

Microbes As Friends, Not Foes: Shifting the Focus from Pathogenesis to Symbiosis

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ABSTRACT

Until about two decades ago, the standard method of studying a microbe was to isolate it, grow it in culture, stain it, and examine it under a microscope. Today, new genomic tools are helping expand our view of the microbial world. Instead of viewing them as “germs” to be eliminated, we are beginning to perceive our microbes as an extension of ourselves – an important organ with unique functions essential to our well-being. Scientists even came up with a new term, “microbiome,” to define our microbes’ genes as an important counterpart to our human genome. With new information about the human microbiome comes the challenge of shifting biology students’ focus from casting microbes as pathogens toward appreciating microbes as symbionts. “The Human Microbiome,” a curriculum supplement produced by the Genetic Science Learning Center, emphasizes that microbes living in and on our bodies perform neutral and beneficial functions, that human microbiota form thriving ecosystems, and that disruptions to our microbial ecosystems may have consequences. In this article, we describe the curriculum materials, provide strategies for incorporating this cutting-edge topic into biology classrooms, list connections to the Next Generation Science Standards, and report on recent research testing the curriculum supplement’s effectiveness for student learning.

Key Words: Human microbiome; microbes; biology; curriculum; high school; education.

○ Introduction

During the summer of 2011, twenty biology teachers from across the nation enthusiastically examined a collection of Petri dishes containing microbes cultured from their skin. Although each teacher had previously led students through the simple protocol used to grow the microbes and had seen similar microbial growth in countless resulting Petri dishes,

this time they had a renewed interest in the results (see Figure 1). Instead of considering microbial growth an indicator of uncleanness, they viewed it as evidence of a flourishing ecosystem living on the skin, one that performs functions vital to human health. Though only a fraction of the microbes living on human skin can be cultured, there were enough species growing on each plate to illustrate differences and similarities among individuals and between locations on the skin.

The teachers were participating in a summer institute at the University of Utah’s Genetic Science Learning Center (GSLC) designed to increase their knowledge of the emerging research into the human microbiome and to brainstorm the best ways to bring this cutting-edge field to high school classrooms. During the institute, teachers developed learning objectives for the new content and outlined ideas for curriculum that would connect these ideas with concepts already taught in a typical life science or biology class. The result is “The Human Microbiome,” a curriculum supplement developed by the GSLC (available online at no cost; see Table 1). By including themes in ecology, microbiology, health, and disease, the teachers connected the human microbiome to content and science education standards taught in life science classrooms.

Here, we introduce the human microbiome, describe new approaches that researchers are using to study it, and highlight the changing perceptions about microbes and health. We then describe the GSLC’s “Human Microbiome” curriculum materials, provide strategies for using the materials in the classroom, and list connections to the *Next Generation Science Standards* (NGSS Lead States, 2013). Finally, we describe the results from classroom testing of these curriculum materials.

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Figure 1. Teachers participating in the summer institute used the instructions for culturing microbes that are part of the teacher resources for the “Human Microbiome” module.

Table 1. Website addresses for the free curriculum materials described in this article and the types of materials that can be found at each URL.

Student & Public Resources	http://Learn.Genetics.utah.edu/content/microbiome/ <i>Interactives, videos, a video game, and “learn more” content</i>
Teacher Resources	http://Teach.Genetics.utah.edu/content/microbiome/ <i>Instructions and downloadable PDFs of student pages for graphic organizers and classroom activities, post-activity discussion questions and extensions, and instructions for a laboratory activity in which students culture microbes from their skin</i>

○ Discovering the Human Microbiome

Before the era of automated DNA sequencing, the standard way of studying a microscopic life form, or microbe, was to isolate it, grow it in culture, stain it, and examine it under a microscope (described in Robinson et al., 2010). For the fraction of microbes (mainly bacteria) that could be grown independently in culture, these

methods revealed a lot – what nutrients a microbe could metabolize, what byproducts it released, and how its membrane was structured. Later, using DNA sequencing tools, researchers gained a more informed view of microbial functions. All of these methods, however, were limited by the fact that most microbes cannot survive in an isolated culture (described in NIH HMP Working Group, 2009). Microbes tend to grow in communities, where each species

depends on its neighbors for resources and, consequently, for survival. Thus, the majority of microbial life remained undiscovered.

Today, new genomic tools are revealing an exponentially broader view of the microbial world. Using next-generation sequencing tools (reviewed in Mardis, 2008), researchers can gather DNA sequences from an entire ecosystem of microbes at once – no culturing required (e.g., Caporaso et al., 2011). These methods, which work on single molecules of DNA, can quickly provide a wealth of information about all the members of a microbial community.

Only after researchers started to use these genomic tools on samples from the human body did they begin to understand how limited the view of our microbial residents had been. Early large-scale genomic studies (e.g., Eckburg et al., 2005) turned up hundreds of microbes that no one had seen before. Researchers found microbes on every internal and external body surface, even in places where none had been found previously. They identified new microbes of all types: bacteria, archaea, fungi, protists, and mites, as well as viruses that infect not only us but also the microbes living on and within us.

Researchers estimate that the microbial cells on and in our bodies outnumber our own cells by about 10 to 1 (Savage, 1977), and that their genes may outnumber ours by more than 100 to 1 (Bäckhed et al., 2005). Instead of viewing them as “germs” to be eliminated, researchers now see our microbes as an extension of ourselves – an important organ with unique functions essential to our well-being (e.g., Eckburg et al., 2005). Microbiologist Joshua Lederberg (2001) came up with a new term to describe this emerging world, the *microbiome*, which he defined as the collection of microscopic life forms that inhabit the human body. Today, most researchers in the field describe those inhabitants as “microbiota” and use *microbiome* to mean their collective genes, a counterpart to the human *genome* (e.g., Human Microbiome Project Consortium [HMPC], 2012). We use the latter definition, both here and in our curriculum materials.

○ Microbes & Human Health

Over the past decade, a number of government-sponsored, collaborative initiatives have been started with the goal of understanding the relationship between microbes and health. These initiatives include the Human Microbiome Project (NIH HMP Working Group, 2009), which started in 2007, and similar programs in other countries. Collectively, these efforts have provided a significant amount of funding for gathering and analyzing microbial DNA sequences. The scale of these projects is overwhelming. To make the point, science writer Elizabeth Pennisi wrote, in 2011, that “a single DNA sequencer can now generate in a day what it took 10 years to collect for the Human Genome Project” (Pennisi, 2011). As the cost of DNA sequencing continues to drop, the collection of data keeps growing at an accelerating rate. The challenge now is to determine what it all means (Sagoff, 2012).

DNA sequence data from the initial deluge are aimed at answering two broad questions: “Who is there?” and “What are they doing?” (HMPC, 2012a, b). To find out who is there, researchers look at genetic “markers.” These short, unique DNA sequences can be used to classify an organism, for example by identifying its genus or species.

Common DNA markers include genes that code for ribosomal RNA. Using ribosomal DNA markers, researchers have studied how the microbial populations at a particular body site vary among individuals (e.g., Costello et al., 2009; HMPC, 2012b) and how microbial populations in an individual vary among body locations (e.g., Grice et al., 2009) and over time (Caporaso et al., 2011). These studies are revealing how microbial populations vary according to a person’s age, gender, diet, health, and much more.

To find out what the microbes are doing, researchers sequence all the genes in a population. Without even needing to know which genes come from what species, researchers can learn what biochemical reactions the population is carrying out as a whole (HMPC, 2012b). These studies are helping to reveal the nature of the symbiotic relationships we have with our microbes by detailing, for example, what microbes are metabolizing and releasing, and how they are interacting with our own cells.

While this information is helping to build an appreciation for our resident microbes and all they do for us, it is still too early to say exactly how we should apply the latest research findings to our everyday lives. Much of the early work on microbiota and the microbiome has turned up what amounts to interesting associations. Often, new associations raise more questions than they answer. For instance, researchers have found microbes in lungs (reviewed in Beck et al., 2012), blood (Amar et al., 2013), and even placenta (Wassenaar & Panigrahi, 2014) – all places that had previously been considered sterile. And they have learned that the microbes in these places differ between healthy and not-so-healthy people – people with asthma, people with heart disease, or women who give birth prematurely. But no one really understands the cause-and-effect relationships microbes have with these and other health issues. Does disease cause microbial populations to shift? Do certain microbes cause disease? Or are some other factors both affecting the microbes and causing the disease? Table 2 summarizes currently available answers to questions teachers asked about the associations between the human microbiome and our health.

Amid the associations, researchers have also found an enormous amount of variability, both among and within individuals. For example, one study of two identical twins found that the majority of the ~800 bacterial species in their lower guts were the same. However, the abundance of each species was remarkably different. In addition, when the researchers looked at bacterial gene expression, they found that <20% of the active genes were present in both twins (Turnbaugh et al., 2010). In another striking example, only ~17% of species are found in common between the left and right hand of the same person (Fierer et al., 2008).

In part, each person’s microbiome seems to reflect their history: where they have been, what they have eaten, when they have had a fever, what antibiotics they have taken, and other life events (Koenig et al., 2010; Caporaso et al., 2011). But much of the variability follows no predictable pattern, complicating attempts at organization according to demographic category (Ding & Schloss, 2014). And so we are left with more questions: What is the significance of all this variability? How do we determine which differences are meaningful?

Answering these new questions will take time and more traditional, time-intensive laboratory approaches, in addition to sequencing. But keep your eyes open: each month, new research articles describe the latest discoveries about our microbial residents, including details about how they are related to health and disease.

Table 2. Answers to frequently asked questions. These questions were collected from teacher participants during two professional development institutes on the human microbiome, held during the summer of 2014.

Frequently Asked Question	Currently Available Answer
Are probiotics effective or a fad?	<p>Studies looking at the health effects of probiotics in yogurts and supplements have had mixed results. Most studies show that they do not hurt, but they do not necessarily help very much either. Part of the issue is that foods and supplements contain nonstandardized amounts and types of probiotics, which makes them difficult to study. Another is that the probiotic organisms in the foods and supplements are typically not found in significant levels in our digestive tracts.</p> <p>However, other studies that looked at treating certain disorders with probiotics that contained standardized numbers of organisms that do live in or on healthy people have had much more positive results (Vitetta et al., 2014). The greatest benefit seems to be for people with diarrheal diseases (Guandalini et al., 2014), but others may benefit as well, including those with mood disorders or skin conditions. In the future, the most effective probiotics may come in the form of a disease-specific pill that is regulated by the FDA and prescribed by a doctor.</p>
Do you think we can, through changing our habits, influence our microbiota for better or worse?	<p>Yes, our habits definitely influence our microbial populations. One way to preserve our microbiota is to take antibiotics only when absolutely necessary. Another rapid route of influence is diet (David et al., 2014). The food we eat nourishes not only our bodies, but also our microbial populations. Research has found that many diseases, including diabetes, obesity, and irritable bowel syndrome, are associated with increases or decreases in certain types of microbes. Fortunately, what researchers are learning about the effects of diet on the microbiome is consistent with what we already know about healthy eating: eat whole foods with plenty of fiber, and limit processed foods, fats, and sugars.</p>
Are human microbiota affected by eating foods (such as cattle) that are treated with antibiotics?	<p>Commercially produced livestock and poultry are typically given antibiotics as a matter of routine. Antibiotics increase weight gain in these animals, helping farmers grow more meat more quickly.</p> <p>Meat grown this way probably does not contain enough antibiotic to affect the microbiota of the people who eat it, but we should still be concerned. Antibiotic use is the driving force behind antibiotic resistance, a huge issue for human health. Bacteria are very good at sharing genes. When antibiotic-resistant genes spread through a population of bacteria in livestock, the genes can be readily shared with pathogenic bacteria that infect people. Antibiotic use also affects the microbiota and the health of the animals. In cattle, antibiotic use leads to an increase in <i>E. coli</i> bacteria, some strains of which are harmful to both animals and people (Looft & Allen, 2012). Having more <i>E. coli</i> in the cattle means an increased chance that these bacteria will end up in our food.</p>
Would changing the microbiota affect gene expression of the host? If so, what would be the mechanism?	<p>The environment, by causing changes in the epigenetic tags on our DNA, can influence the expression of our genes. As a major component of our internal and external environment,</p>

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Table 2. Continued

Frequently Asked Question	Currently Available Answer
	our microbiota are constantly interacting with our cells. Therefore, we can extrapolate that changes to our microbial populations might influence our gene expression. This is an emerging area of research (e.g., Alenghat, 2015). We still have much to learn about microbiota–human genome interactions.
What are the current studies regarding the relationship between weight gain or loss and someone’s microbiome?	Overweight and lean people tend to have different microbial profiles in their guts, with obese individuals having less microbial diversity (Turnbaugh et al., 2009). In addition, gut microbes influence the amount of nutrients and calories we can extract from a given amount of food, as well as how we metabolize it (Moran & Shanahan, 2014). These findings have implications for malnutrition, obesity, and type 2 diabetes. A 2012 study, in which intestinal microbiota were transferred from lean men to obese men with insulin resistance, showed that it may be possible to use the microbiome to treat metabolic disease (Vrieze et al., 2012). Studies in mice show similar results (Ellekilde et al., 2014). And, as described above, eating healthful foods causes a positive shift in the microbiome.
What is the trend in current microbiome research? Are scientists looking for the good microbes we need, the bad microbes we should eliminate, how a specific microbe affects human behavior, etc.?	All of the above! Human microbiome researchers are developing new analytical tools and exploring all types of diseases, with the ultimate goal of making us healthier. To see what researchers are working on, visit the Human Microbiome Project web page (http://commonfund.nih.gov/hmp/index) and follow the links under the “funding” tab. For videos of talks given by some of these researchers, visit http://www.genome.gov/27554404 .

Even though many questions remain to be answered, human microbiome researchers agree that our microbial populations are important for many aspects of our health. Researchers are universally excited about not only what they are learning through study of the microbiome, but also what they are on the brink of discovering. They look forward to a time when information about an individual’s microbiome will inform diagnostic testing and personalized medical treatments.

○ Changing the Conversation about Microbes in the Classroom

While the research community is continually revealing more beneficial functions of the human microbiota, the public is being bombarded with news stories about drug-resistant bacterial strains, food-borne pathogens, and infectious-disease outbreaks. The GSLC’s “Human Microbiome” curriculum supplement offers tools for educating students and the public about this emerging field (for information on accessing the materials, see Table 1). The materials are versatile: they can be used together as a stand-alone unit; or they can enhance content that educators already teach in ecology, microbiology, or health and disease (for a suggested sequence of activities if the curriculum supplement is used as a stand-alone unit, see Table 3).

Since the primary data from human microbiome studies tend to be quite complex, we designed the “Human Microbiome” curriculum supplement to incorporate recent research findings at a level that is accessible and engaging for students. The materials emphasize that (1) microbes living in and on our bodies perform neutral and beneficial functions, (2) human microbiota form thriving ecosystems, and (3) disruptions to our microbial ecosystems may have consequences.

Even if students are aware that microbes live in our guts, they may not appreciate the diversity of the species that live there, or the extent to which microbes populate nearly every region of our bodies. To get an idea of the types of microbes that form our microbiota and what they do, have students visit the “Your Microbial Friends” interactive. While touring the human body and its associated microbes, they can record what they learn on graphic organizers that are structured either by beneficial function or by body location (Figure 2). Students should come away understanding that the roles of our microbiota extend far beyond digestion, and that the large intestine does more than simply absorb nutrients. Those who are not yet familiar with what a microbe is can stop by the “What Are Microbes?” web page for an outline of the major features of each type of microbe. To further explore the diversity of microbes found on different areas of skin and among individuals, have students culture their skin microbes. Instructions for

Table 3. Sample sequence of activities if the curriculum supplement is used as a stand-alone unit.

Activity	Learning Objective	Description
"The Human Ecosystem"	The human microbiome is its own ecosystem that includes biotic and abiotic factors, populations of different organisms, and symbiotic relationships.	Internet-enabled computer or tablet needed. Project to the whole class, or have students explore individually in a computer lab.
"Your Microbial Friends," with associated worksheet	Microbes perform beneficial functions in and on the body.	Computer lab or tablets with Internet access needed. Students explore individually, using either a worksheet organized by beneficial function or one organized by location on the body.
"Examples of Symbiosis"	Interactions between organisms may result in nourishment, reproduction, or protection. One or both organisms may benefit from interacting with one another.	Internet-enabled computer or tablet needed. Project to the whole class, or have students explore individually in a computer lab.
"Symbiotic Microbes"	Humans have symbiotic relationships with microbes in locations around the body.	Paper-based activity
"Microbiome Simulator"	The microbiome can be affected by the environment.	Computer lab with Internet access needed. Students should explore individually, for about 5 minutes.
"Agent Antibiotic"	Antibiotics kill pathogenic and beneficial bacteria. Antibiotic use can lead to a disruption in communities of beneficial microbes and antibiotic resistance in bacterial species.	Computer lab or tablets with Internet access needed. Students should explore independently or in pairs in "Story Mode."

preparing the materials and carrying out this activity are provided in the Teacher Resources.

Despite their reputation for making us sick, most microbes do no harm, and some are important for keeping us healthy. The "Microbiome and Disease" web page describes the associations between disturbances to microbial ecosystems and 15 diseases, including acne, depression, and obesity. This page also explores the idea of using microbial therapies, including probiotics and prebiotics, to treat imbalances. After completing these activities, teachers may choose to lead a discussion about the widespread use of antimicrobial soaps and cleaners.

Two sections of the curriculum supplement explore the dynamic nature of the microbiome. "Your Changing Microbiome" uses engaging graphics along with text to tell the story of how our microbial populations change from birth through old age. The animated, interactive "Microbiome Simulator" puts some of these ideas into motion, showing how events like infection, puberty, or antibiotic use influence a virtual population of microbes.

No unit on the microbiome would be complete without information about antibiotics. While using the space bar to blast microbes in the sinus with a dose of antibiotics in the online "Agent Antibiotic" game, students learn that these drugs indiscriminantly act on harmful and helpful microbes, and that antibiotic use can lead to a rise in

drug-resistant bacteria. A text-based web page titled "What Is An Antibiotic?" provides information on how different families of antibiotics work. Another, "Antibiotic Resistance," offers an in-depth look at this topic, including ways bacteria can acquire drug resistance.

As researchers learn more about the complexity of the microbiome and how it responds to our actions, they have come to view the body as a series of complex microbial ecosystems (Robinson et al., 2010; Costello et al., 2012). Everyone can take an active role in maintaining these ecosystems through actions like cautious use of antibiotics and tailoring their diet to feed their beneficial microbes. A "Human Ecosystem" video (3:56) helps students see that many features of their microbial ecosystem parallel those of Earth's ecosystems. It also highlights our own role as our body's ecosystem manager. The "Symbiotic Microbes" paper-based activity asks students to use contextual clues from short text descriptions to match symbiotic microbes to the areas of the human body where they might survive (Figure 3). An additional paper-based activity, "Symbiosis Scramble," highlights different types of symbiotic relationships. In it, students act as microbes seeking to obtain nutrients as they form mutualistic, commensal, and parasitic groupings. To extend the ecology theme, the "Examples of Symbiosis" video (9:04) shows a variety of symbiotic relationships between microbes and other organisms, both familiar



Figure 2. “Your Microbial Friends” is an interactive piece that introduces students to the beneficial microbes found in different areas of our bodies and their functions. Two accompanying graphic organizers, designed to assist students in summarizing the information in different ways, can be downloaded from the Teacher Resources page.

and unusual. Students should come to appreciate that microbes are important not only to humans, but to all plant and animal life, and that microbes have roles in ecosystems that extend well beyond decomposition.

The “Human Microbiome” curriculum materials connect to the *Next Generation Science Standards* (NGSS Lead States, 2013) by addressing portions of the Ecosystems: Interactions, Energy, and Dynamics Disciplinary Core Idea for life science (LS-2) along with the Crosscutting Concepts of Scale, Proportion, and Quantity; Stability and Change; and Cause and Effect. The materials also provide opportunities for using the Scientific Practice of Planning and Carrying Out Investigations.

○ Testing the Curriculum Supplement: Research Findings

How Teachers Plan to Use the Human Microbiome Curriculum Materials

In 2014, the GSLC conducted two 2-week online professional development institutes to (1) introduce teachers to current research on

the microbiome, (2) familiarize them with the “Human Microbiome” curriculum materials, and (3) facilitate discussions about using the microbiome materials in the classroom. Sixty secondary biology teachers (30 for each institute) were selected from 450 applicants. Selection criteria included having classrooms with >80% underrepresented students and/or >80% with free or reduced-cost lunch. On the end-of-institute survey about their experiences, the teacher participants strongly agreed (73%) or agreed (27%) that the curriculum materials would successfully help their students understand the human microbiome. Participants also strongly agreed (65%) or agreed (35%) that the level of detail of the materials allowed them to be easily integrated into teachers’ current curriculum. Typical feedback from the institutes included “I found the information very interesting, something I can easily work into my curriculum, and something I think the students will find interesting.”

We also asked teachers about the ways in which they planned to use the materials. Almost all (95%) indicated that they would use the materials with biology students ranging from seventh to twelfth grade. Most (78%) intended to include the materials in several courses, including general, honors, and AP biology, and seventh-grade science. Some teachers (38%) planned to use the materials

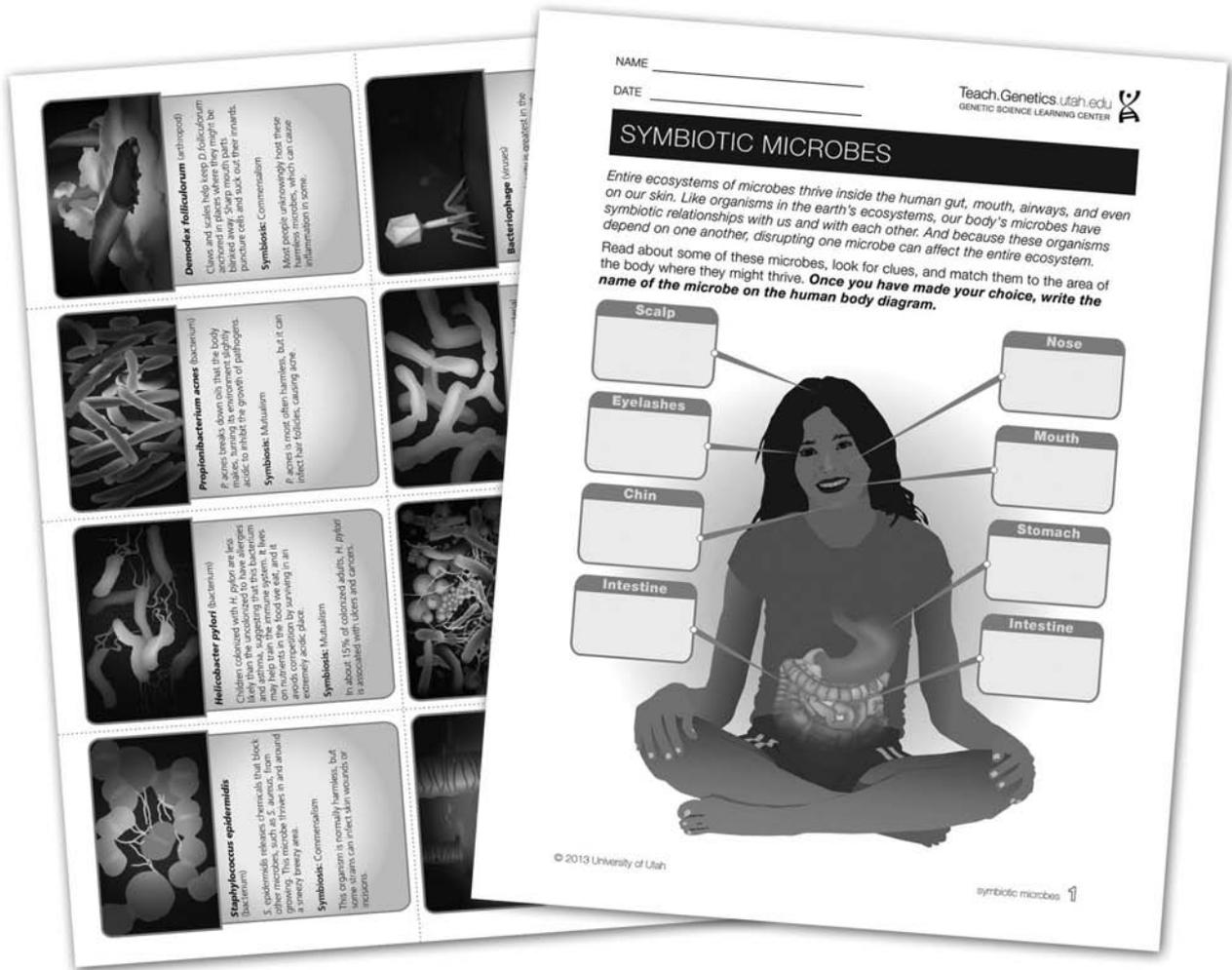


Figure 3. In the paper-based activity “Symbiotic Microbes,” students use clues from cards that describe eight microbial species to identify where these species might survive in or on the human body. The activity can be downloaded from the Teacher Resources page.

in other courses, such as Biotechnical Engineering, Living Environment, Health, Child Development, Zoology, Ecology, Forensic Science, and Anatomy and Physiology.

The majority of participants intended to embed the materials into multiple units throughout the year (66%), some intended to integrate parts of the materials into a single unit they were already teaching (19%), and slightly fewer (15%) planned to use the materials as a stand-alone unit. Teachers who expected to use the materials in multiple units indicated using them in units on ecology, genetics, anatomy and physiology, cell biology, evolution, biomes, immunity, biotechnology, life on other planets, microbiology, and body systems. Teachers who planned to integrate the materials into one existing unit indicated using them in ecosystems, evolution, nutrition, the human body, microbiology, and molecular biology. In addition, some of the teachers planned to complement the GSLC’s materials with other human microbiome–related materials, such as online lectures, videos, animations, and magazine or newspaper articles.

Efficacy of the “Human Microbiome” Curriculum Materials for Student Learning

In 2014–2015, GSLC researchers conducted a field test to assess the efficacy of the curriculum materials for student learning. Because

we were unable to find comparable curriculum materials developed by others that covered the same learning objectives, we could not conduct a comparison test. Instead, we assessed student learning gains on a content-knowledge test before and after they engaged with the GSLC’s materials. Although most teachers planned to integrate parts of the curriculum supplement into existing units and lessons, we chose to test the curriculum supplement as a stand-alone unit in order to control for extraneous variables. Most of the activities in the curriculum supplement were examined, including “Microbiome Simulator,” “Your Microbial Friends” and one of the associated graphic organizers, “Agent Antibiotic,” “The Human Ecosystem,” “Symbiotic Microbes,” and “Examples of Symbiosis.” Teachers were prepared to implement the materials with fidelity via the summer institute and a follow-up virtual meeting.

A 12-item content-knowledge pretest and posttest were developed by evaluators and vetted by content experts to measure learning gains. The items matched the learning objectives covered in the materials used in the field test. To ensure that the assessment items were valid, reliable, and aligned with content, they were pilot tested with teachers (n = 60) and students (n = 56) and revised accordingly. The pretest and posttest are available for teachers to download at <http://Teach.Genetics.utah.edu/content/microbiome>.

Field test results from 196 ninth- and tenth-grade general biology students indicated statistically significant increases in test scores from the pretest ($M = 3.04$, $SD = 3.87$) to the posttest ($M = 3.87$, $SD = 1.83$) ($t_{195} = -5.36$, $P < 0.001$). The students were from six ethnically and linguistically diverse high schools in states across the United States. Following the field test, the six participating teachers completed a survey about their experience using the materials with their students. All teachers reported a high level of student engagement with the materials. When asked what big-picture idea(s) students learned from the materials, teachers indicated that students successfully learned about the symbiotic relationship between humans and microbes. When asked which activities students seemed to like best, teachers reported that students particularly enjoyed the “Agent Antibiotic” game. Several teachers noted that transitioning from one activity to another required additional information and scaffolding, which suggests that the curriculum materials are best used as separate activities to support existing lessons rather than as a stand-alone unit. In addition, some teachers noted that the reading and vocabulary levels may have been too high for some students. However, all teachers reported that they intended to use parts of the curriculum supplement with future classes. In summary, the results revealed that the GSLC’s curriculum supplement is an effective and useful resource for teaching introductory biology students about the human microbiome and for recasting students’ perceptions of microbes living in and on the body. In addition, we learned that the curriculum materials are likely to be most useful when they are integrated into content-related units rather than used as a stand-alone unit.

○ Conclusion

With new technologies available for investigating microbes, researchers are uncovering a wealth of new information and revising notions of microbes’ roles in our lives. Once thought to be mostly disease-causing, microbes living in and on our body are now viewed as benign and even beneficial. The “Human Microbiome” curriculum supplement developed by the GSLC offers biology teachers flexible and effective learning activities to foster students’ interest in, and understanding of, this cutting-edge topic. Educators can seamlessly weave these activities into their existing lessons and units, adding excitement without a large time commitment. The curriculum supplement provides meaningful, real-world connections for students, enhancing their understanding of subjects such as ecology, microbiology, and health.

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