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Integration of the Humanities, Science, and Engineering Aspects of an Undergraduate Engineering Research Experience

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One of his ongoing research areas is the theoretical and applied aspects of traditional chemical engineering separation processes that can be used in drinking water, industrial wastewater, and hazardous waste treatment, including applications such as: • the use of sustainable (non-chemical) additives derived shellfish wastes for the removal by coagulation of nanoparticulate matter • the use of sustainable (no-chemical) additives for the purification and disinfection of potential drinking water sources. • the removal of microplastics from surface water and groundwater that could potentially be used as a drinking water source.

Another of his ongoing research areas is in Socially Responsible Engineering, an area in which he seeks to provide motivation, guidance, and instruction to engineers of good will who believe social responsibility and social justice are important parts of an engineering vocation.

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Abstract

In 2019 the World Health Organization reported that clean drinking water is unavailable to 2.2 billion people worldwide. Water contamination can include multiple issues, including suspended solids, turbidity, dissolved organics, and heavy metals, as well as bacteria or other pathogens. Problems such as water quality may attract students to engineering as a means to pursue a career dedicated to improving the human condition. Opportunities for students to further their knowledge and awareness of humanitarian issues within the undergraduate curriculum can enhance their knowledge of these career paths and build on research or extra-curricular opportunities related to humanitarian engineering.

The authors have sponsored water treatment projects which have linked the goals of humanitarian engineering with experimental research, engaged students through the pursuit of their passions, considered the wider context of technical solutions, and enabled partnerships with other service-learning initiatives. This research also provides an opportunity for the integration of interdisciplinary educational experiences that combine liberal arts, science, and engineering aspects of an undergraduate engineering education. The first section of this paper will provide an overview of the global problem in water quality. The second section will describe several undergraduate experiences related to improving global water quality and share some student perceptions on these experiences.

Overview of the Global Problem of Water Quality and Treatment Considerations

In their 2030 Agenda for Sustainable Development, the United Nations [1] established a goal to "ensure availability and sustainable management of water and sanitation for all" which would include achieving "universal and equitable access to safe and affordable drinking water for all" and improving "water quality by reducing pollution". The World Health Organization [2] estimates that 2.2 billion people worldwide lack access to safely managed drinking water services. Over the years, this problem still exists in developing countries due to the expensive nature of conventional water treatment chemicals and the infrastructure requirements to sustain treatment facilities.

Coagulation and flocculation are water and wastewater treatment processes traditionally used for the removal of suspended solids. A typical coagulation process uses both alum ($Al_2(SO4)_3 \cdot 18 H_2O$) and lime to remove solids and adjust the treated water back to a neutral pH, respectively [3]. Although traditional chemical treatment for coagulation is well-established, disadvantages such as chemical cost and availability, the production of toxic sludge, and the acidification of treated water make the application in developing areas challenging. In addition, incorrect chemical dosing can lead to elevated aluminum levels in the treated water and the aluminum-rich sludge, if improperly handled, could create a new environmental problem.

These issues highlight the need for ecofriendly approaches to minimize the amount of conventional chemical coagulants used for water and wastewater treatment; and, to develop natural alternatives to chemical coagulants that might allow developing nations to use locally available plant and non-plant-based alternatives for water treatment, possibly even at the local community and at the in-home level. Several researchers have provided extensive discussions of plant-based natural coagulants that that can be used in water and wastewater applications [4]. Numerous researchers have also provided extensive discussions on other non-plant-based natural coagulants that have been investigated [4].

Initial research performed at Villanova focused on the use of chitosan as a natural flocculant [5]. The use of chitosan offers the potential to valorize the estimated six-to-eight million tons of sea food waste produced annually, worldwide [6]. Major advantages include a more environmentally neutral sludge and reduced acidification of the treated water as well as effectiveness against bacteria, viruses, and fungi [5]. While a great deal of research has investigated the use of chitosan, an implementation hurdle is created by the chemical processing required to obtain chitosan powder from shellfish waste. Research at Villanova have also built on the literature surrounding the use *moringa oleifera* (MO) seeds in water purification. The MO tree, also known as the horseradish or drumstick tree, is found throughout India, Asia, sub-Saharan Africa, and Latin America in many regions that suffer from water (and food) scarcity [7,8]. It has been reported [4] that some rural communities in Africa utilize crude MO seed extracts to clear turbid river water.

Finally, any proposed water treatment process must also be resilient enough to handle emerging pollutants such as anthropogenic nanoparticles and microplastics. The identification of nanoparticles and microplastics in surface and/or ground water raises questions about ability of traditional treatment processes to remove these materials and their potential health impacts [9,10].

Undergraduate Humanitarian Engineering Efforts to Address Water Quality Issues

The authors have addressed several aspects of this broad problem in their research and provided the flexibility for students to initiate investigations. Projects have addressed the effectiveness of conventional chemical coagulants, such as alum, for the removal of emerging solid contaminants, including nanoparticles and microplastics. These contaminants are generated from consumer product waste and create new obstacles for water treatment in both conventional applications and in developing areas of the world. Although traditional chemical treatment for coagulation is well-established, disadvantages such as chemical cost and availability, the production of toxic sludge, and the acidification of treated water make the application in developing areas challenging. Accordingly, another project theme has been to evaluate the performance of coagulants derived from natural products. One promising candidate is *moringa oleifera* (MO) seed which is obtained from a plant which is available in many areas with limited clean drinking water sources. MO provides a water-soluble protein that coagulates typical metal oxide and suspended material found in surface water [4]. Student interest has also driven new projects involving the adsorption of heavy metals by MO seed solids and the bactericidal activity of MO.

These research projects have provided students with an outlet to pursue their interests in humanitarian engineering and offered experiences that foster creativity and innovation, bringing humanitarian engineering into focus alongside engineering technology. Providing opportunities for students to learn about alternative career paths is a critical step in helping students find rewarding applications of their education [11]. It was, in fact, the interests of an undergraduate student and the life experiences of an international student working in the lab that motivated the authors to begin the first research project that included a humanitarian engineering perspective. This research was initiated as part of a master's degree project and quickly attracted several interested undergraduates. Students were involved in setting goals, developing experimental procedures, analyzing data, and evaluating the advantages and disadvantages of the coagulants.

This project demonstrated that alum effectively removed nanoparticles from water achieving > 99% turbidity reduction. These studies also indicated that while chitosan does display some coagulation capability for nanoparticles, this capability was not sufficient to serve as a "standalone" coagulant. It was shown that the use of chitosan in conjunction with alum could reduce the required alum dose and the associated negative impacts of alum use. The results of this research are presented in the literature [5] and acknowledge the contribution of three graduate students (one as a co-author) and ten undergraduate students who were involved in the preliminary and final experimental investigations. The project helps illustrate the broad approach needed to identify suitable engineering solutions based on the needs and resources of a local community. One of the undergraduates participating in this project completed a Fulbright Scholar experience after graduation.

Another student project involved microplastics, an emerging category of water contaminant for which removal technologies from water and wastewater merit further investigation and development. While coagulation and flocculation have historically been used to successfully settle fine suspended materials, research to determine whether coagulation and flocculation can also be used to effectively remove microplastics from potential drinking water sources has become necessary because of the increased discharge of microplastics into the environment. Accordingly, research performed at Villanova has addressed whether alum could effectively remove microplastics from potential drinking water sources. Research performed at VU showed that alum can effectively remove microplastics from test solutions, achieving turbidity levels of 0.5 NTU, well below the WHO standard of 5 NTU. The results of this research are presented in the literature [12] and include the contributions of one graduate student and one undergraduate student as co-authors.

Another student-motivated project involved the use *moringa oleifera* (MO) seed and the water-soluble protein extract from the seeds in coagulation experiments. To date, numerous experimental investigations have developed purification methods to isolate the active coagulation proteins using various MO powder processing and leaching or extraction conditions, including mass loadings, extraction solvents, and extraction times. However, research performed at Villanova addressed whether MO could serve as an effective, environmentally-friendly coagulant that can reduce or eliminate the need for chemical coagulants in developing nations where access to chemical coagulants is limited. Research (some currently ongoing at VU) has shown MO seeds can be used to not only reduce turbidity in potential drinking water sources but may also have biocidal effects that help disinfect the water. Although turbidity could be reduced by nearly

90%, the lowest residual turbidity of suspensions with an initial turbidity approximately 60 NTU did not achieve the WHO guideline of 5 NTU. The results of this research are presented in the literature [13] and acknowledge the contribution of two graduate students (one as a co-author) and four undergraduate students (one as a co-author) who were involved in the experimental investigations presented in the journal publication. One M.S. student voluntarily participated in research to obtain lab experience to supplement graduate studies in Sustainable Engineering has since formed a related non-profit organization.

In one case, a student who participated in both a Villanova University Engineering Service (VESL) - Learning Field Study in Madagascar and this research reported: "Moringa is found readily in the areas we visited in Madagascar; everyone knows what it is, and it is available to be purchased in Antananarivo. Turbidity is not a big problem in Madagascar water; it is typically between 5 and 20 NTU even when it is untreated. This is above WHO standards, but research has shown that moringa is more effective at higher initial turbidities. After 2 hours, the change in turbidity was not usually visibly noticeable. After 12 hours, some change could be visibly observed, but turbidity readings were not taken to quantify this change." Figure 1 shows preliminary trials performed using MO seed solids for water treatment at a service-learning location.

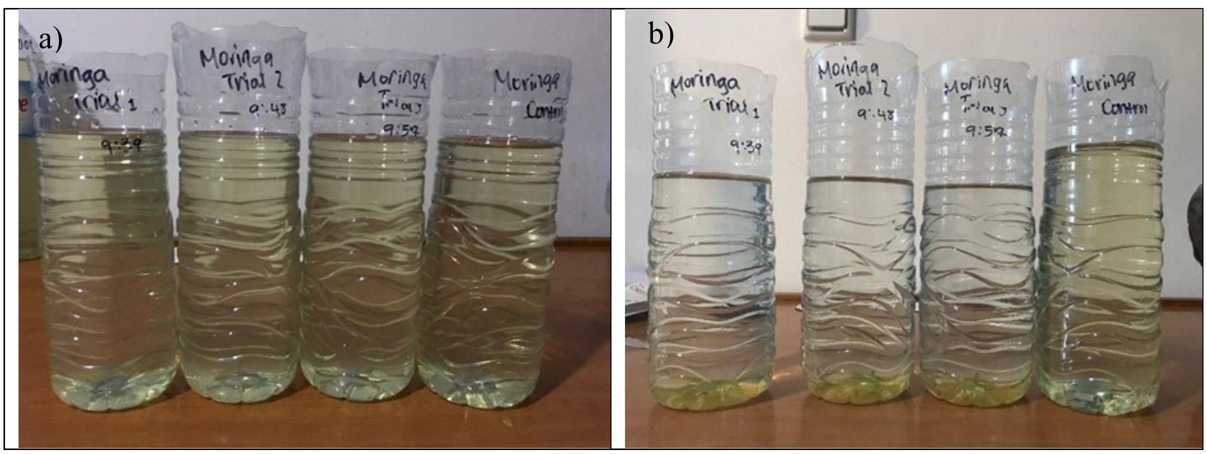

Figure 1. Field trials for treatment of ground water at a service-learning site.

Undergraduate involvement in University service-learning programs has also motivated students to pursue experimentation on the potential use of moringa seed solids in developing communities for removal of heavy metals. Currently, three undergraduate students are performing research at Villanova to address whether environmentally friendly, and renewable adsorbent materials are available that can remove heavy metals from potential drinking water sources. The current ongoing undergraduate research has focused on the use of MO and the results obtained to date indicate these seeds have potential use as an adsorbent for the removal of heavy metals such as copper. Students have developed the experimental goals of this project, helped develop procedures and helped prioritized experimental work based on the needs of the local community.

The three undergraduate students currently involved in this research have provided the following statements describing how the experience relates to humanitarian engineering:

Student 1:

> "I originally was involved with VESL before being part of the moringa team. VESL allowed me to learn more about the humanitarian side of research by going into communities in Madagascar and seeing how the moringa could potentially be used. After I got back from Madagascar, I joined the moringa team and was able to learn more about the chemical side of the moringa research. I think having the experience in Madagascar has greatly influenced the research I do in the lab because I am always thinking about how the moringa can be used practically in water scarce countries."

Student 2:

> "I would say that this research compliments my interests, but it has also opened me up to new possibilities within the chemical engineering field. I am very thankful that I had the chance to connect my research to the world through my trip to Madagascar, and because of this research, I have really started to understand humanitarian engineering and connect it to the world in a way I have never been able to do in the classroom. I would say that it is important to have at least some interest in humanitarian engineering within this research because it has allowed to me to see the bigger picture and think about the research beyond just the technical aspect."

Student 3:

> "At first, I chose to participate in this research, not because of its humanitarian aspects, but because of the specific scientific process we were looking at - namely mass transfer. This project was applicable to a mass transfer course I was currently enrolled in. However, as the research continued and as I discussed with my undergrad partners their motivations, I started to see a wider picture as to the applications and impact of our research. This research, combined with a Catholic Social Teaching for Engineers course I am currently taking, has enabled me to see the tremendous value in the combination of humanitarian projects with engineering research. After this project is complete, I will definitely continue forward with a new perspective on what it means to be a humanitarian, socially responsible engineer in today's world."

Conclusions

Student interest in humanitarian engineering has inspired several projects related to water treatment in developing countries using natural materials. Each natural material must be evaluated to determine effectiveness in water treatment and the broader environmental and societal impacts of its use in a particular community. These considerations have provided multiple opportunities for students to link experimental investigations with broader issues of the common good and to develop greater awareness of how the consideration of local resources and impacts must be included in proposed engineering solutions.

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