PROJECT REPORT

How Well Do You Know Your Closest Bacterial Neighbors?

Promoting Active Learning in Biology Classes

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Abstract

The human body is teeming with microbial life in that bacteria even outnumber the total quantity of human cells. Some of these microbes are non-pathogenic, some cause diseases, some are beneficial, and others have no apparent function. We provide explicit learning activities, reading and homework assignments, and assessment techniques that help instructors to engage their students in exploring and learning about the bacteria that co-inhabit or colonize the human body. Throughout this learning activity, students engage in active learning to explore, research, and learn about both indigenous and foreign bacteria. By engaging today's students in realistic learning activities such as these, we create an environment that promotes active learning through involvement in critical thinking, collaborative learning, problem solving, and knowledge creation within the context of content-based knowledge—skills and habits that are needed in the next generation of physicians, researchers, communicators, civic leaders, and public policy makers. This topic is of civic important because humans live with disease-causing microorganisms all around them and infectious diseases are one of the major causes of death in the world. Students need this knowledge base as they attempt to deal effectively with issues such as nutrition, health, safety, and wellness and public health, for their own and successive generations.

Introduction

A number of organizations including the Association for Prevention Teaching and Research (APTR), the Council of College of Arts and Sciences (CCAS), the Association of Schools of Public Health, and the Association of American Colleges and Universities have affirmed that "an understanding of [individual and] public health is a critical component of good citizenship and a prerequisite for taking responsibility for building healthy societies" (AAC&U 2011). It is important because humans live with disease-causing microorganisms all around them. While some microorganisms, such as bacteria, live on or in the human body without causing diseases and some are beneficial, a number of them are not. Indeed, infectious diseases are one of the major causes of death in the world (Neighbors and Tannehill-Jones 2010). Understanding how microorganisms interact with the human body is important knowledge affecting both individual and public health. Students need this knowledge to make informed decisions about nutrition, health, safety, wellness and public health for their own and successive generations. In this article we describe specific active-learning strategies that help students understand the connections between individual and public health and a working understanding of microorganisms, given them the tools they need to effectively engage in informed civic action.

Civic engagement has been defined as informed individual and collective actions designed to both identify and actively engage in issues of public concern and thus contribute productively to civic and public life. With these instructional activities and teaching strategies, we aim to help students as citizens, to:

- Identify, learn, and talk about vital issues, such as public health and microorganisms, in their lives, communities and organizations,
- Develop understanding, insights and solutions for those issues, and
- Inform others in the community to help insure that public policy supports the well-being of individuals, communities, and societies.

To learn, students need to do more than just receive information by listening to lectures, memorizing facts, and taking quizzes or exams. Instead, students must actively be involved in such higher-order thinking tasks as analysis, synthesis, and evaluation through reading, writing, discussions, and problem solving (Bonwell and Eison 1991, Niemi 2002, Meyers and Jones 1993). Within this context, "active learning would require the instructors to design their instructional activities to engage students in doing things and thinking about what they are doing" (Bonwell and Eison 1991, p. 1). It also would require student to be accountable for their learning, make something out of what they learn, and apply what they have learned in different situations. In other words, student need to show accumulated evidence of content knowledge, academic skills, comprehension, and must meaningfully apply learned knowledge and skills.

Background Information

We frequently hear news and information about bacteria from hospitals, universities, research institutions, and related organizations. There is a lot of interest in bacteria because the human body is teeming with microbes to the extent that their numbers exceed the total quantity of human cells. Microbes have been around for billions of years, living in and on the human body and everything around it. In fact, they outnumber our 100 quadrillion human cells by a factor of ten.

Bacteria are highly prolific, reproducing in a matter of minutes, and cover the human body as a whole, including its individual organs, with a composite of microbial species. Bacteria inhabit many areas of our bodies including our skin, digestive tract, nasal passages, hair and eyelashes, eyes, and teeth (Cf., Bryson 2003, Neighbors and Tannehill-Johnes 2010, Finlay 2010). For example, it has been estimated that human skin "hosts more than a million microbes per square centimeter"; one milliliter of saliva "contains about 1,000,000,000 bacteria"; and the digestive system alone is host to more than a hundred trillion microbes of at least four hundred types (Tenneson 2011, Kirshenbaum, 2011). Some deal "with sugars, some with starches, and some attack other bacteria, and some others have yet no detectable function at all" (Bryson, 2003, p. 302-303).

To give an example of the quantity of bacteria found in the human gut, a patient with *Clostridium difficile* diarrhea could "excrete 10,000 to 10 million organisms per gram of feces; a gram corresponds to just a quarter-teaspoon" (Dunavan, 2010, p. 26). In addition to the bacteria that are crucial to the digestive process, the human gut also contains bacteria-invading viruses. The role these viruses play is largely unknown, but they most likely have a mutualistic relationship in aiding metabolism and contributing to the stability of the gut's microbial community and complex ecosystem (McGowan 2011). Scientists have identified the "complex ecosystem of bacteria throughout a person's body as the microbiome" (Lee, 2010, p. 242). The term microbiome, which was first coined by Joshua Lederberg, is defined as "the totality of microbes, their genetic elements (genomes), and environmental interactions in a defined environment" (Wikipedia encyclopedia, 2011). These bacteria and other microbes including fungi and viruses, live all over our bodies. Microbes are found on our skin, our nose and respiratory tract, our urogenital tract, our mouth, and our digestive tract. These microbes can impact our health in both positive and negative ways. For example, gut bacteria aid in digestion and provide us with nutrients but at the same time, they have been linked to obesity and bowel diseases (Yong, 2012). A person's microbiome can be influenced by a number of factors including what they touch, eat, and breathe as well as how they were born, whether vaginally or by Cesarean section (Lee 2010).

So if you are ever feeling lonely, just remember that you are never truly alone. You are always in the company of your personal microbiome of bacteria. Indeed, in addition to our blood type, DNA, and fingerprints, forensic investigators think that the "ecosystems of bacteria that live on our skin and get left behind on everything we touch are unique and descriptive, meaning that they could provide a new way to establish identity" (Talkington 2010, p. 19). Furthermore, in addition to living on humans and other organisms, bacteria are ubiquitous in every imaginable habitat on the planet earth, including hot springs, salt lakes, and streams polluted with acidic mine runoff. We are in constant contact on a daily bases with bacteria from the world in which we live.

We need to remember however, while m*ost* bacteria are harmless and necessary for supporting humans and all life on Earth, a minority are not. They form a parasitic association with living organisms, causing various infections and diseases.

> *Of all the tens of thousands of known bacterial species, only about 100 are renegades that break the rules of peaceful coexistence and make us sick. Collectively, those pathogens can cause a lot of trouble. Infectious diseases are the second leading cause of death worldwide, and bacteria are well represented among the killers. Tuberculosis alone takes nearly two million lives every year, and* Yersinia pestis, *infamous for causing bubonic plague, killed approximately one third of Europe's population in the 14th century. Investigators have made considerable progress over the past 100 years in taming some species with antibiotics, but the harmful bacteria have also found ways [through the evolutionary processes] to resist many of those drugs. It is an arms race that humans have been losing of late, in part because we have not understood our enemy [meaning microbial* neighbors] *very well." (Finlay 2010, p. 57)*

This is very important because a number of pathogens have "evolved from harmless microbes by acquiring genes that confer new [pathogenic] properties" (Finlay 2010, p. 62). For example, a common microbe living on human skin, "*Staphylococcus aureus*, is usually harmless but can lead to serious infections" (Tennesen 2011, p. 37). Furthermore, some non-pathogenic bacteria that are native to the human body can become pathogenic if the physiological and or anatomical status of the body is changed or if they are introduced into a different area of the body. For example, *E. coli* is a harmless resident of the colon but it can cause meningitis if it gets into the cerebrospinal fluid. *Clostridium difficile* is also found in the colon but it can overgrow and cause pseudomembranous colitis after antibiotic use. The paramecium *Pneumocystis jiroveci* is often found in the lungs but it can cause serious pneumonia in AIDS patients and in patients who have had chemotherapy treatments.

Like other organisms, the human body is equipped with an immune system that is designed to resist, fight, and eliminate an infinite number of changes and attacks brought about by foreign agents in its environment, including microbes (Harry J. Johnson, cited in Wait 2001, p. 235). Bacterial pathogens, however, are equipped with virulence factors designed to elude our defenses so they can survive and reproduce. But bacteria should not be blamed for performing activities that they were created to do and which are programmed in their genetic code. When they make us ill and cause us to sneeze, cough, vomit, or have diarrhea, they are simply facilitating their survival by spreading through the environment and infecting more people (Finlay 2010, Cherif, et. al 2009, Bryson 2003, Konneman 2002). And among those harmful bacteria, some of them still provide essential service to the human body. For example, *Propionibacterium acnes* has been associated with acne. But because *P. acnes* thrives on the oily, waxy remains of dead cells, it breaks down oil into a natural moisturizer for human skin (Tennesen 2011).

Bacteria do not live in isolation. Whether they are harmful or beneficial, or whether they live in the human body or in the external environment, most groups of bacteria form microbiomes of diverse ecosystems and behave as multicellular organisms. (Tennesen, 2011; Williams, 2010), They have developed very sophisticated systems of communication, using a rich chemical lexicon, and they send and receive signals to and from other bacteria. By "talking" to each other, they act in unison to perform fascinating functions, such as bioluminescence, sporulation, DNA transfer, biofilm formation, population density estimates, and pathogenesis. Scientists have used their knowledge of intercellular communication amongst microbes to further their research on topics pertaining to bacterial physiology, ecology and bacterial disease (Bassler, 2009; Winans & Bassler, 2008).

Bacteria such as *Staphylococcus epidermidis,* which live on our skin, work together to prevent deadly *Staphylococcus* *aurous* strains from taking hold (Tennesen, 2011). Other bacteria work together to protect each other when faced with doses of antibiotics. For example James J. Collins and his research team have found that:

> *The few truly antibiotic-resistant bacteria emit a compound called indole that signals the rest of bacteria to ramp up their defenses. When the nonresistant pathogens sense indole, they turn on a pump that expels antibiotics from the cell, and they turn on chemical pathways that protect them from the toxic molecules antibiotics normally induce inside bacteria.* (Williams, 2010, p. 42)

Others turn toxic only when their neighbors are in danger and need help. Still others are opportunistic pathogens that cause disease mainly in people with a compromised immune system as a result of change in their body's physiology or who are suffering from a chronic condition such as cystic fibrosis.

A better understanding of these bacterial strategies of collaboration and communication may help us create inhibitors to disrupt them as well as give us strategies for co-existing with our closest bacterial neighbors in a harmonious environment. Then we will be able to utilize their unique survival mechanisms to improve our own lives. In addition, it will also help us figure out how to support the survival of our beneficial bacterial neighbors, and even help our immune systems to better fight the pathogens. This could reduce the number of patients worldwide with compromised immune systems, which has been rising in the last twenty-five years (Hayden, Carrol, Tang, and Wolk, 2008). It is possible that some of the trillions of microbes that live in the human body will teach us how to fight disease without antibiotics and thus achieve a new level of individual and public health.

Microorganisms that typically colonize the human body (host) without normally causing disease are known as the body's normal microbiota, normal flora, or the indigenous microbiota. There are two types of normal microbiota, resident and transient. Resident microbiota are part of the body's normal flora and do not cause disease under normal conditions. Most of the resident microbiota are commensal, found on the skin and on the mucous membranes of the digestive tract, upper respiratory tract, distal portion of the urethra, and vagina without causing harm (Bauman 2012; Tortora, Funke, & Case 2012; Lim, 2003). Transient microbiota remain in the human body (host) only for a short time (ex. a few hours, days, or months) before disappearing and without causing a disease. While the members of both resident and transient microbiota are found in the same locations, the transient microbiota cannot persist because of "competition from other microorganisms, elimination by the body's defense cells, or chemical and physical changes in the body that dislodge them" (Bauman 2012, p. 412).

Indigenous opportunistic bacteria are non-pathogenic bacteria that are native to the human body but can become pathogenic if the physiological and/or anatomical status of the body is changed. They can also cause infection if they are introduced into a different area of the body. While the human body teams with microbial life forms, many parts of the human body are sites free of any microbes. This type of site is known as an *axenic* environment. For example a mother's uterus is an axenic environment and this is one of the reasons that babies develop in their mothers' wombs without normal microbiota. But after all, to the bacteria themselves, the human beings probably seem like just a small part of their world, a world on which they have existed for approximately 4 billion years (Koneman, 2002; Knoll, 2003; Bryson, 2003; Flannery, 2008). One might say, as Bryson (2003) did, we are but guests in their universe Thus, the best we can do to appreciate them is to learn not only how to co-exist with them but also how to benefit from them to make our life better for us and the world around us.

Learning Activity

In this learning activity, students work in groups of 3-4 to research various types of bacteria that are directly or indirectly associated with the human body. Each group selects at least one from each of the following categories:

1. Indigenous bacterium normally found on humans – e.g., on skin, in colon, gut, etc.
2. Foreign pathogenic bacterium – a bacterium that is not native to the human body and that causes a disease to humans.

Once the members of the groups have finished their research, they prepare a written report and an oral presentation to be given in class. To accomplish this goal, students work together to research, study, and collect information about their selected bacteria. By actively engaging in this activity, students learn and reinforce their understanding of the roles that pathogenic and non-pathogenic bacteria play in the existence and survival of humans and the world in which they live. But most of all, we aim to invoke an interest in learning and stimulate further exploration of these amazing microbes by the students' involvement. In turn, we hope to excite them about issues that may present themselves in their future, and give them supportive insight into solutions that could contribute to achieving desirable individual and public health.

Procedure

1. Divide the class into groups of 3-4 students, and inform each group member to work together to:

   a. Conduct research about bacteria that normally live on or in the human body as well as foreign pathogens which are not native to the human body. See table 1.

   b. Select one bacterial species from each category and then prepare a written paper, handout, and oral presentation on each one. The presentation must convey information and integrate the use of technology such as PowerPoint, animations, interactive activities, etc.

2. Ask each group to prepare two relevant critical thinking questions to submit for a class quiz and potential exam poll questions.
3. Give the students 2 to 3 weeks (time can be shortened or lengthened) to prepare their written paper, hand-out, and presentation.
4. At every class meeting, make sure that students are working on their assignments. For example, give 10–15 minutes to the members of each group at the end of the class meeting to sit together and reflect on the progress they have made toward the written paper, poster, additional aids, and the oral presentation.
5. Students are advised to start their research by reading at least five of the following articles which can easily be found in the college libraries, nearby public libraries, and bookstores: Ananthaswamy (2010), Bassler (2009), Dunavan (2010), Finlay (2010), Hughes (2011), Koening (2010), Koneman (2002), Marsa (2010), Tennesen (2011), and Walsh and Fischbach (2009)
6. Remind the students that the objectives in this learning activity are to help them develop:

   a. Breadth of knowledge and depth of understanding of concepts and vocabulary of the microbial world and the roles of bacteria in human life and in our contemporary technological society.

   b. An understanding of the social, economic and environmental implications and limitations of science, technology, and genetic engineering.

   c. An awareness of their own attitudes, feelings and values about microbes and how they differ from others.

   d. An awareness of the importance of microbial diversity in environmental protection/stewardship, economy and sustainability.

   e. Team work and communication skills.

   f. Critical thinking and problem-solving skills.

Discussion Questions:

1. Where, on or in the human body, are:

   a. the most of the indigenous bacteria found?

   b. the least, or no indigenous bacteria found?

   c. the sites free of any microbes (axenic environment)?

2. Humans constantly come into contact with external agents including disease-causing microorganisms that could be harmful if they enter the body. Through which parts of the human body do most foreign bacteria enter the human body and use as a host for food and/or reproduction?
3. What is an antibiotic? How does an antibiotic work? Who discovered the first antibiotic? If you have to write a letter to this scientist, what would you write and why?
4. What is an antibody? How does an antibody work? Compare and contrast between antibiotic and antibody.

TABLE 1. EACH GROUP SELECTS ONE OF EACH OF THE FIVE CATEGORIES OF BACTERIA TO RESEARCH AND PRESENT

Type of Bacteria	Example	Its Nature	Found	Its relationship with Human body
Indigenous lives inside the human body.				
Indigenous lives on the human body.				
Indigenous opportunistic* lives in or on the human body				
Foreign pathogenic infects inside the human body				
Foreign pathogenic infects outside the human body				

* Indigenous opportunistic bacteria are non-pathogenic bacteria that are native to the human body but can become pathogenic if the physiological and or anatomical status of the body is changed. They can also cause infection if they are introduced into a different area of the body.

5. How do bacteria evolve to become antibiotic resistant?
6. Under what other circumstances might some bacteria develop drug resistance without being exposed to any antibiotics?
7. It has been argued that to fight bacteria, we need better information about how they acquire their disturbing power of attacking us. From your perspective, how might we be able to change those pathogenic bacteria to harmless and or beneficial bacteria?
8. Under what possible circumstances or conditions might a given indigenous harmless or beneficial bacteria become pathogenic?
9. Bacterial infections may be treated with antibiotics, which are classified as bacteriocidal or bacteriostatic. Compare and contrast between the two classes of antibiotics.
10. Conduct research to explain:

    a. Why nitrogen and phosphorus are added to beaches following an oil spill?

    b. Why do scientists insert the so-called suicide genes into genetically engineered cells along with the gene of interest?

    c. Why do you think it is very hard to consider a given bacteria entering the human body as a foreign non-pathogenic bacteria?

11. Which characteristics do bacteria possess that qualifies them as suitable organisms to be genetically engineered?
12. What types of biological facts have made genetic engineering a possible reality and a fact of biological life?
13. If you have to write a letter of appreciation and provide an update about the human understanding of microorganisms to the following scientists, what would you write and why? Anton van Leeuwenhoek (1632-1723) who opened the door to the new world of microorganisms with his early development of microscopies and discoveries of microorganisms; Louis Pasteur (1822-1895) who disapproved the theory of spontaneous generation, developed vaccines for anthrax and rabies, and developed a process of pasteurization; and Robert Koch (1843-1910) who in 1876 established a series of criteria necessary for association of specific microorganisms with specific diseases, which today is known as Koch's Postulates.

Homework Assignment and Additional Related Activities:

When all the groups complete their presentations, give the homework assignments and additional related activities in appendix 1 to students to work on and complete individually or in groups. They can be used as homework assignments or research topics.

Assessment:

Using both formative and summative assessment, students are assessed based on:

1. How well they:
   a. Conduct their research.
   b. Present their research and make it personal and relevant.
   c. Show the significance of the different types of bacteria selected for their presentation.
   d. Respond to the questions asked by their classmates after their presentations.
   e. Answer the imaginative question of "What would the different types of bacteria say to each other in their encounter on or in the human body"?
2. How many relevant critical thinking questions they submit for quizzes and potential exam polls.
3. How well they completed the homework assignment and answered the related questions.
4. The academic quality and integrity of the written paper, oral presentation, poster illustration, and/or any additional aids used by the students to convey their message.
5. Clear evidence that the members of a given group conducted research beyond the suggested articles assigned by the instructor for all the students to read.
6. The delivery of the presentation, the articulation of the perspective and arguments, the demonstration of the long term and short term effects, and the individual's personal involvement and engagement during the presentation and following discussion.
7. The type and quality of questions asked and the quality of the answers the group provided to questions directed at them. Teachers and instructors can refer to Cherif et al. (2009, 2011) for useful tools and techniques that can be used to monitor the level of cognitive involvement of the members of a given group during the activity as well as to record the types of questions being asked by the members of a group, the relevance of the questions to the subject matter and to the point being debated, and the number of questions asked by the members of each group.

The instructor of the class must reinforce the principles of DNA structure and replication, genetic mutations, genetic engineering, microbiomes, indigenous and foreign microbes, infectious diseases, antibody and antibiotic, and resistance to drugs and insecticides. Other topics that can be discussed include the role of microbes in biological diversity, environmental sustainability, economic prosperity, and the importance of microbes in public health, both beneficial and disease-causing. Also, additional relevant topics to address may include when and how harmless bacteria acquire genes and evolve to be pathogens and vice versa.

Conclusion

Today, human societies are faced with many complex challenges, including medical, environmental, agricultural, and economic to name a few. These challenges require revolutionary approaches to understanding the characteristics and the functions of microbial communities, including how they support all life on Earth and how bacteria inhabit living bodies and ensure their healthy survival. In this learning activity we aim to increase students' awareness of our paradoxical relationship with the microbial world, with the main emphasis on bacteria. The goal is to motivate students' curiosity and earnestly explore and understand the unseen microbial world within the context of the human body. After all, microorganisms, which may always invade our tissues, may also be a means for providing us with healthy bodies and supporting environmental well being.

Microbes are everywhere; they live in our bodies, and in everything that surrounds us. We cannot live without them. Therefore, understanding microbial communities is necessary to enhance our understanding of ourselves and how we can solve many of the challenges that are facing us today, such as public health, global environmental changes, the use of biologically-based energy resources, restoring healthy ecosystems, and producing food for feeding the rapidly increasing world population, to name a few.

By engaging today's students in realistic learning activities such as these, we create learning environments that promote active learning, critical thinking, collaborative learning, and knowledge creation—habits that are urgently needed in the next generation of physicians, researchers, communicators and public policy makers. They will need this knowledge base as they attempt to deal effectively with issues such as nutrition, health, safety, and wellness for their own and successive generations.

Answers to Questions Raised in the Learning Activities:

A complete and detailed list of answers to all the questions raised in the learning activities in this paper are available electronically based on individual request by e-mailing anyone of the authors.

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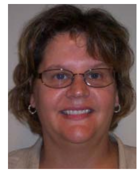

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Appendix 1

Additional Related Learning Activities

We frequently hear news and information about bacteria from hospitals, universities, research institutions, and related organizations. The following are additional homework assignments and related activities designed as startup learning activities to motivate students to explore and discover more about the bacterial world. Instructors can select those they find useful to integrate in their instructional time or to assign as individual or group projects for their students.

Activity: Bad Guys, Here I Come

Forensic scientists are very excited about the potential of new tools that might help them catch criminals more effectively. In addition to fingerprints and DNA, forensic scientists, lawyers, and law enforcement personnel have new tools to use, including pollen and some types of bacteria. Forensic investigators think that the "ecosystems of bacteria that live on our skin and get left behind on everything we touch are unique and descriptive, meaning that they could provide a new way to establish identity" (Talkington 2010, p. 19). Conduct internet research to find out how the ecosystems of bacteria could be used as an additional tool to help solve forensic problems and catch criminals.

Activity: The Human Body and its Bacterial Cohabitants

The human body is made up of trillions of cells. Additionally, it houses about 10 times that number of bacterial cells. Conduct research to identify at least five locations on the human body and their bacterial cohabitants. Then draw a structural map of the human body and indicate the location of those bacterial cohabitants that you identified. Draw the shape of these bacteria and identify their characteristics.

THE HUMAN BODY AND ITS BACTERIAL COHABITANTS

	Body Part	Bacterial Cohabitants	Bacterial Shape	Bacterial Characteristics
1				
2				
3				
4				
5				

Activity: Quorum Sensing

The phenomenon by which bacteria sense and respond to changes in microbial density in the vicinity by utilizing signal and receptor molecules is known as bacterial quorum sensing (Lim 2003; Bassler 2009; Bauman 2012). As a result, bacteria are able to "coordinate their activities and respond to changes in environmental conditions such as adaptation to nutrient availability and avoidance of toxic compounds or host immune responses" (Lim, 2003, p. 482). The main goal of quorum sensing research is to come up with inhibitors that could be used to alter the ability of bacteria to cause diseases. Researchers do this by identifying how bacteria communicate with each other and then interfere with their communication so they don't send and receive the messages or so they receive different messages and change their natural (innate) behavior.

In the bacterial world, there are two approaches of how pathogens cause illness after they find their way into a human body: either wait for help like *E-coli* or attack immediately like *Vibrio cholera.*

> *When E. coli finds its way into a human body, it doesn't start attacking immediately. It waits until it has a quorum, and then pow! Virulence factors turn on, and the human gets sick. In the case of E. coli, the bacteria start to produce a toxin that wreaks havoc. The idea is to trick the E. coli into thinking that only a few other E. coli are around. Then no virulence factors turn on, so there's no toxin, and no grave illness.* (Staton, 2010, p. 70)

On the other hand, *Vibrio cholera* works in the opposite manner of *E. coli* and most other bacterial signals. This bacterium "doesn't wait until it's swimming in a critical mass of fellow bacteria to turn on virulence. It's virulent from the get-go; attacks immediately" (Staton, 2010, p. 70). The research scientists who work with quorum sensing are trying to trace the early stage signals of those germs that get humans seriously sick such as *V. cholera*. When they figure this out, then they can develop a strategy to treat and prevent the illness. This could be as simple as an amino acid or a sugar without the need for using complex and expensive drugs (Staton, 2010).

Conduct internet research to find out:

1. What is the difference between bacterial inter-species and intra-species communication?
2. How does quorum sensing contribute to a microbe's pathogenicity and virulence?
3. What are anti-quorum sensing molecules and why do some scientists refer to them as the next generation of antibiotics?
4. Is quorum sensing a characteristic associated only with pathogenic bacteria or pathogenic and non-pathogenic bacteria? Explain.

Activity: Bacteria Working Together

New studies on antibiotic resistance have shown that some types of bacteria have developed a very sophisticated strategy of collaboration that is essential for their species' survival. For example, *"E. coli* are more resistant to antibiotics as a group than as individual cells" (Williams, 2010, p. 42). Researchers from HHMI have found that "when faced with an oncoming dose of antibiotic, bacteria work together in a neighborly way. Microbes that are resistant to the drug protect their weaker kin in the colony" (Williams, 2010, p. 42). Under the wing and watchfulness of the stronger bacteria, this approach might help the weaker bacteria to slowly develop effective resistance over time, according to James J. Collins, an HHMI investigator at Boston University.

> *The usual thinking about resistance is that a mutation arises in one bacterium, and then that bacterium has a survival advantage and thrives, growing and dividing, while the others die off. But the team found that the bacterial population as a whole showed far more antibiotic resistance than did small sample of bacteria. And only a few bacteria had resistance-causing genetic mutations. The scientists found that the few truly antibiotic-resistance bacteria emit a compound called indole that signals the rest of the bacteria to ramp up their defenses. When the nonresistant pathogens sense indole, they turn on a pump that expels antibiotic from the cell, and they turn on chemical pathways that protect them from the toxic molecules antibiotics normally induce inside bacteria. Bacteria, although they are unicellular organisms, can behave as a multicellular organism from population standpoint.* (Cited in Williams, 2010, p. 42).

Conduct internet research to find out:

1. What is the difference between bacteriocidal and bacteriostatic antibiotics?
2. Why are multidrug resistant (MDR) strains of bacteria becoming more prevalent?
3. How do you treat MDR tuberculosis?

Activity: Planned Eradication of Bacterial Species to Prevent Diseases
(Adapted from Cherif, et al, 2011).

Given the fact that species become extinct "all the time" and some types of bacteria cause serious disease, planned extinction doesn't seem to be a bad idea. After all,

> *Humans have aggressively worked toward the extinction of many species of viruses and bacteria in the cause of disease eradication. For example, the smallpox virus is now extinct in the wild—although samples are retained in laboratory settings, and the polio virus is now confined to small parts of the world as a result of human efforts to prevent the disease it causes.* (Wikipedia encyclopedia, 2010b)

In her article, "A Bug's Death", Olivia Judson (2003) has advocated the idea of "specicide", the planned extinction of an entire species that causes serious diseases. Even though it has never been tried before, Judson's "specicide" idea is a simple and straight forward concept.

> *Specicide … could be engineered by exploiting the biology of selfish genetic elements… which contribute nothing to the well-being of their hosts, but simply proliferate themselves… As a result, a selfish genetic element can spread through a population extremely fast—far faster than a regular gene—even if it is harmful to its host… [Therefore] to engineer extinction, devise an extinction gene—a selfish genetic element that has a strongly detrimental effect. The element could, for example, be designed to put itself into the middle of an essential gene and thereby render it useless, creating what geneticists call a ''knockout.'' If the knockout is recessive (with one copy of it you're alive and well, but with two you're dead), it could spread through, and then extinguish, a species in fewer than 20 generations..* (Judson 2003)

While Judson (2003) was talking specifically about malaria which is spread by *Anopheles* mosquitoes and dengue fever, yellow fever, and elephantiasis which are spread by *Aedes* mosquitoes and not bacteria, it is not easy to predict the possible risks and consequences of planned extinction, especially for living forms such as bacteria. Conduct internet research to find out:

1. Why planned eradication of a given bacterial species might not be an easy task or might not work in comparison to other life forms?
2. If planned extinction of a given bacteria is possible, what is the possible ecological collapse and genetic escape for planned extinction of bacteria that cause deadly illness to humans?
3. Do you agree with the idea of planned extinction of a species to prevent serious diseases?
4. If you were to write a letter to Olivia Judson what would you write and why?
5. Compare and contrast genetic modification (engineering) as a tool of creation and as a tool of extinction.
6. If you have to select one over the other in supporting biological diversity, environmental sustainability, and better life and living for human societies, which one of the two mechanisms in question 5 would you select? Explain.

Activity: A Bio-based Computer

The new advances in genetic engineering and synthetic biology have created the potential for biology-based, instead of silicon-based, computers that one day might solve complex biological and mathematical problems. According to Karmella Haynes, a researcher at Davidson College and lead study author, "The computing potential of DNA far exceeds that of any other material… If we figure out how to increase that capacity in a practical manner we will have much more computing power" (Cited in Bland 2008, p. 3).

> *A traditional, silica-based computer would run through every single possible solution to the problem, one at a time. In a biology-based computer, each bacterium becomes a single computer that runs a different part of the problem simultaneously. Since a million bacteria-based computers can fit into a single drop of water, all of them working together could speed up the calculations dramatically.* (Bland 2008, pp. 8-9)

This type of computer has the potential to allow researchers to conduct a wide variety of biological computing such as "telling researchers how many times they have encountered a certain chemical" (Bland 2008, p. 16).

1. Conduct internet research to find out:
   a. How biology-based computers work.
   b. What type of problems might biology-based computers face that reduce their efficiencies?
2. In 1937, the theoretical physicist John Vincent Atanasoff, who was a professor at Iowa State College in Ames, Iowa, built and operated the first electronic digital computer. Atanasoff's first computer was "a 12-bit, two-word machine running at 60-hertz wall-plug frequency and could add and subtract binary numbers stored in a logic unit built with seven triode tubes" (Hauptman 2010, p. 8). If you have to update professor Atanasoff of your research finding, what would you write to him in a single page letter?

Activity: Having trouble with math problems?
No problem, Escherichia coli *can help.*

E. coli has been engineered to count. While a lot of work still needs to be done, biologists have already demonstrated the concept and the foundation for *E-coli's* ability to count, which is very important for several reasons.

> *Right now cells, bacteria and otherwise, act as one-and-done detectors. As soon as they detect a particular chemical, it triggers a reaction. This can be helpful for detecting the presence of a chemical, but not useful for measuring the number of times a chemical occurs.* (Bland, 2009, p. 10)

Recently, a group of research scientists from both Boston University and the Massachusetts Institute of Technology successfully programmed E coli to count to three. These scientists believe that with this type of ability which could be used as a read-out mechanism or control switch, the engineered bacteria "could lead to environmental or biological sensors that measure toxins and then self-destruct once their job is done" (Bland, 2009, pp. 2-3).

Conduct internet research to find out:

1. How were scientists able to program *E. coli* to count?
2. How the tools and mechanisms that are used with genes that encode for the bacterial counters:
   a. Could be transferred to other bacteria?
   b. Could be enhanced to program the bacteria to count to higher numbers?

Activity: E. coli *as a Potential Electronic Data Storage Device:*

After counting and solving math problems, scientists are now testing the capability of storing electronic data in *E. coli* that has already been genetically engineered.

> *Cambridge University's student magazine BlueSci reports that researchers from the University of Hong Kong have managed to place 90GB of data into the DNA of a colony of 18 E. coli. The data can also be encrypted by site-specific genetic recombination; a purely natural process that means data can be jumbled up.* (Fish 2010)

Conduct Internet research to find out and answer the following questions:

1. Why do you think this could lead to some pretty enormous storage capacities of electronic data?
2. Why are scientists only trying to experiment with the storing of electronic data in genetically modified *E. coli*?
3. Why do scientists think that bacterial cells and data in them could even survive a nuclear blast?

Activity: Keeping Bacteria Away

Not all bacteria are harmful; indeed, the vast majority of bacteria are harmless. What is more, many of them are helpful for humans, and some others are even *essential* for human life.

Conduct internet research to:

1. Identify the main differences between bacteria that cause disease and bacteria that do not cause disease.
2. Find out the many divergent ways to minimize exposure to possible harmful bacteria that could lead to water and foodborne illnesses that could be deadly to human life.
3. How could a given non-pathogenic bacterium become pathogenic bacterium?
4. Select one type of bacteria from the environment in which humans live such as soil, air, water, and plants and animals around us to search, study, and present.

Bacterial environment and or biome	Bacterial genera	Specifically found in	The economy of the microbe	Its relationship with Human body
Soil				
water				
Air*				
Animal biome				
Plant biome				

* Bacteria don't live in the air but they can be transferred through air. Students are expected to come to this conclusion and/or encounter this information during their research.

Activity: Fecal Transplant

A fecal transplant is a medical procedure that was recently developed and implemented by Australian doctor Thomas J. Borody and his team as an alternative for using antibiotics to treat pseudomembranous colitis which is caused by *Clostridium difficile* infection. While fecal transplant is very simple, safe, and can save thousands of lives, not all doctors use it (Ananthaswamy 2010, MacConnachie, et.al. 2009, Smith 2007).

Conduct internet research to find out:

1. What is a fecal transplant?
2. Why is it conducted?
3. How is it conducted?
4. Why don't all doctors use it?
5. What is your own perspective about fecal transplant?
6. In addition to the treatment of pseudomembranous colitis, is there any other use for fecal transplant?
7. What is the theoretical basis behind fecal transplant or fecal bacteriotherapy?
8. Why do you think this medical procedure to treat pseudomembranous colitis is less popular in North America in comparison to the rest of the world?

Activity: Abundance and diversity of microbial flora in various environments

Sustainable agriculture requires managing both the biota and the crops.

Conduct internet research to find out if there is:

a. Relationship between the use of antibacterial soap and hand lotion and the abundance and diversity of skin microbial flora.

b. Relationship between the use of fertilizers and the diminishing of the abundance and diversity of the soil microbial flora.

Activity: Making Vaccines More Effective

Vaccines are extremely effective at preventing disease. Scientists think that they could work better for more people and against a wider variety of illnesses if we add ingredients that can "supercharge old vaccines and make entirely new ones possible" (Garcon and Goldman 2009, p. 72). It is a fact however, that immunity provided by certain vaccines may weaken over time and thus prevention is always the best option if it can be achieved.

Conduct internet research to answer the following:

1. What is a vaccine? How do they work?
2. What are the common types of vaccines?
3. Compare and contrast the most common types of vaccines?
4. How could vaccines be enhanced to help the immune system? What is the depot effect?
5. Can a "one-size-fits-all" vaccine be possible? Explain.

Activity: Acquiring Normal Microbiota

The human body is teeming with microbial life. Microorganisms that typically colonize the human body (host) without normally causing disease are known as the body's normal microbiota, normal flora, or the indigenous microbiota. However the mother's uterus is an axenic environment and thus babies develop in their mothers' wombs without being exposed to normal microbiota. Conduct research to explain when and how babies start to acquire normal microbiota.

How well do you know your own enterotype?

Joshua Lederberg, who first coined the term "microbiome", argued that microorganisms inhabiting the human body should be included as part of the human genome because of their ability to influence human physiology. A group of microbiologists have reported three distinct ecosystems in the human gut that are not nation or continent specific. They referred to these distinct ecosystems as "enterotypes".

Conduct research to find out:

1. Why do scientists think people can be classified based on their enterotype?
2. What is the significance of recognizing that there are three distinct enterotypes that are not nation or continent specific?
3. From your own perspective, how can this discovery be used to help us to better understand the microorganisms that colonize the human body and how we could better coexist with them?
4. If you were told that this discovery was made based solely on combining twenty-two newly sequenced fecal metagenomes of individuals from four countries with previously published data sets, how would you feel about the discovery?

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