Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2018 Volume II: Engineering Solutions to 21st Century Environmental Problems

Is This Water Safe to Drink?

Curriculum Unit 18.02.05
by Jason Ward

Introduction

On a hot, summertime San Diego day, my 8-year-old self and a friend were riding bikes around the neighborhood. We were thirsty and several blocks from home when my friend stopped to use his bike tire to dam a stream of runoff water that was aggressively picking up pace on its way down the gutter. Someone up the street must have been watering their lawn or washing a car. He dared me to drink it, but I refused. I could see a rainbow sheen of either soap or motor oil from the road glistening on the top of the water. In his attempt to convince me the water was “safe” to drink, he hopped off his bike and laid flat across the sidewalk, his face inches above the trickling water. He began lapping up the water like a thirsty dog. His efforts to convince me had no effect on my decision to not drink the water, but for several days thereafter I was deeply concerned for my friend’s health. Fortunately, he survived. He didn’t even get sick, although I’m sure that soapy/oily water didn’t taste as good as he let on. My concern was based on him getting poisoned from the oil, or the dirt, or some other contaminant that anybody could have dumped into the gutter. Several years later, in junior high school, I was introduced to the microbial world of bacteria, viruses, and protozoa. I finally began to understand pathogens and how they spread, including through water.

At the beginning of the 2017-18 school year at Strong 21st Century Magnet School in New Haven, CT, a pair of students approached me at the beginning of class. It had been raining all weekend, and both boys were curious if it was safe to drink the water that was streaming along the sidewalks and into the storm drains. One boy was convinced that rain water was pure, so it would only have a little dirt in it but should be safe to drink. The other wasn’t so sure. I advised them not to drink the water and offered them a brief explanation about pathogens and toxins the water could have picked up along the way. As they returned to their class activity, I was reminded of my own experience as an 8-year-old. At this age, children have grown increasingly aware of their environment and know that there are risks out there, but may not understand why. Most children would hesitate to drink water from an untreated source, but probably do not understand why there is a health risk. They just know that drinking dirty water might make them sick. In this unit, I will use this relatively common and appealing wonderment to lead a study of water quality and an engineering project of water filtration.

I have been running the STEM lab at Strong School for three years. Our demographics are typical of New Haven, CT – about 50% Hispanic, 45% Black, and 5% White or other. All 380 students from kindergarten to fourth grade spend one hour a week with me in our STEM lab. During their STEM time, we study elementary science topics and practice engineering solutions to problems based on the science we have learned. Often one question will lead to a variety of other good questions, and before long we have a trail of learning several layers deep. As I began working with the Yale New-Haven Teacher Institute and Dr. Jordan Peccia, a Yale professor of Chemical and Environmental Engineering, I knew the topic of microbial water quality and treatment would be a part of our work. After several months of working closely with Dr. Peccia, I am pleased to present the following unit. It is written with third graders in mind, but can be adapted up or down if needed.

Like most good learning, this unit starts with a question – Is this water safe to drink? (Note that "safe" is a relative term and could be better phrased in terms of reducing risk.) Along the way, students will learn different ways water can be treated to make it less likely to get them sick. They will be introduced to microbes and learn how public drinking water is treated and sent to homes and businesses. Finally, they will match their scientific knowledge with their ingenuity and problem solving skill sets as they engineer a water filter out of various materials under the hypothetical situation, "If I was stranded on an island, how could I make clean drinking water?"

But first…

A Brief History of Water Treatment

Some of the earliest known records of water treatment were found in Sanskrit writings dating as far back as 2,000 B.C., although some researchers suggest water treatment dates to 7,000 B.C. in the ancient city of Jericho. The most common methods of water treatment included the boiling of water over fire, heating of water under the sun, dipping heated iron into water, and filtration through gravel and sand. [1] Water treatment at that time was meant to reduce turbidity (particles of organic material that cloud the water) and foul odor, while water treatment systems mimicked natural processes of filtration.

Inscriptions on the ancient Egyptian tomb walls of Amenophis II and Ramses II depicted water filtration systems as early as 1,500 B.C. It is also known that Egyptians used alum to accelerate the coagulation of fine particles so they could more easily be filtered – a process still applied today in many water treatment facilities. [2]

Around 500 B.C., Hippocrates developed a water filtration device known as the "Hippocrates Sleeve." It consisted of folded cloth bags that were used to further filter boiled water. Once again, without knowledge of microbes, the purpose was to cleanse the water as much as possible by reducing turbidity and odor. This water was often used for medical treatments. Ancient Greeks and Romans used several different methods to produce cleaner drinking water, including the use of cisterns to let particles settle, boiling water over an open fire, and filtering water through charcoal or ash. The Romans are also famous for their extensive aqueduct construction to keep water flowing from mountain streams to nearby cities. The invention of the Archimedes screw, basically a screw encased in a pipe, was also used to pump water.

Public water treatment remained largely unchanged during the middle ages. Then, in 1671, Sir Francis Bacon experimented with desalination of water using sand filtration. He was not successful, but his work renewed interest in water treatment. [3] Also in the 17th century, the Italian physician Lucas Antonius Portius provided details of a sand filtration method using three pairs of sand filters. Water would enter the settling compartment of the system after it had been strained through a perforated plate. [4] It is important to note that in the 1670s, innovation in the field of glass lenses led to the invention of the microscope by Antonie van Leeuwenhoek. Along with Robert Hooke, they made observations of “tiny animals” that are today classified as protozoa and bacteria. Eventually this led to the scientific realization that there was more to our water than just turbidity and odor.

Between the 17th and 18th centuries, filtration became the preferred water treatment method for many communities, and more town officials were considering the possibility of providing clean drinking to their residents. In 1703, French scientist Phillipe De La Hire suggested that every household in Paris should have a rainwater cistern and a sand filter. His system included a covered and elevated cistern, which could prevent the growth of moss and freezing. [5] In 1804, over 100 years after La Hire’s advice, the town of Paisley in Scotland debuted the first municipal water treatment plant in the world. This treatment plant used gravel and sand filters developed by Robert Thom to treat water, and the treated water was distributed manually through horses and carts. . As sand filtration technology improved, it became more viable (but still an expensive investment) for use in towns wishing to provide residents with a source of filtered water. Sand filtration methods evolved to include a pretreatment process of coagulation and sedimentation of particles, since a reduction of sediment reduced the load on the filter. Charcoal filtration was added to improve taste and odor. [6] In the 19 th century, a connection was made between recent cholera and typhoid outbreaks and water treatment. Significantly fewer cases of these diseases were reported in places where water had gone through a filtration and disinfection process using chlorine.

London passed the Metropolitan Water Act of 1852 to ensure that all water supplied to the city would be filtered. In America, it was not until 1972 when the Clean Water Act was passed. This legislation was designed to protect existing waterways from excessive pollution. At the time, the Great Lakes and the Chicago River, to mention a few, were severely polluted. In 1974, the Safe Drinking Water Act was passed. This law was designed to set standards for drinking water treatment, including acceptable maximum contamination levels of various pathogens and chemicals in water supply systems serving more than 25 people.

Clean tap water is now a reality for most people in developed countries. Having clean, treated water delivered to our communities and homes is a luxury that more than half of the world’s population enjoys. Per the World Health Organization, about 71% of the global population has access to a safely managed drinking water service. Unfortunately, that means over 2 billion people do not have access to clean water across the world (mostly in Africa and Asia). [7]

Outbreaks due to contaminated water still happen in the developing world. In 1993, the city of Milwaukee experienced a major outbreak of *Cryptosporidium* , a protozoan linked to runoff water possibly contaminated by cow manure. Over 400,000 suffered symptoms of gastrointestinal discomfort, and over 100 people died. The elderly and children are usually most at risk. *Legionella* is a common bacterium that can also cause illness. It can colonize in water storages or pipes, and is responsible for over 2/3 of bacteria-related illnesses through public drinking water. [8] In 2014, a switch in water supply and improper treatment of water caused corroded lead pipes to leech a substantial amount of lead into the public water system in Flint, MI. Public water treatment in developed countries still carries a very low risk of contamination, as systems are not always perfect and require extensive monitoring to insure public safety. The greatest concern for treated water lies in providing it to the over 2 billion people without it.

A Crash Course in Microbiology

Students will need a basic understanding of some elements of microbiology before embarking on a study to test the risks of consuming untreated water. While a typical third grader may be vaguely familiar with the concept of “germs,” it is safe to assume they have had no prior knowledge of the microbial world.

What are bacteria?

Bacteria are single-cell organisms that are neither plants nor animals. They usually measure a few micrometers in length and colonize in communities of millions. For example, a gram of soil can contain about 40 million bacterial cells and thousands of different species.

All living organisms can be broadly classified as either prokaryotes or eukaryotes. Bacteria fit in the prokaryotic classification. The major difference between eukaryotes and prokaryotes is their cell structure. Eukaryotes have a nucleus enclosed in a membrane as well as other organelles that serve various cell functions, while a prokaryote does not. Eukaryotes contain multicellular organisms such as plants, animals (people included), and fungi, but also single cellular organisms such as yeast and protozoa. In contrast, prokaryotes are only single celled organisms that do not contain a nucleus and they lack many of the organelles found in eukaryotes. Prokaryotes, also called bacteria, have a simple cell structure in which DNA floats freely inside a twisted thread-like mass called the nucleoid. Bacteria are typically much smaller than eukaryotes, yet their extreme number causes them to be the most prevalent lifeform on earth. [9]

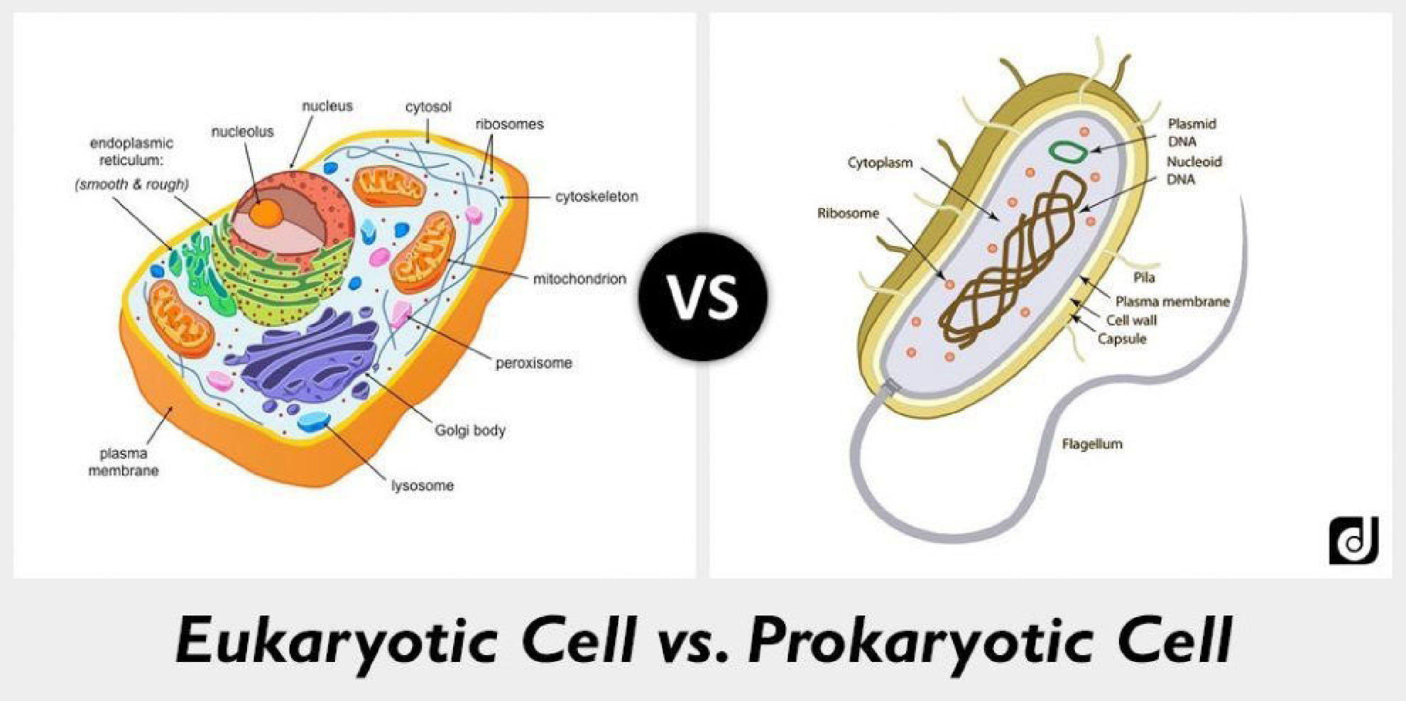

Figure 1. A comparison of eukaryotic and prokaryotic (bacterial) cells. Size is not to scale. Prokaryotic cells (typically 0.1–5.0 µm) are many times smaller than eukaryotic cells (typically 10–100 µm). Image from

https://www.differencebtw.com/difference-between-eukaryotic-cell-and-prokaryotic-cell (public domain). This size difference will be an important consideration when engineering a water treatment system.

Bacteria come in a variety of shapes, but the most common are variations of cocci (spherical), bacilli (rod), and spirilla (spiral). Some bacteria have one or more flagella used for movement, while others may use hair-like appendages called pili that help to stick to surfaces and transfer genetic material. [10]

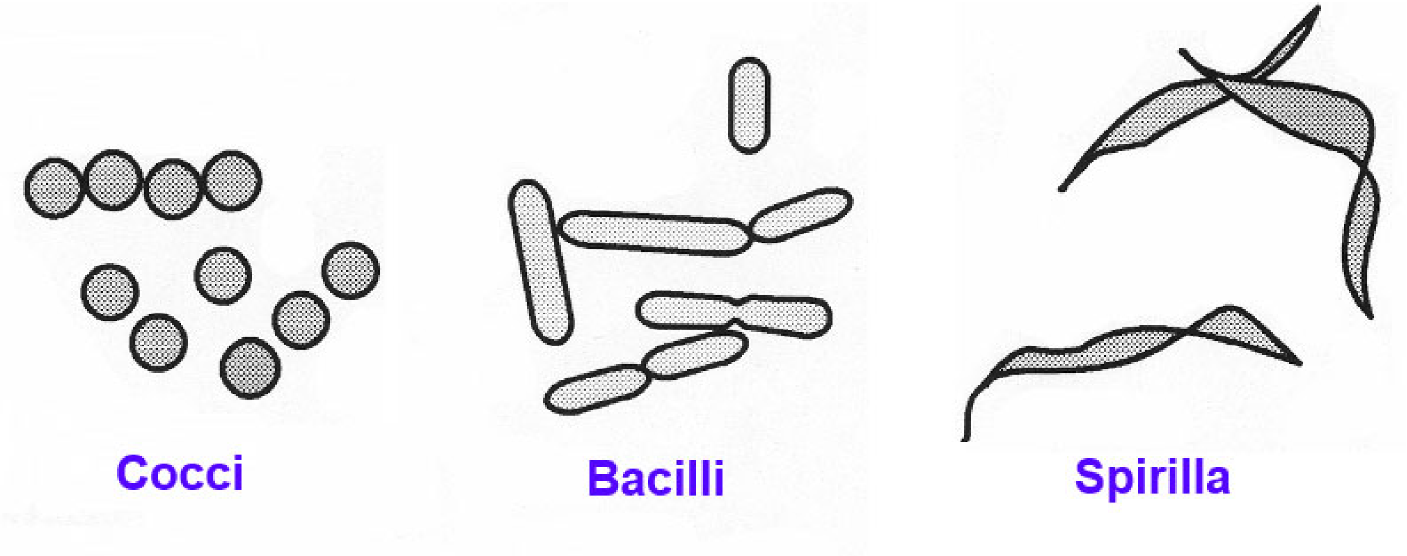

Figure 2. Three common bacterial shapes. Image from https://upload.wikimedia.org/wikipedia/commons/2/2e/Bacteria_shapes_01.png (public domain).

Some common diseases caused by bacteria include sinus infection, bacterial pneumonia, Legionnaires disease, typhoid, tuberculosis, cholera, and *E. coli* gastro intestinal infections and *Salmonella* diarrhea.

What is a virus?

A virus is either a single or double strand of DNA or RNA encased in a protein coat and are typically between 20 to 300 µm. Some viruses also contain lipid-based envelopes. Its sole purpose is to replicate and it is dependent on a host to do so. Therefore, a virus is considered a parasite, but because it cannot replicate on its own, viruses are not considered a form of life. Some viruses can cause illnesses and even fatalities, while others are harmless. [11] Viruses can infect all forms of life, including bacteria, fungi, and all multicellular organisms. Viruses are often organism specific, resulting in a virus infecting one type of organism, but not another. This explains why a cat or dog can contract a viral illness that has no ill effect on a person, or how bacteriophages (viruses that infect only bacteria) can be used to reduce bacteria on lunch meat.

Some common diseases caused by viruses include influenza, stomach flu, Ebola, AIDS, and the common cold.

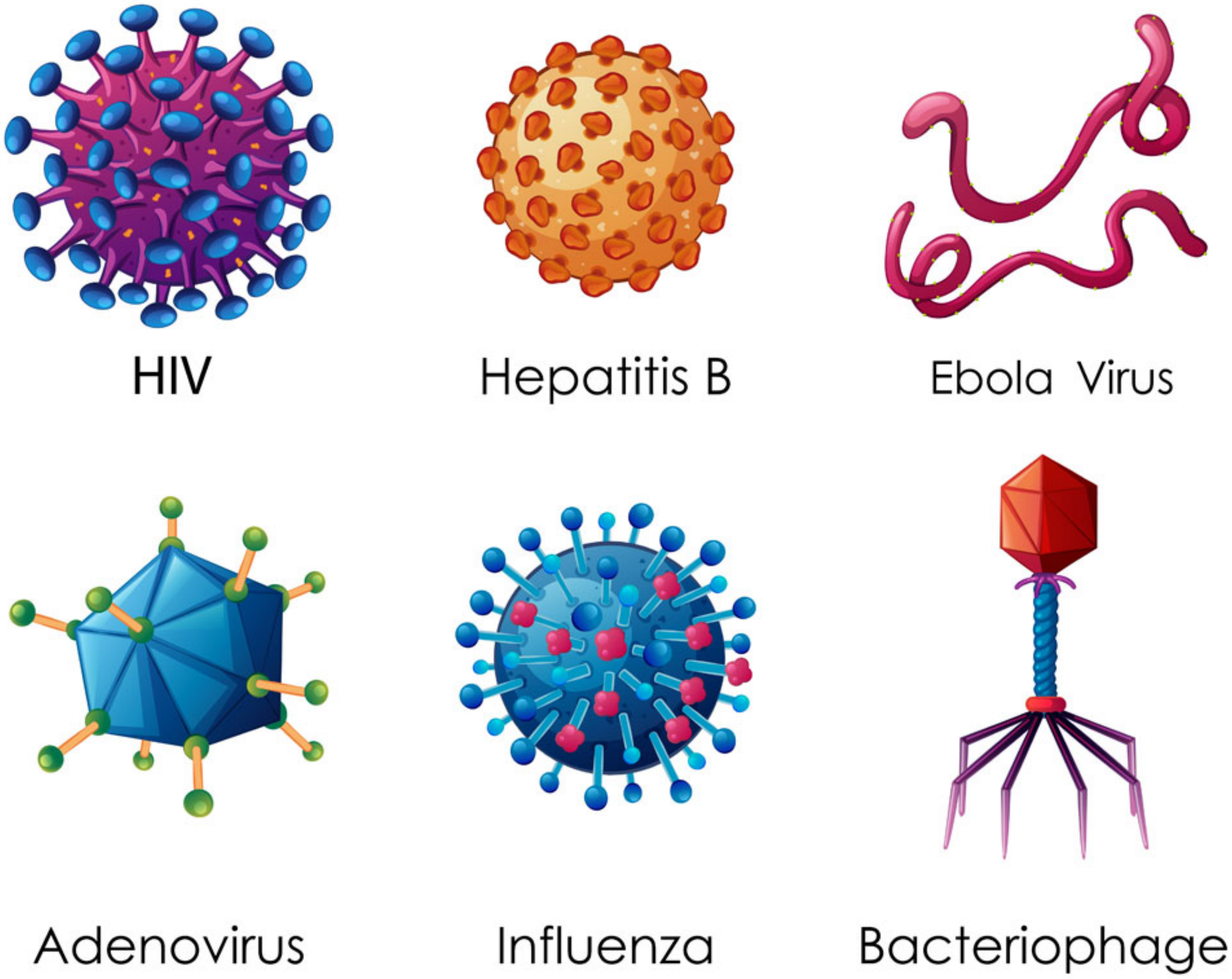

Figure 3. Six different viruses. Image created by Brgfx - Freepik.com.

What are protozoa?

Protozoa are single-celled eukaryotes that are distinguished by their almost animal like qualities of locomotion and consuming "prey." They range in size from 20 to 100 µm. [12] These are the creatures you might observe swimming in a sample of pond water under a microscope. Some protozoa live within a host as a parasite, while others can be free floating in water or soil. While they typically need a moist environment to survive, they can also live outside a host in their cyst stage. In the cyst stage, they can withstand extreme conditions such as high or low temperatures, exposure to chemicals, and lack of nutrients.

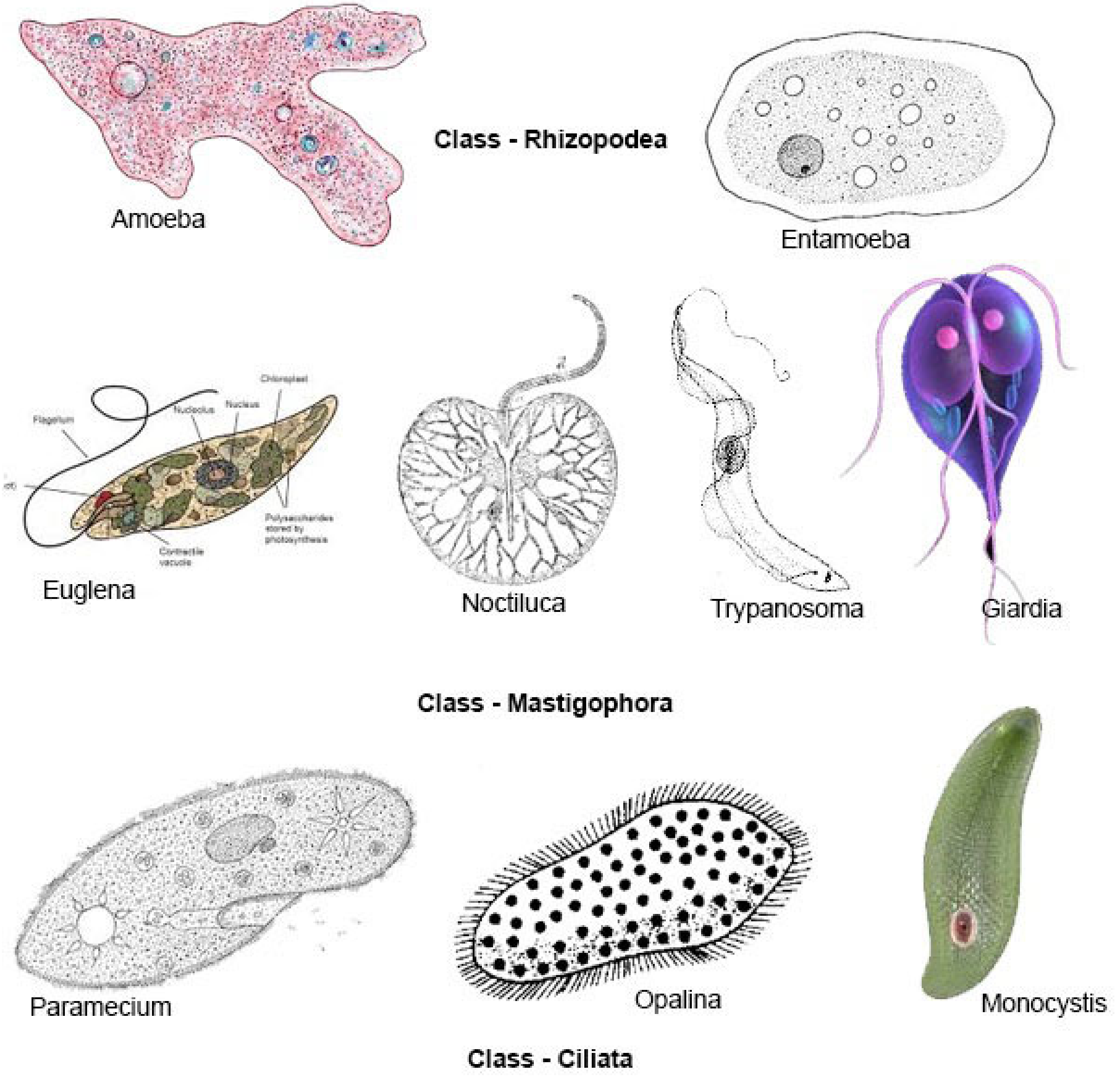

Figure 4. Nine types of protozoa. Image from bioweb.uwlax.edu (public domain).

Not all bacteria, viruses, or protozoa are harmful to humans. In fact, some types of bacteria are beneficial; they help process and digest food, train our immune system, and there is some evidence suggest they can help control inflammation. [13] Bacteria and protozoa are a food sources at the base on many food chains. Most types of viruses, protozoa and bacteria types are simply innocuous. In this next section, I will highlight some of the known harmful types of bacteria, viruses, and protozoa that a person could encounter through drinking untreated water.

Common Water-related Pathogens

A pathogen is a microorganism that can cause a disease. The following microorganisms are known causes of illness and death.

Escherichia coli (E. coli): We sometimes hear of an *E. coli* breakout on the news that is causing people to get sick. Unfortunately, *E. coli* has developed a bad reputation due to this exposure. The truth is, out of hundreds of strains of *E. coli* , only a few pose any threat. In fact, *E. coli* is one of the beneficial bacteria that aids in digestion and is found in the intestinal tract of mammals. Unfortunately, some trains of *E. coli* produce a Shiga toxin that can harm the intestinal tract and cause bloody diarrhea and kidney damage. Most cases of *E. coli* poisoning result from contaminated beef that has encountered fecal matter during processing or has become deposited onto produce by irrigating crops in contaminated wastewater. *E. coli* gets into the water supply through contact with fecal matter from untreated wastewater and is estimated to cause about 157,000 worldwide deaths each year, mostly in developing countries were sanitation systems are limited. [14]

Salmonella: Like *E. coli* , *Salmonella* spp. are another common type of fecal bacteria found in food or water. It can also be found on the skin of reptiles and amphibians. Salmonella can cause intestinal discomfort and diarrhea, and in some cases typhoid fever. It is estimated to cause about 215,000 annual worldwide deaths. [15]

Shigella: Shigella spp. are another type of fecal bacteria found in food or water. It infects only humans and primates, and typically causes severe diarrhea and cramps that can last from five to seven days. It is responsible for an annually estimated 74,000 to 600,000 deaths worldwide. Exposure to less than ten *Shigella* organisms is enough to be an infectious dose. [16]

Vibrio cholerae (cholera): Vibrio cholerae is responsible for the disease cholera, which kills an estimated 120,000 people a year. This type of bacteria is primarily transmitted through water and food. The toxin it produces causes severe diarrhea that can lead to extreme dehydration if untreated. Throughout history, there have been widespread cholera epidemics that have affected hundreds of thousands of people in single outbreaks. [17]

Giardia lamblia : *G. lamblia* is a type of protozoa that causes symptoms of nausea and diarrhea for about four to six weeks. As a cyst, it can live outside a host until it is transmitted to a human through animal contact, or through contact with contaminated food, water, or soil. As a trophozoite, it lives and feeds on the lower intestinal tract of infected humans or animals. [18]

Cryptosporidium parvum: C. parvum (commonly known as "Crypto.") is a protozoan that causes the disease cryptosporidiosis. Symptoms include diarrhea, abdominal cramps, and slight fever for up to one week. As a hardy cyst, it can last for months and is resistant to chlorine-based disinfectants. It can be passed from fecal/oral contact, as well as through contaminated soil and water (including swimming pools). [19]

Rotavirus: Rotavirus is an enteric virus that is highly contagious and difficult to prevent. It can even survive in water from nine to nineteen days. It produces stomach flu-like symptoms that can last for a week. Humans do develop an immunity to it, so chances of reinfection from the same type of rotavirus are low. Children are most susceptible to this virus and the best way to control it is through vaccination. [20]

Norovirus: While typically spread through direct human contact, this highly contagious virus can also be spread through contaminated food, water, and even air. There is no vaccine for norovirus, and symptoms include one to three days of vomiting and diarrhea. While most of the pathogens described above typically affect the developing world more severely, norovirus is also prevalent in developing countries as well. It is responsible for an estimated 685 million cases globally, with about 200,000 of those cases resulting in death. [21]

New Haven Water Treatment

There are ten reservoirs and three aquifers utilized for tap water in all of Connecticut, although over 80% of the water in New Haven comes from four local reservoirs according to Jim Hill, the project manager of Regional Water Authority. Each plant has a slightly different treatment process, but in general the same principles apply. Water is passes through several barriers designed to prevent large items, such as logs, fish, turtles, etc... from passing through. Alum is added to the water to expedite the coagulation and sedimentation of organic particles and turbidity. This solution is given time to settle. After this stage, the water from the top of the collection chamber passes through a filtration system. Next, the filtered water is disinfected with chlorine, and fluoride and phosphate (for corrosion control) is added to the water. The water is then ready for distribution through a network of over 1,700 miles of piping. Over 110,000 tests are done on more than 10,000 water samples each year to insure high quality water is delivered to every residence and business.

Engineering vs Science

> “Science is about knowing, engineering is about doing.” -Henry Petroski

The terms “engineer” and “scientist” are sometimes used interchangeably, but it is important to note that there is a big distinction between the two. A scientist pursues knowledge and understanding of the world through observation, research, and experimentation. An engineer, in contrast, concentrates on creating solutions to real world problems. An engineer will surely use scientific knowledge as part of his or her process as a tool. You can think of the work of a scientist being the guide for an engineer. The more complicated the problem, the more helpful the information provided by scientific research will be in engineering a practical solution. There is certainly an overlap between the two fields, but it is the engineer who will be solving the problem while the scientist helps the engineer understand the cause of the problem.

Lessons

Prior to teaching this unit, it will help if your students understand the hydrologic cycle and local watersheds.

Lesson 1: I find it is helpful to introduce a topic through a piece of literature. *Germs Make Me Sick* by Melvin Berger, the Kid’s Discover Series issue on *Microbes* , or *Tiny Creatures: The World of Microbes* by Nicola Davies are three recommended suggestions. After sharing the book, lead a discussion about what students know about “germs.” Use a KWL (three columns, what I Know, what I Wonder, what I Learned) chart to record student thoughts. This provides an excellent way to reveal prior knowledge and misconceptions. Simple questions such as “Why do we wash our hands before we eat?” or “What will happen if you drink dirty water?” can be asked to promote discussion.

Lesson 2: (can possibly be combined with lesson 1) In my STEM lab, I have access to several light microscopes, a digital microscope that can be attached to a document camera, and prepared slides that include several types of bacteria, worm eggs, protozoa, etc. If you have access to these materials as well, this would be an excellent opportunity for students to get an up-close look at several microorganisms. Prepared slides can be purchased from many different school science supply stores, and are also carried on Amazon.com. You can also create your own with blank slides and a drop of pond water, although prepared slides often produce better results. Students can record sketches of what they see under the microscope and label them on chart paper or in a lab notebook.

Lesson 3: Testing for bacteria coliforms, specifically *E. coli* . 3M produces a product called a Petrifilm. It is essentially a prepared petri dish on a paper card with a plastic cover. You may be able to obtain these for free directly from 3M since they are for use in a classroom. You want the version that tests for *E. coli* . It has a pink agar surface. To test for bacteria, give each student a Petrifilm and a sterile cotton swab. All they need to do is swipe the swab on a surface they want to test, and then swipe the swab on the pink agar. Cover it up with the included plastic sheet, and bacteria coliforms should appear within 24 to 48 hours. Students can count each coliform to get an idea of how much of these bacteria are present on the object they tested. *E. coli* will appear as a blue splotch per the 3M web site. Students will use this testing method later to determine if their engineered water filter is working to filter bacteria, but for now they should enjoy learning about the testing procedure and this gives them an opportunity to practice.

Lesson 4: Model water purification with calcium hypochlorite. This demonstration will show how particles in dirty water can congeal for easier filtration. You will need a packet of calcium hypochlorite, two buckets or clear containers, dirty pond water, two 3M Petrifilms, and two t-shirts or similar material. The calcium hypochlorite can easily be obtained through Amazon.com or other science retailers and is inexpensive. Have students observe the water, and then filter the water through a piece of cloth to remove any large particles. The water will still appear cloudy. Test the water on a Petrifilm and label it “untreated.” Add the contents of the calcium hypochlorite and gently stir. Allow the particles to congeal and settle over several hours. You will notice rust colored blooms that look like snowflakes in the water. This is the calcium hydrochloride at work, causing particles to congeal. After several hours, filter the water through a cloth. You might need to do this twice, although now the water should look clear. Run another test on the Petrifilm and label it “treated.” After 24-48 hours, you should see bacteria coliforms on the untreated test PetriFilm, while the treated Petrifilm should be free of bacterial coliforms.

Lesson 5: Model sand filtration. In this lesson, you will demonstrate how to construct and test a handmade water filter using gravel, sand, and activated charcoal.   The combination of these materials, in layers, will trap particles as the water percolates through them. This is a great method for making the water clear, but it does not necessarily purify the water by killing all microbial pathogens. Do not drink the water! In an emergency, however, this type of filter will reduce your chances of getting sick. A quick google or Pinterest search will reveal several ways to make a water filter in your classroom. You will need a two-liter bottle, gravel, clean sand (often sold as playground sand), activated charcoal (available at most hardware stores), cloth, and a container to catch the clean water. Start by cutting the bottom off the two-liter bottle, leaving the bulk of the body and neck of the bottle as one piece. Secure a piece of cloth (or coffee filter) to the small opening of the bottle with a rubber band. Then add an approximately two-inch-thick layer of activated charcoal, followed by several inches of sand, then several inches of gravel. Pour dirty water over the gravel. As the water percolates through the layers of gravel, sand, and charcoal, you will need a container to catch the clean water as it passes through. Use 3m PetriFilm strips to test the water for microbes before and after it passes through the filter. If you happened to be stranded on an island, you could make charcoal by burning wood and dousing it with water before it burns completely. Grind it into small pieces, then rinse it well. In this situation, it is much easier to buy activated charcoal at a hardware store.

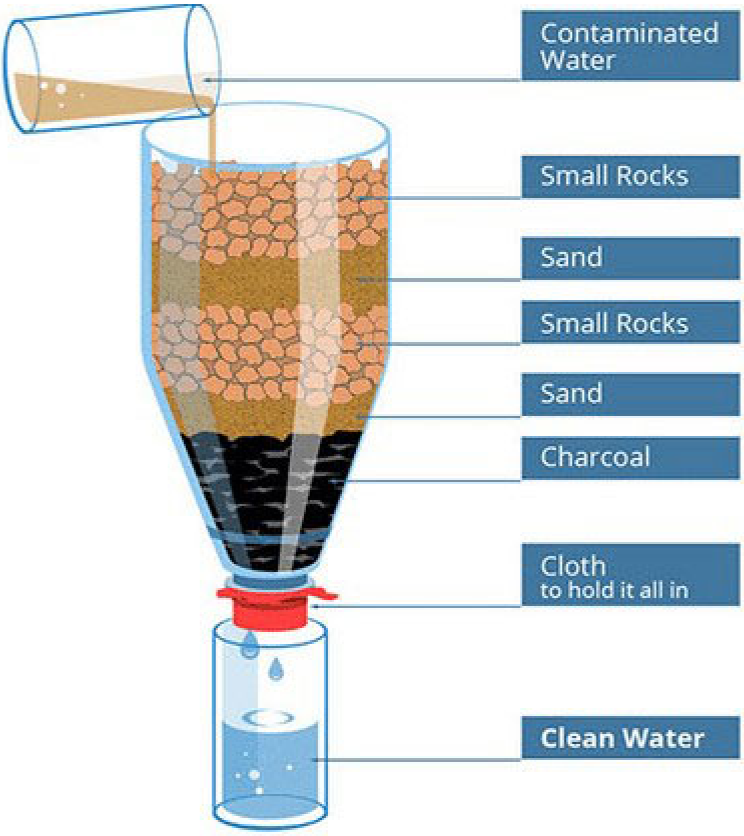

Figure 5. A basic water filter. Image from http://100-best-water-filters.com/build-water-filter/ (public domain).

Lesson 6: Engineering a Water Filter Project. In this final project, students will create a water filter much like the one modeled in lesson 5. Group students how you see fit. Given the situation that they are stranded on an island and need fresh water to drink, students will need to construct a water filter out of found materials. Provide students with sand, gravel, maybe some activated charcoal, and a variety of containers and materials that could be used as a filter. Having a large variety of materials to choose from should lead to more unique designs. Students will select from the materials and construct a water filter of their own design, then test the filtered water with 3M PetriFilm. In my STEM lab, the final project counts as either a pass/fail, but you could certainly develop a more structured grading rubric if you choose.

Teaching Resources

Recommended Read Aloud books

Germs Make Me Sick by Melvin Berger

Kid’s Discover Series issue on *Microbes*

Tiny Creatures: The World of Microbes by Nicola Davies

Activity Materials

The amount of these materials will depend on the number of students you plan to teach, so the number is based on a class of 25 students.

Microscope slides of various bacteria, viruses, and protozoa. Preferably types mentioned in the background information of this unit.

100 sterile cotton swabs (wrapped)

100 3M PetriFilm *E. coli* coliform plates (you might be able to get them directly through 3M for free)

2 four gram packages of P&G Purifier of Water (Calcium Hypochlorite)

Several large, clear containers for water (1-2 gallons).

10-20 pounds of playground sand (often sold in 50 pound bags).

10-20 pounds of rinsed aquarium gravel (often sold in 50 pound bags)

5 pounds activated charcoal

About a yard of cloth (cheese cloth preferred)

25 clean, clear 2-liter bottles (less if you have students work in groups)

Various materials for making water filter cases – canisters, pipe, plastic jars, etc.…

Notes

---

1. Angelakis, Evolution of Water Supply throughout the Millennia.
2. Angelakis.
3. “History of Water Treatment - Advanced Water Solutions.”
4. Juuti, Katko, and Vuorinen, Environmental History of Water : Global Views on Community Water Supply and Sanitation.
5. Angelakis, Evolution of Water Supply throughout the Millennia.
6. Angelakis.
7. “WHO’s First Ever Global Estimates of Foodborne Diseases Find Children under 5 Account for Almost One Third of Deaths.”
8. “Current Waterborne Disease Burden Data & Gaps | Healthy Water | CDC.”
9. “Difference between Eukaryotic Cell and Prokaryotic Cell.”
10. Murat, Byrne, and Komeili, “Cell Biology of Prokaryotic Organelles.”
11. Albers and Meyer, “The Archaeal Cell Envelope.”
12. “Water Microbiology - Bacteria, Microorganisms, Drinking, and Microbes - JRank Articles.”
13. Vidyasagar, “Bacteria: Definition, Types & Infections.”
14. “Current Waterborne Disease Burden Data & Gaps | Healthy Water | CDC.”

15. “Common Waterborne Bacteria and Cysts - Global Hydration.”
16. Yates, “Introduction to Introduction to Waterborne Pathogens Waterborne Pathogens.”
17. Yates.
18. Yates.
19. Yates.
20. Young, “The Most Common Pathogens Found in Water.”
21. “Current Waterborne Disease Burden Data & Gaps | Healthy Water | CDC.”

Bibliography

Albers, Sonja-Verena, and Benjamin H. Meyer. “The Archaeal Cell Envelope.” *Nature Reviews Microbiology* 9, no. 6 (June 1, 2011): 414–26. https://doi.org/10.1038/nrmicro2576.

Angelakis, Andreas N. (Andreas Nikolaos). *Evolution of Water Supply throughout the Millennia* . IWA Publishing, 2012.

“Common Waterborne Bacteria and Cysts - Global Hydration.” Accessed July 13, 2018. https://globalhydration.com/waterborne-disease/common-waterborne-disease-bacteria-viruses-cysts/.

“Current Waterborne Disease Burden Data & Gaps | Healthy Water | CDC.” Accessed July 13, 2018. https://www.cdc.gov/healthywater/burden/current-data.html.

“Difference between Eukaryotic Cell and Prokaryotic Cell.” Accessed July 13, 2018.

https://www.differencebtw.com/difference-between-eukaryotic-cell-and-prokaryotic-cell/.

“History of Water Treatment - Advanced Water Solutions.” Accessed July 13, 2018.

https://www.advancedwaterinc.com/history-water-treatment/.

Juuti, Petri., Tapio S. Katko, and Heikki S. Vuorinen. *Environmental History of Water : Global Views on Community Water Supply and Sanitation* . IWA Publishing, 2007.

Murat, D., M. Byrne, and A. Komeili. “Cell Biology of Prokaryotic Organelles.” *Cold Spring Harbor Perspectives in Biology* 2, no. 10 (October 1, 2010): a000422–a000422.

https://doi.org/10.1101/cshperspect.a000422.

Vidyasagar, Aparna. “Bacteria: Definition, Types & Infections.” Accessed July 13, 2018. https://www.livescience.com/51641-bacteria.html.

“Water Microbiology - Bacteria, Microorganisms, Drinking, and Microbes - JRank Articles.” Accessed July 13, 2018. http://science.jrank.org/pages/7311/Water-Microbiology.html.

“WHO’s First Ever Global Estimates of Foodborne Diseases Find Children under 5 Account for Almost One Third of Deaths.” Accessed July 13, 2018. http://www.who.int/news-room/detail/03-12-2015-who-s-first-ever-global-estimates-of-foodborne-diseases-find-children-under-5-acco unt-for-almost-one-third-of-deaths.

Yates, Marylynn V. “Introduction to Introduction to Waterborne Pathogens Waterborne Pathogens.” Accessed July 13, 2018. http://www.cws.msu.edu/documents/Yates_presentation.pdf.

Young, Mike. “The Most Common Pathogens Found in Water.” Accessed July 13, 2018. https://blog.katadynmilitary.com/most-common-pathogens-found-in-water.

Appendix

Implementing District Standards

While I designed this unit for my third-grade students, the truth is that understanding microbes is not anywhere in the Connecticut Science Standards for elementary grades – yet it is a topic that does have an impact on their daily lives. After all, there is a reason we aske them to wash their hands! While elementary students may not be required to know about microbes, that information is essential to building a successful water filter.

The nature of his unit, however, involves using scientific knowledge to engineer a solution, and this ties directly into the eight science and engineering practices laid out in the Next Generation Science Standards. Those eight practices are:

Asking Questions and Defining Problems

In this unit, the problem is unhealthy water, and the question is “how can we make it safer to drink?”

Developing and Using Models

A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. In this unit, students will construct a physical model of a working (hopefully) water filter.

Planning and Carrying Out Investigations

Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. In this unit, students will use what they have learned about microbes and water treatment to investigate how they can create a water filter.

Analyzing and Interpreting Data

Scientific investigations produce data that must be analyzed in order to derive meaning. In this unit, students will collect data in the form of a count of bacterial colonies. This data will be used to judge the effectiveness of a water filter.

Using Mathematics and Computational Thinking

In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; statistically analyzing data; and recognizing, expressing, and applying quantitative relationships.

Constructing Explanations and Designing Solutions

The products of science are explanations and the products of engineering are solutions. In this unit, the product is a working water filter.

Engaging in Argument from Evidence

Argumentation is the process by which explanations and solutions are reached. In this unit, students will argue whether a water source is “safe” to drink based on collected evidence.

Obtaining, Evaluating, and Communicating Information

Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity. In this unit, students will be able to analyze the effectiveness of their filter as well as the filters of others. They can also use this information to communicate safe drinking water practices to the public.