings (optional)
    - How do microbes influence the presence of acne? (U9_L5_Additional_Reading_Acne.docx)
    - The rise of antibiotic resistant Acinetobacter in hospital acquired infections (U9_L5_Additional_Reading_AntibioticResistance.docx)
    - Bacteriophage therapy (U9_L5_Additional_Reading_BacteriophageTherapy.docx)
    - Forensic microbiology (U9_L5_Additional_Reading_Forensic Microbiology.docx)
- 6 folders (optional)

Preparation:

- Arrange 6 folders with the topic clearly labeled on the front of each folder. Print 4 copies (or enough so that there is 1 copy per student or pair of students in that group) of each reading for each folder. (Note: Group 3 reading is easiest to analyze when printed in color.)

Activity 2: Putting the pieces together: How microbes interact with humans

Materials:

- Students' completed expert questions (1/student)
- Jigsaw group's model construction questions, 1/group or student (*U9_L5_ StudentSheet_JigsawGroup.docx*)
- Whiteboards or large poster paper
- Markers
- NPR video – The Invisible Universe of the Human Microbiome
  - http://www.npr.org/blogs/health/2013/11/01/242361826/exploring-the-invisible-universe-that-lives-on-us-and-in-us

Preparation:

- Print one Jigsaw Group Student Sheet for each jigsaw group or individual student.

Homework and Assessments

Materials

The following materials can be assigned as homework and/or used for assessment:

- Expert Group Student Sheet (in Reading files)
- Jigsaw Group Student Sheet (*U9_L5_StudentSheet_JigsawGroup.docx*)

- The jigsaw groups' responses to the questions on the Jigsaw Group Student Sheet and models construction should be based on the readings provided in the Expert Group folders and should meet the assessment criteria for the learning objectives.

VII. Resources and references

Teacher resources

For additional information on the human microbiome as a representative ecosystem:

- Arnold, C. (2013). The hologenome: A new view of evolution. *New Scientist*. 2899: 30-34. Retrieved from http://www.newscientist.com/article/mg21728992.000-the-ho
- Dunn, R. (2011). The wild life of our bodies: Predators, parasites, and partners that shape who we are today. New York: Harper Collins.
- Fierer, N., et al. (2012). From animalcules to an ecosystem: Application of ecological concepts to the human microbiome*. Annu. Rev. Ecol. Evol. Syst*. 43:137-55.
- Gonzalez, A., et al. (2011). Our microbial selves: What ecology can teach us. *EMBO reports*. 12(8): 775-784.
- Morgan, X.C., Segata, N., and Huttenhower, C. (2013). Biodiversity and functional genomics in the human microbiome*. Trends in Genetics* 29(1): 51-58.
- NIH funded Human Microbiome Project - http://commonfund.nih.gov/hmp/

References

- Atarashi, K., et al. (2011). Induction of colonic regulatory T cells by indigenous *Clostridium* species. *Science.* 331: 337-341.
- Buck, S. S. and Gordon, J.I. (2006). A humanized gnotobiotic mouse model of host-archael-bacterial mutualism. *PNAS.* 103(26): 10011-10016.
- Driver, R., Squires, A., Rushworth, P., Wood-Robinson, V. (1994). *Making sense of secondary science*. New York: Routledge.
- Grice, E.A., Kong, H.H., Conlan, S., Deming, C.B., Davis, J., Young, A.C.,…Segre, J.A. (2009). Topographical and temporal diversity of the human skin microbiome. *Science, 324*(5931), 1190-1192.
- Grice, E.A. & Segre, J.A. (2011). The skin microbiome. *Nature Reviews Microbiology, 9*, 244-253.
- Kim, K.S. (2008). Mechanisms of microbial traversal of the blood-brain barrier. *Nature Reviews: Microbiology*. 6:625-634.
- Kong, H.H. (2011). Skin microbiome: Genomics-based insights into the diversity and role of skin microbes. *Trends in Molecular Medicine*. 17(6): 320-328.
- Leja, D. (N/A). Skin microbiome [Graphic]. Bethesda, MD; National Human Genome Research Institute. Retrieved January 31, 2014, from http://www.genome.gov/dmd/img.cfm?node=Photos/Graphics&id=85320

- Mathur, R., Amichai, M., Chua, K.S., Mirocha, J., Barlow, G.M., and Pimentel, M. (2013). Methane and hydrogen positivity on breath test is associated with greater body mass index and body fat. *J Clin Endocrinol Metab.* 98(4): E698-E702.
- Morgan, X.C., Segata, N., and Huttenhower, C. (2013). Biodiversity and functional genomics in the human microbiome*. Trends in Genetics* 29(1): 51-58
- NIH funded Human Microbiome Project http://commonfund.nih.gov/hmp/
- Palmer, C., Bik, E.M., DiGiulio, D.B., Relman, D.A., and Brown, P.O. (2007). Development of the human infant intestinal microbiota. *PLoS Biology.* 5(7): 1556-1573.
- Rowan, K. (2012). "Poop Transplants" may combat bacterial infections. *Live Science*. Retrieved from http://www.livescience.com/36701-poop-transplants-bacterial-cdiff-infections.html
- Stein, R. (2013) Exploring the invisible universe that lives on us – and in us. *NPR*. Retrieved from http://www.npr.org/blogs/health/2013/11/01/242361826/exploring-the-invisible-universe-that-lives-on-us-and-in-us
- Vignali, D.A., Collison, L.W., and Workman, C.J. (2008). How regulatory T cells work. *Nat Rev Immunol*. 8(7): 523-32.

VIII. Lesson Implementation

Opening of Lesson

Review with students what they have learned about the microbial populations that exist within a Winogradsky column. Ask them in discussion format or in a “warm up” or “bell ringer”:

- What types of environments exist within a Winogradsky column?
- What types of relationships exist between the microbes in the Winogradsky column?
- How could disruption of one microbial species affect other microbes and the ecosystem overall?

Crosscutting Concepts: Systems and system models

According to A Framework for K-12 Science Education, “a system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, and numbers.” Therefore, an ecosystem can be broadly defined as any group of organized objects (such as organisms and their non-living components) that form a whole. In this unit, we examine different ecosystems through the lens of two system models, the Winogradsky column (previous lesson) and the human body. There are many interactions occurring in the different communities of organisms that live in these ecosystems, and these models serve to teach students about the importance of ecosystem dynamics, such as interdependence between organisms and resource availability.

After reviewing the learning goals of the previous lesson, tell students that they will be examining similar relationships between microbes, but this time with a focus on the human body as an ecosystem. Ask them:

- Why can our body be described as an ecosystem?
  - An ecosystem is a community of living organisms that live in conjunction with non-living components of the environment (e.g., water, oxygen, other chemical compounds). Our body is home to many living organisms, not just our cells. Thus, we are not only a multi-cellular organism; we are also composed of many organisms living together!
- Do you know of any relationships that exist between microbes in our body? Where do microbes live in/on our body?
  - Students will investigate the various relationships between microbes and our body in Activities 1 and 2. This question is meant to gauge students’ prior knowledge on the topic.

Student Misconceptions

Students may have a limited view of what microbes do in/on our body. They will probably be familiar with the role of bacteria in digesting (decomposing) our food and making us sick, but may not know the extent to which microbes assist us with various functions (Driver et al., 1994). Encourage students to also think about how microbes may protect us from pathogenic microbe infections and how microbes play a role in educating our immune system.

E.coli and Clostridium are examples of microbes where students may not have the full picture. Even though *E. coli* and clostridium are most known for pathogenicity and disease (which is also important to know), not all strains of these organisms are harmful. Many strains are harmless and some even exist as a normal part of our human microbiome. In addition, E. coli is a very important organism used in science research. It has been used as a model microbe as it is easy to culture in labs and is used in recombinant DNA applications (ex: *E.coli* can be genetically modified to produce human insulin).

Ask students to work in groups of 6 (these should be the same groups they return to during the jigsaw portion (Activity 2) of the main part of the lesson) to develop a model to communicate what they currently know about human-microbe interactions. They should use the whiteboards or large poster paper to draw their models. In their model, they should include the interactions between microbes and humans that they already know about. Once all groups have drawn their initial models of the human microbiome, ask each group to either share their model with the whole class or have groups pair up and share their models. Ask students questions such as:

- What does your model show?
- What types of relationships between microbes and humans do you know about?
- While developing your model, what kinds of questions came up?

Explain to students that they will collect more information throughout this lesson which they can hopefully add to make their model of the human microbiome more robust.

Show students the TED Talk video clip featuring Bonnie Bassler (see "Advanced prep and materials" section for link). Play from beginning to 2 minutes, 20 seconds (2:20). After students watch the video, ask them:

- Was there anything that Dr. Bassler discussed that was surprising to you? Why was it surprising?
    - Possible responses: There are 10 times more microbial cells than human cells in/on our body! Researching the various niches that microbes play in/on our body could have huge implications for how we look at human health and disease.

- Based on Dr. Bassler's discussion, what would happen if our microbial partners disappeared or their function was somehow disrupted?
    - Possible responses: Many diseases result from a disruption or misregulation of the microbial communities in/on our bodies. This includes, but not limited to, bacterial infections and autoimmune diseases.

Teacher Content Knowledge

When we discuss the human microbiome, we are referring to microbes of all three domains of life. Bacteria are the most abundant domain of our microbiome (*Lactobacilli*, *E. coli*, *Bacteroides*, etc.) but there are a number of archaea (*M. smithii*) and eukarya (*Candida albicans*) that also live in and on humans and serve important functions. When discussing the human microbiome, make sure to not refer to the microbiome as just Bacteria, as that could lead to a misconception about the diversity of microbes that make up the human microbiome.

In this unit, the terms human microbiome and microbiota will be used interchangeably to refer to the microbes that inhabit the human body.

Show students the Human Microbiome Image (*U9_L5_ Image_HumanMicrobiome.ppt).* Tell the students that this image is from a 2013 review of the current understandings of the human microbiome based on the Human Microbiome Project (HMP). The HMP is funded by the National Institutes of Health (NIH) and relies on various research groups to fulfill its mission of "characterize[ing] the microbial communities found at several different sites on the human body, including nasal passages, oral cavities, skin, gastrointestinal tract, and urogenital tract, and to analyze the role of these microbes in human health and disease."

While looking at the image projected at the front of the class, or color images printed for pairs of students to look at more closely, tell students to turn and talk to a partner about what they notice about the figure. Ask them to discuss:

- What kind of information is represented on the figure? What kind of information is not represented in the figure? That is, what gaps exist in the knowledge of the human microbiome?
    - The figure highlights the four most abundant phyla of the microbiome, which all happen to be bacteria. There is no mention of the archaea or eukaryotes. Certain bacteria are singled out for elaboration but even there, the figure discusses the relative amounts of the bacteria in healthy people, but does not provide details on the function of the highlighted bacteria. Also, the figure focuses on six habitats in/on our bodies, as those are the most heavily researched areas to date. Finally, it shows the various bacteria that can become pathogenic as well as the commensal bacteria.

After discussing the diversity of the human microbiome, tell students that they will now examine various roles that microbes serve in/on our bodies.

Main Part of Lesson

Activity 1: What roles do microbes play in/on our bodies?

	Scientific Practices: Developing and using models In this lesson, it is important that students develop initial models of how they believe a certain microbial community serves a particular niche. They should not look at the information contained in their group's folder before drawing/describing their initial model. After the reading and data interpretation, students should return to and revise their initial model. In the second activity, students integrate models about the different microbial communities to develop a more comprehensive model of the human microbiome.

Tell students that they will now become "experts" on a certain field related to the human microbiome. Form expert groups by taking one person from each of the original groups. This is so that, when students return to their original groups, each one will be an "expert" on a different article.

Hand out the folders, each containing copies of a different reading and the associated expert questions (so that all students in each expert group are reading about the same topic.) Share with students that they will have the opportunity to analyze current research data, or read a recent report, on the various microbial communities in/on our body. In their expert groups, each student will answer the expert group questions that correspond with the reading their group has been assigned. The questions will help students to discuss the reading and analyze the data.

As students work in groups to answer their group's questions, circulate the room to assist students in making meaning from the data they are presented with. Some of the articles may contain forms of data that they are not as familiar with. Therefore, it is important to monitor student conversations and guide students who may struggle with the data analysis.

	Scientific Practices: Analyzing and interpreting data As students work through the readings, they will see data presented in a number of different ways including bar graphs, line graphs, tables, and diagrams. They will need to analyze and interpret these data figures to draw conclusions and make inferences about how microbes' interact with humans. Students can also be asked to be attentive to the different types of sources these readings come from. The readings include information from both primary and

secondary sources, such as recent scientific research and news articles. Students can discuss the different sources and how these are important to determine the quality of the data and research findings.

Students can also see how analysis of new data generated by advances in technology and scientific thinking can propel scientific knowledge and current scientific practices. For example, the skin microbiome reading (Group 2) focuses on data collected from recent advances in molecular biology techniques that have greatly improved scientists' abilities to identify the microbes that live in/on our bodies. Just as Carl Woese's use of rRNA sequencing led to the revised tree of life model, the advances in microbial genome sequencing have helped scientists characterize the human microbiome.

Activity 2: Putting the pieces together: How microbes interact with humans

Once students have finished answering the questions in their "expert" research groups, have students jigsaw into the groups with whom they developed their initial models in the opening activity. Each person in these jigsaw groups should represent a different expert group. Just as researchers from different fields of science work together to answer current research questions, and develop scientific models, students will revise their initial model to answer this lesson's driving question "How do microbes interact with humans?" based on the collective knowledge of their jigsaw group. To assist in the development and revision of their models, each jigsaw group will answer a series of questions (*U9_L5_StudentSheet_JigsawGroup.docx*) so the main ecological concepts are pulled together and represented in their more complete model of the human microbiome. Each expert group's data and information must be represented in the collective model.

Teacher Content Knowledge

The NPR video, The Invisible Universe of the Human Microbiome, is an animated video that gives a nice overview of how the human microbiome becomes established early in life and the many important roles that microbes play in our bodies (e.g. educating the immune system, protection from harmful microbes). The video also details how a lack of microbial diversity and decrease in microbial abundance may lead to health problems.

Once students have completed their jigsaw questions the information in this video can be used as additional content that supports what they learned from the readings about the diversity and importance of the human microbiome. Students can then use the information in this video to revise their initial model of the human microbiome.

Students can either work to add to or change their initial model of the human microbiome, or they can be given a new paper or whiteboard to draw their new model. Either way, a version of their initial model should be kept. In their groups, students should work to incorporate the new information they have gathered to develop a model that answers the driving question: "How do microbes interact with humans?". As students work on their models ask them questions such as:

- What new types of interactions between microbes and humans did you learn about?
- Were any of the questions you had from your initial model, answered?
- Does this new information fill any gaps that were present in your initial model?
- What are some things you know now that you didn't know before?

Once the groups have completed their models, have each group present their model to another group and compare/contrast how the different "collaboration groups" designed their models of the human microbiome. While the groups are presenting their models, circulate the room and monitor the conversations occurring between the groups. Ask students questions about their models to push their thinking and also encourage students to question each other's models. This could easily become a presentation assessment, where students' presentation and question-asking skills are assessed along with the quality of their model. Some questions to ask student groups as they are presenting are:

- What types of advances in controlling the obesity epidemic could be made based on the research presented in Group 1's reading?
- In Group 3's reading, researchers used mice as a model organism to study the microbes of the GI tract. Why do you think they used mice and not humans for this study?
- What other questions may researchers ask based on the data from Group 4's reading?

Crosscutting Concepts: Stability and change

Systems can seemingly remain stable even if there are many changes occurring; this is referred to as dynamic equilibrium. In any ecosystem, there are nutrients cycling in and out and various species are created and destroyed, all the while the ecosystem remains in relative stability. An ecosystem can become unstable, or in disequilibrium, if one or more of the living or non-living components changes drastically, such as the case when *Listeria* crosses the blood-brain barrier or *C. difficile* colonizes in the human gut. Listeria causes instability in the human central nervous system, as the bacteria use resources and produce waste products that harm neurons. *C. difficile* takes advantage of compromised conditions of the human gut (low levels of native bacteria) by colonizing the gut, thus causing a drastic change in the microbial communities.

Activity 2 Extension: Additional microbe readings.
There are many, many examples of how microbes interact with humans and a great deal is being learned by the scientific community on this topic every day. To cover some more of these human-microbe interactions, 4 additional readings are provided with this lesson. The 4 readings cover the following topics: microbes and acne, forensic microbiology, bacteriophage therapy, and antibiotic resistance. These readings can be used as additional readings in class, homework assignments, assessments, or simply to provide more information for curious students. All of the additional readings were created by undergraduate biology students at the University of Illinois as part of their microbiology course.

Conclusion of Lesson

After students have presented to the other collaborative group, ask them the following types of questions in either in whole-class discussion format or on an exit-slip assessment:

- How did your model of the human microbiome compare to the other groups'? What were some similarities and differences?
    - Researchers often arrive at different conclusions based on the same data and/or experimental design. Encourage students to discuss the strengths/weaknesses of the models they created and how they could improve upon them.
- How do microbes affect our different body functions? What questions are researchers still investigating?
    - This question assesses whether students have met learning objectives described earlier in the lesson plan. Also, encourage students to think about what remaining questions they may have about the role of microbes in/on the human body, as much is still not known about many communities of microbes.
- How does this change the way you view the human body and the role of microbes?
    - Prior to this lesson, some students may have known only about how microbes can be harmful to humans. Ask students to address how their thinking on this topic may have changed after all they have learned in this lesson.
    - Encourage students to think about how microbial infections are viewed and what the benefits/costs are of using antibiotics to treat infections. Ask them to think about what an antibiotic's purpose is and potential side effects of using an antibiotic.

Tell students that in the next lesson, they will analyze real data about two antibiotics being tested for their effectiveness at treating a *C. difficile* infection. As they have learned, *C. difficile* is an infection that often occurs when the native microbes of the gut have been disturbed. Thus, they will have to be careful when choosing which antibiotic to prescribe and closely analyze all of the presented data.