Water Quality: Adaptable Modules for Engaging K-16 Students

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***Abstract*—Highlighting the role engineers have in solving community and global challenges has been shown to positively affect students' engineering identity development. Poor water quality and water scarcity have been recognized as a critical global issue by many organizations, including the United Nations. Students of all ages can relate to the importance of having drinkable water through their experiences with thirst, drought, floods, news stories, or just accidentally swallowing salt water while on holiday at a beach. This talk describes the development and implementation of a series of engineering education activities focused on water quality. These activities ranged from three-minute activities for community outreach events to week-long lessons for engineering freshmen. Younger students were able to readily recognize how using different types of filters and natural media can increase the clarity of water with particulate or color contamination. Middle and high school students were able to design and test filter set-ups and learn about the role of nanotechnology in water purification. They also developed analytical and data analysis skills through qualitative and quantitative water quality measurements. Freshman engineering students learned about the water industry, local and global water issues, and performed water quality sampling around their campuses using portable meters that log data via a cell phone app. The activities and results were then used to meet university-course outcomes related to the societal impacts of engineering, statistical analysis, plotting data, and written communication. By centering learning on a tangible and important engineering challenge, this work provides a flexible framework for learning and problem solving that can be tailored to the needs of students from different age groups and for different learning outcomes.**

Keywords—engineering education, engineering grand challenges, K-12 outreach, undergraduate education, water access

I. Introduction

According to goal congruity theory (GCT), students' interest in a career field can be enhanced when they perceive that their values and the values associated with that profession are aligned [1, 2]. Research has shown that GenZ students, underrepresented minorities, women, first generation college students, and students from rural areas are more likely to value helping others [3]. As a result, they may not identify with fields that they perceive as being focused on achieving high income, social status, and having a low societal impact. Over the last decade, there have been numerous efforts by the National Academy of Engineers (NAE) and other organizations to highlight the role that engineers have in improving quality of life, social justice, and solving local and global challenges. These efforts include identifying 14 Grand Challenges for Engineering and establishing a Grand Challenge Scholars Program to facilitate undergraduates developing the skills needed to address societal needs through engineering [4]. In spite of these efforts, many parents, teachers and students perceive engineering as a career best suited for people who are driven by material values often at the expense of the well-being of others and the planet. Efforts to recruit students may also mistakenly focus on the salary and employment opportunities rather than the opportunity to create technology that addresses important societal needs. Activities that connect engineering concepts and careers to societal needs such as medicine, clean energy, carbon dioxide sequestration, infrastructure improvements, and clean water can highlight that "engineers make a world of difference," and "engineering is essential to our health, happiness, and safety" [5]. Short experiences at festivals and STEM open houses as well as more in-depth interventions at summer camps and in courses can increase student and public awareness that engineering is an altruistic, pro-social profession, that plays a key role in social justice issues such as unequal access to resources [6-8]. A variety of studies have demonstrated that interventions—even brief interventions such as videos, readings, or guest speakers—that show career fields as serving altruistic goals can improve students' perceptions of many STEM career fields [7]. For example, in a series of experimental studies, Brown et al. showed that a brief intervention of reading communal-focused versus non-communal descriptions of a biomedical career field enhanced students' motivation for pursuing that field of study [9]. These effects have been studied in depth with the goal of increasing girls' interest in STEM career fields [10, 11].

Amongst all the societal challenges, the need for clean water is one everyone can relate to since everyone needs to drink water. Water covers approximately 71% of the Earth's surface. However, around 97% of the planet's water is salt water contained in the Earth's oceans [12]. It is predicted that by 2030 there will be a 40% deficit in freshwater resources and 1 in 3 people already do not have access to safe drinking water [13]. Access to clean water and sanitation is one of the United Nations' sustainable development goals, and they declared 2018-2028 a water action decade [13, 14]. In addition [13], the

National Academy of engineering has named access to clean water one of the fourteen grand challenges for engineering [15], and the World Health Organization has highlighted the importance of safe, clean water to public health [16]. Even in regions with well-established water distribution and treatment systems, sustainable access to clean water remains an ongoing issue due to ppopulation growth, emerging contaminants and other pollutants, and aging water related infrastructure [17]. In United States, the 1972 Clean Water Act set goals and guidelines for fighting pollution and restoring water quality in the nation by imposing effluent discharge limitations and standards for water quality protection [18]. However, U.S. municipal and well water drinking water supplies still face significant challenges related to public water infrastructure, global climate effects, waterborne disease (including emerging and resurging pathogens), land use pressure, contamination and depletion of groundwater aquifers, surface water contaminations, and updating regulations [19].

K-16 students may not be initially aware of the scope or multifaceted nature of global water challenges, but they can easily relate to the importance of clean drinking water. most will have experienced a time when they have been inconvenienced by not having readily available clean or drinkable water. For some, personal relevance could be something as simple as being thirsty or accidentally swallowing salt water at the beach. However, many students will have directly experienced their household needing to conserve water due to drought, or incidents of municipal or well water contamination that necessitated boiling water or acquiring bottled water. Even those who have not been directly affected may have heard of news stories related to these topics such as the lead contamination crisis in Flint Michigan [20]. There is also significant public awareness of how communities have been affected by water contamination with lead, arsenic, PFAS, and other contaminants [21]. Therefore, people from early childhood through adulthood can relate to activities related to the need for access to clean water.

This report describes a group of water quality activities that have been adapted for implementation at open houses for K-12 students and their families, summer camps, and freshman engineering students. The required time for the activities ranged from 5 minutes for open houses, to 3 hours for summer camps, and 5 hours for an Auburn University (AL, USA) freshman Introduction to Engineering Course. Similarly, the activities ranged from completely qualitative to requiring the use of spreadsheets and basic statistical methods. All of these activities garnered student interest and the longer activities were associated with increased knowledge of and interest in engineering.

II. Short Activities

The simplest activity focused on the concept of size-based filtration with natural materials using only visual observation to assess changes in water quality. The core concept is that size-based filtration relies on physical removal of suspended contaminants by porous media. Pollutant particles have different sizes, and they can be eliminated from the water by passing through a media with adequately small pores to prevent their passage. In this activity, participants are asked which group of materials would clarify a container of muddy water containing debris such as crushed leaves and why. This tabletop activity has been used at open houses for students, teachers, and families with attendees ranging from twenty participants to over one thousand participants. The activity is best suited for smaller group sizes due to the need for fresh filtration media after a few filterations cycles. The set-up requires preparing a dirt water mixture using either potting soil or natural dirt. Crushed leaves or other small objects may be added as well. For safety, it is advisable to add some bleach to the water and have participants use hand sanitizer after the activity. The set-up also includes synthetic or natural filtration materials, funnels or containers for holding the filtration media, as well as containers for collecting the water. Towels for cleaning the possible spills should also be present. The materials can include synthetic materials such as cheesecloth, kitchen towels, coffee filters and filter papers. Participants are asked to make observations about the water and filtration materials and engaged in a discussion of what they think will provide the most thorough or fastest filtration and why. Depending on time constraints students may hold the materials up to the light for examining the texture or be shown cell phone images of the materials such as the ones show in Fig. 1. If time allows, they can take their own images using low-cost cell phone microscopes.

After being engaged in discussion, the facilitator or a participant pours the water through one of the materials using a standard ring stand and funnel. Emphasis is placed on how water that looks clear may not be safe to drink. Participants are told how clean water requires additional treatment and they should always check with an adult before drinking from a water source. This concept is reinforced with pictures of bacterial test strips or agar plates from water that was filtered but did not contain bleach or other sterilizing agents. In another variation of the activity, natural filtration is described using materials such as sand, pebbles, and larger rocks. Participants either pack, or watch a facilitator pack, a column with the materials and then pass the water through and see how it clarifies with multiple passes. For this activity, a clear 1 L PET bottle that has had the top cut off and holes in the base works well. To ensure containment of small sand and rock particles, placing a coffee filter at the bottom can be helpful. Ideally, the filtration column should be packed in a way that water goes through the media with larger objects first for the filtration column to work effectively without getting clogged. Use of a ring stand for holding the filtration column/setup can reduce the likelihood of spills. An example of set-up using the natural and synthetic materials is shown in Fig. 2.

Assessment of activities at open houses is challenging because collecting the participants feedback should be quick and not disrupt/interfere with participation in other activities of the event. Informal assessment can include student engagement with the facilitator or coming back to the activity with a family member or friend to explain it to them. Quick pick assessments based on pictograms such as emojis on tablets/interactive screens or even slips of paper can be an effective way of getting Likert scale feedback. Both types of assessments have shown that this activity is enjoyed by a wide range of age-groups. In 2018, the water quality enhancement using the water filtration column described in this section and water quality assessment using the commercially available test strips was used as a

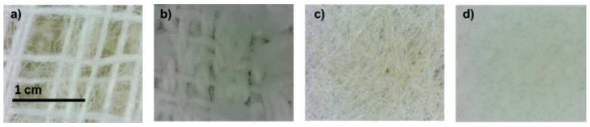

Fig. 1. Cell phone microscope images of a) cheesecloth, b) dish towel, c) coffee filter, d) Number 2 Whatman qualitative cellulose filter paper.

Fig. 2. Materials for activity on designing a filter column with natural and synthetic materials.

demonstration activity at an Auburn University Samuel Ginn College of Engineering Expo with students in grades 2 - 7. Over 100 students attended the event. Twenty students completed an optional survey on their enjoyment of this station. The water filtration activity compared favorably to other activity stations. When asked whether the activity made them more or less interested in engineering, 88% responded favorably.

III. Middle and High School Classes and Summer Camps

Expansions of the short activities were used in middle school classrooms as well as middle and high school summer camps. The in-school activity was aligned with state and national teaching standards for 7th grade life science [22], but is easily adoptable to other courses. It includes an engagement activity highlighting how odors can go through latex balloons, but not mylar balloons. Students then perform an augmented version of the short activity with cheese cloth, kitchen towels, and filter paper using bleach-free dirt-water suspension. The augmented version included the additional use of filter papers that had been impregnated with silver nanoparticles via a simple microwave synthesis method [23]. In this version analysis extends beyond visual observation of water clarity; qualitative measures of bacterial contamination are also included. To reduce costs, agar plates were replaced by potato slices which had been quickly boiled in water and placed in petri dishes or bags [11]. Students place drops of the initial and filtered water on potato slices and close the container. After approximately two days of incubation at room temperature, and preferably in a dark place, all samples except the ones filtered through the silver nanoparticle impregnated papers show significant bacterial growth. The bactericidal action of the silver nanoparticles is discussed as well as the low-cost technology used to make the nanoparticle impregnated filter papers and how communities with limited access to resources might use the technology. As part of the discussion, a video on "The Drinkable Book" for water decontamination using silver nanoparticle impregnated paper is shown. The video describes how the "Drinkable Book" contains information about water quality, the pages can be used as biocidal filers, and the book is shipped in a box that serves as the filter holder [24, 25]. After the video, students engage in a discussion about the current and future availability of clean water locally and globally. Students are also asked to discuss times they experienced challenges due to excess water, not enough water, or not enough clean water.

At teacher training events, teachers appreciated the hands-on nature of the activity for teaching about size scale while incorporating environmental science and biological science concepts. Assessment of the classroom activity was primarily in the form of post activity tests on students' knowledge and in a format available in the online resources [22]. In summer camps, the water filtration activity was conducted after an assessment of students' attitudes towards engineering followed by an engagement activity called "What's the Challenge?"[26]. In this activity, students brainstorm on important social and engineering challenges and problems they think somebody should prioritize and solve. The results are often a list that include problems and challenges ranging from minor inconveniences and local issues to global issues. They are then asked to group and prioritize the list as a large group. This invariably leads to many of the items listed as Grand Challenges for Engineering or United Nations Sustainable Development Goals [27], including access to clean water, to be prioritized on students' list. The first few iterations of the activity in summer camps used the same filter materials as the 7th grade life science activities. In one iteration, creating the filter column was a design challenge among groups of students. The students were given the freedom to pick their column packing materials (filtering media) and sequences and they could compete based on criteria such as fastest flow rate, or cleanest water in the fewest passes. Testing of biological contamination using test strip, potatoes, or agar plates depended on whether it would be possible for students to see the results after the two-day incubation period. For this reason, when less time was available, a greater emphasis was placed on chemical analysis. Water known to contain chlorine, carbonates, or nitrates was used and the chemical analysis is conducted using chemical test strips and Exact iDip meters. Regarding water analysis for chemical properties, the authors suggest addition of agents such as vinegar (for increased acidity), salt for increased chloride content, or bleach (for increased hypochlorite salt content and reduced bacterial load) to create a variety of water samples that will yield significantly different results. Either the chemical test strips or Exact iDip meters or similar handheld spectrometers can be used to provide similar information, but each method has different advantages and disadvantages. The test strips are inexpensive, readily available, and easy to read. They rapidly provide information on several water quality parameters (e.g., pH, alkalinity, hardness, chlorine, and nitrate content) in the form of color changes on an adsorbent pad. Semi-quantitative information can be obtained by comparing the color to that on a key provided on the test strip bottle. In contrast to test strips, the Exact iDip meters are quantitative handheld spectrophotometers. The cost is considerably less than professional instruments, but still on the order of $100 - $300 and they also require disposable test strips to enable analysis. Therefore, meters are only cost effective for recurring events where they will be used many times. For the meters, a few milliliters of water is placed in the sample chamber and a test strip for specific parameters like free chloride and nitrate is used to stir the water. Turbid water samples or water containing too much sediment are not suitable for being read with the meter because optical opacity interferes with the readings. Depending on the parameter being measured, the meter displays the result in a few seconds to a few minutes and also uses Bluetooth to send it to a cell phone app that logs the result, date, time, and geolocation. The app also allows for storing historical data to look for trends. Therefore, the meters enable a discussion of citizen science and tracking historical data in natural or municipal systems. Students also typically enjoy the cell phone interface.

The first formal evaluation of the water activities in camps was multiple half-day sessions in week-long residential engineering camps sponsored by Auburn University, a US land-grant and R1 state university. This included a camp consisting of 27 high school girls (Women in Engineering) and a co-ed Senior High Engineering camp with an additional 29 participants. At the end of the lesson, students completed an attitudes survey of their enjoyment of the activities and a short post-test of their knowledge. Findings indicate many of the student participants of the camp found the water quality assessment and enhancement introductory lesson and lab activities interesting and educational (Table I). In the post-participation surveys, 86% of the co-ed Senior High Engineering camp participants and 96% of the participants of the Women in Engineering camp found the lab activities focusing on water filtering and quality assessment either very interesting or somewhat interesting. In addition, 97% of the co-ed camp participants and 100% of the Women in Engineering camp participants indicated that they have either learned something or learned a lot from taking part in the activity.

IV. FRESHMAN INTRODUCTION TO ENGINEERING CLASSES

The activities used in the summer camps were further extended for use in a university freshman "Introduction to Engineering" course. As part of a larger research assessment [1, 28], students completed surveys on engineering knowledge and attitudes during the first and last weeks of the course as well as surveys and knowledge tests before and after activities related to the engineering grand challenges. Each week the course consisted of a 50-minute lecture for approximately 120 students and two 75-minute laboratory or problem-solving sessions. The course is intended to ensure students from all pre-college backgrounds are prepared for engineering course work. It includes introductory engineering problem solving methods, laboratory activities, engineering design, data analysis, teamwork, written and oral communication, exposure to speakers from industry, and engineering ethics. Planning the curriculum to meet a balanced mix of these topics is challenging particularly at a university where students come from both highly resourced and severely under resourced schools. As a result, the course often seems fragmented, particularly from a student perspective.

The water module was developed to provide a cohesive theme over two weeks of the course while meeting multiple course objectives and ABET Student Outcomes. The course was taught before the revised accreditation criteria, but met the following ABET student outcomes at an introductory level: 1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics 2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors 3. an ability to communicate effectively with a range of audiences 4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts 5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives, 6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions [29].

The module started with an industry speaker highlighting global water challenges, both municipal and industrial needs, and her career path. Next, students worked in teams of 5 to 6 on a 75 min water filtration lab similar to what conducted in the summer camps using the Bluetooth Exact iDip meters. After the lab, students borrowed the meters to obtain data for water sources on and around the campus and made observations about the bacterial test strips prepared during the lab period. As homework, students were assigned to research on water scarcity, water contamination, and water purification. During the second lab period of the week, students used their laboratory data to learn key chemical engineering principles such as the factor-label method, unit conversion, calculating moles, and calculating mixture compositions. This lab activity took the place of the standard homework exercises on these same topics.

TABLE I. ASSESSMENT OF CLEAN WATER ACTIVITIES FOR SUMMER CAMPS.

		Senior High Engineering		Women in Engineering	
		Mean	***% selecting 2/3***	***Mean***	***% selecting 2/3***
Interest[a]	What is nano?	2.3	97%	2.4	89%
	Water lecture	2.1	97%	2.2	89%
	Lab	2.2	86%	2.3	96%
Learning[b]	What is nano	2.4	100%	2.5	100%
	Water lecture	2.3	93%	2.4	96%
	Lab	2.3	97%	2.4	100%

a. Was it interesting?: 1=needs improvement; 2=somewhat interesting; 3=very interesting

b. Did you Learn Something: 1=didn't learn much; 2=learned some; 3=learned a lot

The following week, students were introduced to technical writing in the lecture session. The first laboratory period was used to address the disparities in students' understanding of statistics and spreadsheet software. The instructor collated team measurements of water quality parameters from various campus locations into workbooks. This data set was used to introduce essential statistical analysis, data communication, and Microsoft Excel skills. The goal was for students to be able to use Microsoft Excel for basic statistics (averages, minima, maxima and standard deviations) and to make different types of plots that include error bars. Most students brought their own laptop and worked through a series of tasks led by the instructor. Since no specific version of Excel is required at Auburn University, the specifics of how to perform each task varied with the version a student was using. Students appeared significantly more engaged than in past years when either an arbitrary data set was used or when students used separate data sets from smaller laboratory activities. Significant peer-to-peer discussion enabled everyone to learn how to meet the goals using the version of Excel most readily available to them.

The second laboratory section of the second week was used to begin compiling all of the information into a group lab report that included background information, laboratory procedures, results and discussion, conclusions, and references. This report was due at the beginning of the following week. For many students, it was the first time they had written such a large report. Some students reported no prior experience with Microsoft Word or Excel. Even students with significant word-processing experience initially expressed uncertainty about how to include equations, tables, and figures.

The water activity was conducted in Introduction to Engineering classes consisting of approximately 120 freshmen pre-engineering students during multiple semesters over three years. Representative assessment data is shown in Table II. When asked to rate the module components from 1 to 3 based on whether they were interesting and whether they helped in learning about engineering students gave the activity 2.40 and 2.17 respectively.

TABLE II. INTRODUCTION TO ENGINEERING EVALUATIONS

scale 1 to 3	**Was it interesting?** [a]	**How did it help you learn about engineering?** [b]
	Mean (% selecting 2/3)	***Mean***
Industry Lecture	2.33 (95%)	2.04 (81%)
Assigned Reading	1.86 (75%)	1.91 (76%)
Water Lab	2.40 (96%)	2.17 (88%)
Report Writing	1.75 (66%)	1.90 (72%)

a. was it interesting?: 1=needs improvement; 2=somewhat interesting; 3=very interesting
b. did you learn something: 1=didn't learn much; 2=learned some; 3=learned a lot

V. CONCLUSIONS

Access to clean water is an important educational topic that is a perpetual challenge, affecting people around the globe. Due to the social, economic, environmental, and technical significance of water quality and access to clean water, students are intrinsically interested in the topic, creating the opportunity to use this topic as a means of engaging K-16 students' interest into real life engineering challenges. Connecting engineering to an important issue like water can enhance their perceptions that engineering is a career field that meets the pro-social career goals that many students hold. Teaching students about water quality enhancement and assessment methods through interactive activities ranging from a few minutes to hours can be used for raising awareness toward these challenges. These activities can also help K-16 students gain basic understanding of water quality parameters and teach them methods for water quality enhancement and assessment, data analysis and basic statistics. Simple water quality enhancement methods such as size-based filtration coupled with silver nano particle-based filtration can be easily adapted into classroom lessons and be presented as demonstration STEM activities. They demonstrate new technology engineers have creating to address on-going water quality challenges. Readily available tools, such as pool test strips, water quality meters and bacterial culturing can be used independently or paired with the described water quality enhancement methods to give students some hands-on-experience with assessment of various water quality parameters and connect the engineering to everyday tools. The results from surveys filled by K-16 students who have participated in the water quality enhancement and assessment activities described in this work, show the positive impact of the activities in engaging the students' interests into the topic of water quality and teaching them about water quality enhancement and assessment methods. Additionally, the activities have positively impacted students' attitudes towards engineering career paths.

The reported activities on the topic of access to clean water, highlight how similar activities can be used for a range of age groups as well in both formal and informal educational settings. They show that lessons and activities related to the societal implications of engineering do not need to be an additional topic added into the curriculum, but can easily be adapted to meet K-12 or ABET standards. Using similar activities at multiple levels also reduces barriers to curricular innovations by making it easier to maintain both needed supplies and trained facilitators who are comfortable with the topic. Similar approaches could be adapted to introduce other topics that highlight the importance of engineering in mitigating societal challenges and facilitating social justice.

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