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Using Backpacking Water Purification Systems as a Means of Introducing Water Treatment Concepts to an Introduction to Environmental Engineering Course

Dr. Brenda Read-Daily, Elizabethtown College

Dr. Brenda Read-Daily is an Assistant Professor of Engineering at Elizabethtown College in Pennsylvania. She holds a BS in Civil Engineering from Bradley University, and a MS and PhD in Environmental Engineering from the University of Notre Dame.

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Abstract

Active and experiential learning activities are highly regarded for delivering engineering content. This paper explores an inexpensive hands-on activity where students purified lake water using backpacking systems as a way to introduce water treatment concepts in an Introduction to Environmental Engineering course. Teams of two students were given one of the following methods of water purification: membrane filtration, membrane filtration coupled with an activated carbon adsorption, ultra violet disinfection, iodine tablet disinfection, solar water disinfection (SODIS), or disinfection via boiling. As part of this assignment, students evaluated the treatment methodologies in terms of their cost, ease-of-use, energy requirements, time of treatment and efficacy. They made observations about the effectiveness of their particular method by inspecting the reduction color, turbidity, and odor. In addition, they kept track of the time it took to purify one liter of water. Students also calculated the amount of time it would take to purify the minimum amount of water necessary for sustaining a person in one day as recommended by the World Health Organization and assessed the appropriateness of using each of the technologies in the developing world. Following this class session, students researched their respective purification technique and reported back to the class on its mechanism for removing contaminants as well as its limitations. The students then collectively discussed the tradeoffs of each method and debated which one would be most effective under a range of conditions such as turbidity, volume needed, availability, and cost of materials. This activity was followed by in class lectures on water quality and conventional drinking water treatment methods, which were related back to the backpacking water purification techniques. Overall, these activities were successful in providing a meaningful and engaging way to introduce physical and chemical treatment processes while concurrently examining water quality issues in the developing world. Student feedback from these activities was positive, and students demonstrated proficiency of water treatment concepts on subsequent exams. Numerous students reported that the activity helped them understand the principles behind water treatment while also challenging their preconceived notions about water treatment technologies in the developing world.

Introduction

Inductive learning has repeatedly been shown to improve learning outcomes in engineering students. Inquiry-based learning is a type of inductive learning method where students are first presented with unanswered questions, unsolved problem, and observations without explanations.[1] Therefore, the student is responsible for generating questions, determining results, and formulating conclusions. These student-centered methods increase student engagement and tap into their intrinsic motivation. With these established methods in mind, the hands-on activity and corresponding assignments described in this paper were used to present new engineering content to an Introduction to Environmental Engineering class.

The lessons were inspired by the author's personal experience with purifying water while backpacking. Backcountry water purification methods use similar treatment principles as conventional drinking water where physical and chemical treatment techniques such as filtration, disinfection, and adsorption are commonly used. Additionally, the author's previous observations of students' lack of understanding of appropriate technology in the developing world led to some of the pre and post lab activities. The goals in these assignments were to:

- Introduce water treatment concepts in an engaged, hands-on way
- Acquaint students with centralized and decentralized water treatment approaches while showing how the underlying principles are similar
- Relate students with personal water use and link to global water use
- Contribute to the department's coverage of ABET outcome h "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context"

Studies show that Millennial students have a strong inclination to help others.[2] In a survey administered on the first day of class students indicated interest in the developing world with one student citing her experience of building schools in Africa as a reason for becoming an engineer. In particular, some students expressed a desire to provide safe potable water. However, the students generally lacked understanding of the methods, economics, and sociological factors involved in providing potable water. Therefore, these activities were intended to tap into their intrinsic motivation as well as bridge some of these gaps by providing knowledge on water quality, water treatment technologies, and appropriate technology for developing versus developed world.

Students learn more effectively when they can make connections between the old (familiar) and new (unfamiliar) ideas[3]. While not used everyday, most students are familiar with backpacking water treatment systems. The hypothesis in this study was that students could more readily learn about water treatment processes when they could relate to filtration devices that they had seen or read about before. Previous reports detail methods of incorporating everyday products or other familiar systems that students are lessons in engineering classes. At North Carolina A&T University instructors used a basic water filtration pitcher to illustrate the concepts of adsorption and ion exchange.[4] Students evaluated different brands based on their flow rate, pH, and sediment size distribution introducing those concepts in an introductory mechanical engineering laboratory.[5] Environmental engineering students at Rose Hulman Institute of Technology, constructed wetlands that fit within a greenhouse to aid in the learning of biogeochemical processes.[6]

This series of lessons presented in this paper were implemented in an Introduction to Environmental Engineering course at a small, private, Liberal Arts College with approximately 1800 undergraduate students. The college is primarily residential, and the large majority of the students being eighteen to twenty-two years old. The Department of Engineering, with 170 students, offers an engineering degree with concentrations in mechanical, electrical, and sustainable design. No civil or environmental engineering degree or concentration is currently offered, but students may take several civil/environmental courses as part of the sustainable design concentration or as free electives.

The class where these activities were implemented consisted of fifteen students: three sophomores, ten juniors, and two seniors. A few of these students expressed interest in pursuing a career in environmental engineering with the remaining having a general interest in sustainability. The class counted for three credits with no laboratory component and met twice a week for eighty minutes. This course was offered for the second time in the spring of 2015, and at that point, few pieces or equipment were available for conducting traditional water quality labs. Therefore, the lessons described in this paper were designed to be inexpensive and easy to implement with minimal facilities. As at many other institutions, this marked the first time first students were presented water treatment technologies in a formalized setting.

The series of lessons were conducted beyond the midpoint of the semester prior to the water and wastewater treatment units. Students had recently learned about physical, chemical, and biological water constituents and why certain water contaminants are a threat to human and ecological health. The lessons were implemented over the course of three weeks with traditional lectures and classroom exercises interspersed. The key lesson objectives for the presented activities were to primarily provide an introduction to water treatment concepts and technologies but also acquaint them with the challenges of providing appropriate technology in the developing world. Students were to observe the correlation between level and cost of treatment.

Methods

As a first activity, students completed a brief survey in class on how much water they guessed that they used each day, and more specifically, how much they needed for drinking and basic hygiene (hand washing). They were tasked with conducting a personal water audit as a homework assignment. In this assignment, they estimated their water use/consumption over the course of a week by recording the length of their showers, amount of time spent washing hands, dishes, or brushing teeth along with the time spent showering and how much they drank. Students were given flow rates for sinks and showers, and amount of water used per urinal or toilet flush. Students totaled up these values and determined an average water use calculation per day. This first assignment was intended to acquaint the students with the frequency and quantity of water they relied upon for their daily lives. In addition, the students were tasked with completing a water audit online using waterfootprint.org. The online water footprint assessment is different from the personal audit in that it takes a more holistic look at water use by accounting for such factors as income level, transportation use, and food consumption.[7] In order to bridge the two tasks, students were asked to compare their results from each analysis and discuss why one estimated a larger amount than the other.

In another class one week later, the students performed this hands-on activity using a physics laboratory equipped with a sink. Water collected from an on-campus lake served as the water to be treated. Each student partnered with another and was given a box with an unknown water purification method. They were told that they would be purifying water using the method in the box, and that for the remainder of the class they needed to purify the water recording details on the length of treatment time, the ease of use, the quality of the water before and after. They made observations about the water quality before and after completing a report sheet. Following the in class activity, the students were instructed to research their particular water purification determined the mechanism through which it improved the water. They also determined the limitations of the technology such as its efficacy at removing bacteria, viruses, protozoa, turbidity, sediments, and tastes and odors. They calculated on the cost to treat one liter of water, and reflected on which scenarios would be most appropriate for each of the purification methods used in class.

In a follow up class, the instructor created a table that the class collectively completed that included the method, whether the method was effective at removing various contaminants. A guided discussion on water quality and the biological, chemical, and physical contaminants that contribute to water quality ensued.

Seven purification in total were used: solar water disinfection (SODIS), ultraviolet (UV) disinfection using SteriPEN, membrane filtration using the LifeStraw family size hanging filter, boiling, filtration using a Katadyn filtration system, another hollow fiber membrane by Sawyer, and iodine tablets. Each method is described below. Five of the purification methods were either purchased from Amazon.com, but could be purchased from a backpacking or camping supply store. The remaining two methods were assembled using common laboratory supplies such as hot plates and glass beakers and an empty plastic liter bottle.

Table 1. Summary of Implemented Water Treatment Methods

Purification Method	Purification Mechanism(s)	Source or Materials	Cost
SODIS	UV disinfection and thermal heating	Clear 2-liter emptied and cleaned soda bottle	Negligible
Sawyer PointOne Squeeze Water Filter System	Membrane filtration	Purchased on Amazon	$31.94
Katadyn Vario Water filter	Membrane filtration, activated carbon adsorption	Purchased on Amazon	$61.00
SteriPen Traveler	UV disinfection	Purchased on Amazon	$39.97
Potable Aqua Water Treatment Tablets (50 pack)	Chemical disinfectant	Purchased on Amazon	$5.99
Boiling	boiling	Hot plate, glass beakers	variable
LifeStraw Family	Membrane filtration	Purchased on Amazon	$69.99
		Total	$208.89

SODIS

While not widely practiced, solar water disinfection (SODIS) is an inexpensive method of and effective method of purifying water in the developing world. It involved filling a clear two-liter bottle with the water to be purified, placing it in the sun or a sunny window for six or more hours and allowing the UV light to disinfect the water. A black piece of paper or cloth can be attached to one side of the bottle to further heat the water and enhance the solar disinfection. Also, placing the bottle on a reflective surface can increase the amount of UV light absorbed by the water. This method is appealing in that it is inexpensive uses only a few materials which are readily available in the developing world.[8] However, its tradeoff is that it dos not remove other contaminants or tastes and odors.

LifeStraw

The LifeStraw products are promoted for both backpacking and developing world scenarios. One product is designed for people to carry around on a necklace and suck up water through the filter that is safe. Each LifeStraw costs around $79 and can be used to filter up to 18000 liters without replacing any materials. Since the activity was not designed for students to drink the water, another LifeStraw method was selected instead. The LifeStraw family consists of a reservoir that holds the untreated water. By gravity, the water travels through an eighty micron pre-filter and then through a hose to a 20 nanometer pore size hollow fiber membrane filter.[9]

Katadyn Filter

The Katadyn filter is marketed to backpackers and utilizes a combination of a fine media filter with carbon to remove pathogens as well as tastes and odors. The user inserts tubing into the water source and pumps the water through a tube through the filter. The filter water is collected in a receptacle such as a bottle.[10]

Boiling

A hotplate and glass beaker were provided. Students added the untreated lake water to the beaker, and then boiled the water for 1 minute as recommended by Center for Disease Control.[11] Boiling is effective at disinfecting water but does not remove other contaminants and does not improve tastes and odors.

Iodine Tablets

Aqua Potable iodine tablets were added to the untreated water and the manufacturer's instructions were followed. The tablets consist of 6.68% titratable iodine. The iodine acts as a germicide by oxidizing cell proteins and protoplasms associated with waterborne diseases. The tablets cost $0.12/tablet and treats 0.5 liters of water.[12] Like boiling, the iodine tablets merely inactivate pathogens and do not remove other contaminants. Iodine tablets are only to be used during short-term scenarios.

Sawyer Pointone Squeeze Water Filtration System

The Sawyer Pointone Squeeze Water Filtration System works by filtering untreated water through a 0.1 micron filter. Purified water passes through the filter while contaminants such as bacteria and protozoa are removed. Untreated water was added into the bag, and students carefully rolled the top of the bag, which built the pressure to drive the water through the filter.

The Sawyer Pointone system uses a hollow fiber membrane, which consists of a collection of hollow fibers with tiny pores. The purified water travels through the tiny pores and down the fiber where it is collected together and runs through the bottom.[13] Like the LifeStraw and Katadyn systems, this method is comprehensive as it removes a range of contaminants.

SteriPEN

The SteriPEN is a UV light pen that inactivates pathogens. The light is added to the untreated water and must stay immersed in the water for 90 seconds when treating one liter of water.[14]

Results

Week 1 Pre-laboratory activity

In a survey administered at the beginning of class the students were asked to guess their average per capita consumption. The average estimate was 255 L/d (Table 2) but answers varied widely from 7.6 L/d to 760 L/d. They also guessed that the water they use each day costs $50. Once again, the estimates varied dramatically from $0.67 to $200 per day. This activity illustrated the students' lack of awareness of their personal water use and the cost of tap water.

Table 2. Student Survey, Personal Water Audit, and Online Water Footprint Calculator

Students' Reported Values	Class Average
Initial Survey Responses for daily use	274 L/d
Personal Water Audit	244 L/d
Water Footprint Calculator	3690 L/d

In the same class period, the students were assigned homework where they were required to monitor their water use over the course of a week. Additionally, they completed an online water footprint. Using the online water footprint calculator, the students found their daily usage was 3690 L/d, nearly fifteen times larger than their initial guess or their tabulated value. The students critiqued the online calculator because it asked for such values as income and the amount of times dishwashers were used. The students found these not to be relevant as they are college students and many of them only have summer jobs, internships, or work-study jobs as sources of income, and they were not sure whether they should use their own income or their parents. However, the students did find it informative as factors such as food and transportation made a major difference. One student commented, "I was surprised by how much food production contributes to water footprints. When we buy food that's been shipped from other states and countries, we're tapping into distant and often limited water supplies." Another student noted, "One of the major things I did not factor in was all the water needed to process the food I eat."

Following the discussion of the class's results, the instructor described the World Health Organization's quantity of water required for life in the developing world at 7.5 L/d.[15] Students were surprised to learn how little water was considered necessary given their own calculations of personal use. One student commented, "I think this project did a good job of showing how dependent we are on water and how much we actually use on a daily basis."

Week 2 – Laboratory activity

The following week the students conducted the water purification activity in class. The students enjoyed the element of surprise of picking a cardboard box with an unknown water purification method. They noted that doing an in class activity was not only more enjoyable than learning through a lecture-only class, but also improved their understanding of drinking water concepts. One student noted, that they liked having to research their own water treatment method and having to report on it in the following class.

The instructor observed that students were highly engaged throughout the class period. Groups of two appeared optimal as partners were able to discuss the water treatment method together with one giving instructions while the other worked the purification method. Some of the treatments took minimal time so they were able to research the methods while they had down time. When students had finished their water treatment method, they were able to pour out their treated water in the sink. The group who selected SODIS located a suitable windowsill for locating their water bottle.

In the follow up assignment, students reported their findings to their classmates in the following class (Table 3). They determined that the most expensive method was the iodine tablets at $0.24/L and the least expensive was the SODIS assuming a plastic two liter bottle was available for free. However, the students debated the cost of the boiling method as boiling involves using a fuel source, and depending on the source and the efficiency of the heating unit, the price could vary significantly. One aspect of the cost that the students noted was that the upfront cost for some of the purification devices was cost prohibitive for someone in the developing world, despite the longevity, and price per liter of water treatment.

Table 3. Students Results from Water Purification Laboratory

Purification method	Cost per liter of water treatment	Time to treat one liter	Does the method reduce turbidity?
SODIS	$0.00	9 hours	N
Sawyer Hollow Fiber Membrane	$0.01	1 min	Y
Katadyn Water filter	$0.04	22 min	Y
SteriPEN	$0.02	6 min	N
Iodine tablets	$0.20	35 min	N
Boiling	$0.02-$0.10*	1 hr	N
Lifestraw	$0.004	10 min	Y

*Depends on the efficiency of heating source and type of fuel

The students considered the ease of use, treatment time, cost, and overall efficacy of to determine which method was best in the developing world. They were split between SODIS and boiling as being the best method in the developing world. Some argued that while boiling required the cost of fuel, fire that was already used for heating or cooking could be used, thus making it highly effective at a low overall cost. Others chose SODIS because it only requires sunlight and a plastic bottle while still doing a reasonable job of reducing pathogens. However, they noted that both methods did little to remove discoloration or other contaminants. The students also mentioned that all methods required different types or levels of energy.

Relating the Decentralized to Centralized Approaches

During subsequent classes, the water purification methods used in class were related to water treatment concepts discussed during lecture (Table 4). The SteriPEN and SODIS were related to UV disinfection used as a final step in water and wastewater treatment processes. (Table 4) While chlorination and chlorine dioxide or frequently used methods of disinfection in North American water supplies, there was not a safe hands-on method of using these in class. Therefore, the iodine tablets were related to these chemical processes, as iodine works by chemically oxidizing cell components. The Concentration/Time (CT) or Intensity/Time (IT concept) were related back to the SteriPEN and iodine tables by discussing how that as the concentration of chemical oxidant (iodine) or intensity of light increased, less treatment time is required. When the concentration or intensity was less, the treatment time must increase in order to achieve the same level of disinfection.

Table 4. Water Treatment Approach and Treatment Mechanisms

	Disinfection		**Filtration**		**Adsorption**
Approach	UV	Chemical Oxidation	Gravity	Pressure	
Decentralized	SteriPEN SODIS Boiling	Iodine tablets	LifeStraw	Sawyer Squeeze, Katadyn	Katadyn
Centralized	UV lights	Chlorination, Chlorine dioxide	Media filtration	Reverse Osmosis	Activated carbon

The carbon filter in the Katadyn filter was used to introduce students to the concept of adsorption. Likewise, when describing membrane processes and reverse osmosis, LifeStraw Family and Sawyer hollow fiber membrane products were used as analogous examples.
While boiling water, is not commonly used as method for large-scale water purification, students were familiar with boil orders when municipal water supplies become compromised. Students were also told that the turbidity or the suspended solids content in the water impacts the efficacy of the disinfection process. Students demonstrated their understanding on a follow up exam covering water treatment with all students performed well (4 out of 5 or better) on a conceptual short answer question involving the different types and stages of water treatment processes.

Discussion/Conclusions

The laboratory activity, assignments, and class discussions proved beneficial to the students as it allowed students to explore water treatment concepts using backpacking or emergency water treatment methods. The in class water filtration day coupled with the surveys and questions aligned well with the course lectures. The students responded positively to the activities, and demonstrated a better understanding of water treatment concepts as evidenced by classroom conversation and exam results. Students demonstrated the relationship among cost of treatment and level of treatment as well as the appropriateness of certain technologies in the developing world and gave them insight into the challenges surrounding providing potable water.

The instructor plans to repeat this activity with a heavier emphasis on reflections and have the students report on their drinking water technology in a more formalized fashion. Also, the instructor plans to require students to research common contaminants as another bridge to the water quality portion of the course. Additional plans include some different drinking water treatment methods such as the addition of alum as a coagulant and possible integration of the three-pot water treatment method.

As an alternative, this activity could be used in the first week of class a way of introducing course content or prior to a water unit in an Environmental Engineering class. It also could be adapted for an outreach activity. Additionally, these activities could be expanded if basic water quality analysis equipment is available. For example, the water could be assessed pre and post purification so students have more quantitative data to factor into their assessment. Measurements such as turbidity, suspended solids, total dissolved solids, biochemical oxygen demand (BOD), coliforms, and nitrate could be conducted as part of the class and also serve as a method of introducing those contaminants. Another possible option is to make this set of exercises a multidisciplinary effort, where students taking an environmental course in sociology or philosophy such as Population and Global Issues or Environmental Ethics complete the tasks together and engage in debates using frameworks common to those courses

Overall, the backpacking water filtration activity coupled with the personal water assessment is a highly effective to introduce water concepts in a student-centered manner. The presented activities are highly adaptable and easy to implement. At under $210 for all five backpacking water treatment products were also inexpensive, and the large majority of the items can be reused in future classes.

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