AC 2008-449: ADAPTIVE WATER LABORATORY FOR K-12 OUTREACH ON SUSTAINABLE WATER USE

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Adaptive WaTER Laboratory for K-12 Outreach on Sustainable Water Use

Abstract

Over one billion people worldwide do not have access to a safe, reliable source of drinking water. Of these, up to five million will die each year of waterborne diseases due to unclean water sources and poor sanitation and hygiene[1]. As part of a capstone senior design project, an educational device was created to teach students in developed and developing nations about the environmental impacts of water contamination and to promote sustainable water utilization. To accomplish this goal an interactive, educational, cost-effective water purification system, known as the Adaptive Water Treatment for Education and Research Laboratory (Adaptive WaTER Lab), was developed. The design includes six different purification methods contained in individual housings that can be connected and reordered to create multiple purification solutions. The purification methods selected for this project include: sediment filtration, carbon filtration, chemical disinfection, reverse osmosis, forward osmosis, and ultraviolet light disinfection. Accompanying educational materials include lessons on contaminants, background information on the methods, seven laboratory experiments and study questions. The Lab has been demonstrated to over 300 students at several Houston-area schools (3rd -12th grade), thus disseminating knowledge on sustainable water use while receiving valuable feedback to improve the design. In addition to interactive demonstrations by students from Rice University, the system has been independently used by high school students in Houston for an Earth Day presentation. The use of the Adaptive WaTER Lab for an independent project, supervised by the authors and carried out by an underrepresented minority high school student, will be discussed. The student determined the effectiveness of the various purification techniques for removing contaminants ranging from dirt and sediment to chlorine and bacteria. Also, the student compared the various techniques based on the rates of production of clean water, operation costs, energy efficiencies and sustainability.

Introduction

A senior capstone design project was undertaken in the 2006-2007 academic year to create a device for use as an educational tool for water quality and purification. Inspiration for the project came from the fallout after hurricane Katrina. The project eventually lead to the founding of a long-term water project for education and implementation in developing nations, where potable water is scarce[1]. Initially, the project built on a collaboration with Schlumberger Oilfield Services, Inc. via their nonprofit Schlumberger Excellence in Educational Development (SEED) Foundation. SEED supports nearly 200 schools around the world by providing power, air-conditioning, heating, and educational tools including computer labs and internet access[2]. Working with the existing SEED Water Project, which focuses on water quality testing, five Rice University senior mechanical engineers developed the Adaptive Water Treatment for Education and Research (WaTER) Laboratory (henceforth referred to as the Lab) under the supervision of two Rice University faculty members, Drs. Houchens and McStravick. The project has since become independent, extending the scope to educational outreach in the greater Houston area. The first such implementation has been through integration into science fair and science club programs at a Houston public high school. Through new partnerships with the Rice Beyond

Traditional Borders[3] and Rice 360° programs, the scope of the project now includes service projects to developing nations in Africa, Latin America and the Caribbean, as discussed below. These include both educational and community scale water purification efforts, which build off current work through an EPA P3: People, Prosperity and the Planet grant[4].

Adaptive WaTER Laboratory

The partnership with Schlumberger introduced several design requirements. For example, the project was to fit inside of the existing SEEDPack, a backpack that includes solar panels to power battery chargers and educational tools[5]. The SEEDPack can provide 1.5 watts from each of its three solar panels. Additionally, as the project was to be deployed in developing nations, it had to be reasonably low cost, and could not rely on electrical infrastructure. Only human power and the SEEDPack solar panels were acceptable sources of energy. The cost of the kit, limited to $1000, had to support not only the initial materials, but also sufficient replacement parts to be used heavily for roughly a year.

The Lab was to provide as many different purification methods as possible, in addition to addressing the many different ways that the purification methods can work together. Arising from this idea were the requirements that the filtration methods be independently housed, and be easily connected and disconnected in series. This setup would allow students to use one kit to create a variety of experimental water purification systems, and test both intermediate and final output water qualities.

The final design of the Lab came to be six independently housed purification methods: sediment filtration, activated carbon filtration, reverse osmosis (RO) filtration, chemical treatment, forward osmosis (FO), and ultraviolet (UV) purification. The sediment filter is used principally as a pre-filter for the rest of the purification methods, removing larger particles from the water, of a nominal size of five microns. The nominal rating of the filter indicates that about 80% of particles larger than five microns will not pass through the filter. The carbon housing is also used as a pre-filter, removing chemicals like chlorine and heavy metals such as mercury from the water[6], and also serves as a secondary sediment filter, with a nominal rating of 0.5 microns. The carbon filter works by passing water through a charcoal like substance, known as activated carbon, which bonds to chemicals in the water and binds them to the filter. The porous structure of the carbon filter provides a large surface area for the water to pass over, making the filter highly effective at removing many contaminants that were left by the sediment filter. The carbon filter also can be used after chemical treatment, which noticeably eliminates the smell of chlorine, making it a useful classroom demonstration.

The chemical and UV treatments destroy or neutralize biological contaminants including bacteria and viruses. Both require pre-filtration to reduce turbidity for effective sterilization. How each chemical disinfects depends on the chemical and the pathogen being attacked. Typically chlorine tablets are used in the chemical disinfection. For bacteria and other microorganisms, chemicals can either rupture the cell wall or diffuse through the cell wall and cause the pathogen to disintegrate from the inside out. Chemicals break up important bonds, which may prevent protein production or negatively affect membrane fats. Chemicals also disrupt chemical bonds in viruses by destroying their protective shell, preventing protein production, or other methods[7].

UV purification works similarly, attacking the building blocks of bacteria, viruses, and other pathogens, disrupting their ability to reproduce or manufacture essential proteins, by destroying the pathogens' DNA or RNA. Two rechargeable AA batteries provide power to the UV sterilization unit. These can be recharged using the solar backpack.

The RO filter is used to remove particles smaller than what the carbon filter can remove, including bacteria, viruses, and even parts of viruses. This removal is accomplished by forcing water through very small pores, of a nominal rating of 0.0009 microns, which requires a high pressure differential to force the water across a concentration gradient (from concentrated contaminated water on the exterior of the membrane, to dilute clean water on the interior). RO does require pre-filtration[8] in order to function properly. Sediment filters remove large particles that can clog the RO membrane, and the carbon filter removes chemicals that can damage the membrane. Finally the FO filter can remove all contaminants, from dirt to viruses, without pre-filtration. FO filtration doesn't require a pressure differential, because of the favorable concentration gradient. The contaminated water on the exterior of the FO pouch is dilute with respect to the thick syrup placed in the inner portion of the pouch, driving pure water across the membrane by osmosis.

The prototype housings were created primarily from standard PVC components, ensuring that the different housings would fit securely together. Sediment and carbon filters were housed in nearly identical PVC housings. The RO housing is built from PVC and PVC bar stock, and the UV and FO housings are created from acrylic and PVC parts. Chemical treatment does not require a special housing, as it is simply a tablet added to the outlet container for the system. The actual design of these housings is best described through Figures 1 through 4, below. Machine drawings are available by contacting the authors.

For safety concerns and logistical reasons, the Lab itself is not currently designed to generate drinking water. While combinations of fast acting methods could produce safe, potable water (sediment filtration, followed by chemical sterilization, followed by carbon filtration) the most direct method would be to simply use RO filtration. However, flow rates through the RO filter are far too low using pressure generated by children with a bike pump to produce more than a few milliliters per hour. The Lab is, however, an intriguing teaching aid, keeping students engaged via interactivity[9]. Supporting documents were developed to allow students to walk themselves through various combinations of purification methods. These documents describe suggested experiments that allow the students to gain a deeper understanding of what each water purification method does to the water. For example, the sediment filter may remove dirt from water and make it look clear, but harmful chemicals and biological contaminants could still be present, so the student is advised to run the water through the sediment filter and then test for these chemicals and bacteria using test kits that are included in the current SEED Water Project. The housing can also be assembled in inefficient setups, allowing students to learn from mistakes. If a carbon filtration is chosen as the first step and is followed by a sediment filtration the students will observe lower overall flow rates (due to clogging of the carbon filter). Also, this inefficient combination makes it is possible to reintroduce chemicals that might be suspended in the sediment filter following carbon filtration, negating the purpose of the carbon filter. These would be detected through chemical tests, allowing for trial-and-error learning. Further details of the testing, including bacterial tests, can be found in Beach *et al*.[9]

Figure 1: Sediment and Carbon Housing

Figure 2: RO Housing

Figure 3: FO Housing

Figure 4: UV Housing

The originality of the Lab has lead to a patent application recently being filed. A patent will allow for production of the Lab for dissemination to other institutions for use as an outreach tool. The inventors will donate proceeds generated from sales to build additional Labs for donation to schools in developing nations.

Implementation in Educational Outreach

The Adaptive WaTER Laboratory was used in the spring of 2007 to introduce students in Houston area schools to the intricacies of water treatment. The five Rice University seniors involved with the project demonstrated the Lab to roughly 300 local area students ranging in age from elementary school to high school, both on the Rice campus and at their own campuses. The majority of the students that the project was demonstrated to were from underrepresented minority groups, predominately Hispanic and African-American, with many classified as "at-risk" or qualifying for reduced-price lunch[10]. The aim of this outreach was less to demonstrate the Lab itself, and more to generate interest among these students because of the concerning numbers of minorities entering science, technology, engineering and math (STEM) fields. The idea for the local outreach program came out of a study that suggests that involvement by college students with grade school students is an effective means of generating student interest in STEM fields[11]. This program utilized existing relationships from the **D**.**R**.**E**.**A**.**M**. (**D**esigning with **R**ice **E**ngineers – an **A**ustin High School **M**entorship) mentoring program developed by one of the authors at Stephen F. Austin High School, a public school in the Houston Independent School District (HISD)[12].

During the presentations the students were asked to participate with the setup and execution of the experiments. The interactive nature of the Lab generated a frenzy of volunteers from the crowd of elementary school students (Figure 5), and although the high school students weren't as active, they too volunteered to work with the Lab. Working with and observing the Lab generated questions among many students regarding not only the science behind the Lab, but also the design of the Lab housings. One elementary school student asked us if there was an issue with the UV light destroying the housing. This actually prompting a reevaluation of the housing by the inventors, and it was found to be sufficient for the amount of UV exposure it would receive. In addition to the presentations, in the spring of 2007 two high school students used the sediment and carbon filters at an Earth Day fair, successfully demonstrating the capabilities of these two filters to younger students, their peers and teachers.

Figure 5: Cornelius Elementary Students Interact with the Adaptive WaTER Laboratory

Work this year involves the Lab for more aggressive projects. The lab has been used by a high school senior interested in water purification. The work on the project has been supervised by a Rice graduate student in hopes of introducing STEM fields as viable education paths. Such outreach has proven effective in previous studies[13,14]. As a means of assessing the educational value of the Lab, a set of questions was compiled to determine the level of understanding of the terminology and function of the various water purification technologies. The 25 question assessment was administered prior to introducing the Lab and the written materials associated with it, and again following a study of the lab materials and interaction with the Lab components. The results of the primary test showed that the student possessed a limited understanding of the basics of water purification, answering one question completely correctly, and partially answering three more. The student was instructed to read through the laboratory materials thoroughly, and then examined the equipment. The student gained hands-on experience with the sediment and carbon filters, and had the RO, FO, UV, and chemical purification processes explained in pictures and in a lecture format. Given the costs associated with bacteria testing and time constraints, the student didn't carry out significant independent research with the purification abilities of the Lab. However, the student was able to examine the materials used for testing. After carefully covering the reading material and answering questions that the student didn't fully understand from the material, the same assessment was administered. The student was allowed access to the written materials during the assessment, but was not allowed to ask any questions or use outside resources. The results of the assessment are quite positive, the student answered 18 questions completely correctly, and provided partially correct answers for an additional three questions. Upon verbal questioning, the student was able to reason through the three questions left blank, and correct the four wrong and partially wrong answers.

Implementation in Service Projects

The second implementation of the Lab will be as a teaching tool in schools in Haiti, Swaziland and Lesotho, via a collaboration with the Rice Beyond Traditional Borders program[3]. This program, spearheaded by the Bioengineering Department, addresses global health through sustainable design, education and medical care. Approximately a dozen Rice students, faculty and staff members will travel to these developing nations this spring and summer to assess medical and infrastructure needs, and implement solutions. Current engineering undergraduates will use the Lab to teach grade school students and teachers about the importance of water purification and quality.

This group will also implement larger scale systems for potable water production. This project is funded by an EPA P3: People, Prosperity and the Plant Student Design Competition for Sustainability grant (SU833-547), awarded based on a proposal by the inventors of the Lab. In this project, a Manz biosand filter[15] and UV purification tank are being designed to supply clean drinking water for between 300 and 3000 people. The original site selected for the EPA project is a community in Mexico, however the system is also being considered for implementation in a school in Swaziland and a community in Lesotho. This system incorporates a novel biosand mold which is lightweight and reusable. In addition, the new biosand filters are completely sustainable in that no resources other than concrete are required to produce them. The new mold eliminates piping and other components that typically are not sustainable. Molds will be donated to the communities to produce more biosand filters, to increase potable water production capacity. A few systems will also feature UV sterilization tanks, powered by solar arrays. While not sustainable, these systems will offer a backup to the biosand filtration, and provide modest power at other times.

The current work on water purification in developing nations is extensive, with many products already developed for the purpose of providing clean drinking water, but not necessarily for educating the population about water purification. One such product is the LifeStraw, a handheld, portable, personal water filter[16]. The LifeStraw utilizes a resin to kill or inactivate viruses and bacteria, and a carbon filter to remove chemicals; however, the LifeStraw does not remove parasites, or effectively treat turbid water. The WaTER Lab does treat these contaminants, and provides an educational component, although the water it produces is not intended for consumption. The WaTER Lab will be used primarily as an educational tool by the team currently collaborating between the EPA project and the Beyond Traditional Borders program.

Future Work

Currently the Adaptive WaTER Lab is undergoing a redesign to improve usability and ease of manufacturing. The current design has presented several issues in use, the first being the inability to create a reliable seal. The two PVC components that screw together to form the sediment and carbon housings require substantial torque and Teflon tape to seal properly. Achieving a seal can be difficult to accomplish in the field, especially by children using the Lab. The sediment and carbon filters also occasionally slide out of place, allowing unfiltered water to seep through the housing, and contaminate the output of the filter.

The current design also calls for several custom made and difficult to manufacture parts, including PVC barstock that is machined to precision inner and outer diameters and includes difficult to fabricate o-ring recesses to properly seal the RO membrane. The manufacturing of this component, and others like it, make mass production labor intensive and costly. Two undergraduate students are currently completing a design-for-manufacturability study, with a target completion date of May 2008. The redesign will not affect the patent process currently underway, and should result in a system for fabrication by an existing company's not-for-profit branch, or by a newly formed not-for-profit firm. This work is in conjunction with the Rice Beyond Traditional Borders program[3].

Through Beyond Traditional Borders, the second generation Lab will be donated to schools in Swaziland, Haiti and Lesotho. The group that will be traveling to Swaziland and Lesotho is currently working on implementing their large scale water purifier in these two nations, and would take along the Adaptive WaTER Lab as a demonstration tool on these trips. Additionally, if the patent for the Lab is granted, then funds generated from its sales will be used to produce more Labs to donate to developing nations.

Conclusions

Current experience with the Lab shows that it is a very effective teaching implement. The students the Lab was demonstrated to last year seemed to grasp the concepts based on the question and answer periods following the presentations. The student working with the Lab gained firm knowledge about its components, and demonstrated a much deeper understanding of the purification methods presented following the study of the Lab materials, and hands-on experiences. The assessments taken prior to and following the use of the WaTER Lab indicate that the Lab is not necessarily a stand alone learning tool in its current state. Refinements to the procedures and supplemental materials that accompany the purification housings should allow the Lab to be easily used in a classroom setting to demonstrate to and educate students on the fundamentals of water purification.

The Lab itself has garnered interest from several universities as a method of outreach to the community. When the patent process and design-for-manufacturability study are completed the system should enter production and generate enough revenue from each Lab sold to build a full Lab for donation to developing nations to spread knowledge of the importance and methods of water purification. The hope of this outreach program is not to fix the water problems in the rest of the world, but to inspire future to work to address this pressing issue. Additional assessments of the Lab will be carried out following the revisions to the written materials and the physical Lab components. The Lab is currently under review for inclusion into the curriculum of an environmental science class at a public high school in Houston.

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