A New Program in Sustainable Engineering (Year 1): Multidisciplinary Teams Design Innovative Water Treatment Technologies for Developing Coastal Communities

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Abstract

Currently 2.5 billion people, over one third of the Earth's population, are affected by water scarcity and are without sanitation. The majority of humanity is concentrated in coastal communities: approximately half of the world's population lives within 200 kilometers of a coast. In many developing countries, raw wastewater is discharged into coastal waters without being treated. These issues show a present and growing need for engineers trained in a broad suite of sustainable water treatment technologies, and with an ability to work in interdisciplinary teams in complex international settings.

As part of a new program in Sustainable Engineering at Penn State, a senior-level, elective course in Ecological Engineering was offered for the first time in fall 2014 with a focus on empowering real coastal communities in the Caribbean to improve their quality of life and protect their natural resources. In this course, undergraduate and graduate students worked in multidisciplinary teams to design ecological wastewater treatment systems with an emphasis on producing beneficial byproducts of food, income, and/or education for the targeted community. The team project was strategically designed as a training and recruitment tool to help identify and prepare student leaders in Engineers Without Borders (EWB) for the project.

In an optional online survey conducted at the end of the semester, students were asked to reflect on their learning experiences in the course compared to other courses taken throughout their time at university. The survey consisted of 50 randomized multiple choice questions, provided in both positive and negative voice, with five possible answers to select from: strongly disagree (SD), disagree (D), neutral (N), agree (A), and strongly agree (SA). Survey participants (n = 21 out of 23 enrolled) overwhelmingly liked the real-world application of the design project (76% SA; 24% A), felt that it enhanced their fundamental technical skills (29% SA; 67% A), inspired them to learn more than if it had been a theoretical problem (38% SA; 62% A), and believed that it was a better learning experience than a typical classroom activity (45% SA; 50% A). Working with a team made students more effective collaborators (14% SA; 71% A), contributed to their learning in the course (19% SA; 48% A), and enhanced their leadership skills (19% SA; 62% A). The international aspect of the project enhanced student learning (19% SA; 62% A), encouraged them to think about social impacts while creating engineering solutions (38% SA; 52% A), and inspired them to deliver a quality design for the community (33% SA; 62% A).

This work is significant because it is one of the first international, multi-disciplinary programs in Sustainable Engineering at our university to leverage a student outreach organization (EWB) to engage both developing communities and fundamental research activities. The longevity of this program will be supported by a team of faculty committed to cross-disciplinary research, course

development, and mentoring of EWB projects containing interdisciplinary, multi-component systems. This paper presents the foundational goals and first survey data in this effort.

Introduction

Currently 2.5 billion people, over one third of the Earth's population, are affected by water scarcity and are without sanitation. The majority of humanity is concentrated in coastal communities: approximately half of the world's population lives within 200 kilometers of a coast. In many developing countries, raw wastewater is discharged into coastal waters without being treated, in the belief that these discharges do not significantly affect the environment. In reality, these contaminants not only threaten human health, but also often contribute to the loss of marine animals which local peoples often rely on for food and income. In the future, continuing population growth and economic development will increase the demand for water and the severity of pollution. There is a clear and overwhelming need for sanitation and water purification in developing coastal communities, but it is not afforded by conventional, energy-intensive and chemically-intensive water treatment systems. In high-poverty equatorial coasts, the stable temperatures and predictable solar input greatly facilitate sustainable practices for water treatment. These issues show a present and growing need for engineers trained in a broad suite of sustainable water treatment technologies, and with an ability to work in interdisciplinary teams in complex international settings.

At our university, we have recently begun to develop a multi-disciplinary, collaborative, international initiative in Sustainable Engineering to train undergraduate and graduate students to meet the current and emerging global needs of society, while enabling research by faculty on topics with broad technical and scientific impact in the vital area of the water-energy nexus. This goal is directly in line with the mission of our college, which is to "nurture and train world-class socially-aware, globally-connected, diverse engineers, educators and researchers….to develop innovative solutions to the world's most pressing challenges through transformational interdisciplinary research". The proposed program also aligns and supports several of the institutional thrust areas of our college, including: 1) **Innovative Engineering Education** through the provision of global engineering education and experiences; and 2) **Sustainable Water-Energy-Food Nexus** through water resources sustainability, management, treatment, and energy consumption.

Indeed, overcoming the crisis in water and sanitation has been identified by the United Nations as "one of the greatest human development challenges of the early 21st century" (1). The timeliness of this program is also evident in that it addresses four of the Grand Engineering Challenges for the 21st Century, namely: providing access to clean water; managing the nitrogen cycle; and restoring and improving urban infrastructure (2). To meet these challenges, collaborative relationships between faculty, students, and professional engineers in a variety of disciplines are necessary to lead innovative research and bring it to practice.

The integrated program described herein is the first for our college, and enhances existing collaborative efforts between faculty in several engineering departments, as well as creates opportunities for robust collaboration with others across the University. This work is significant because it is one of the first in the country to develop an international, multi-disciplinary program in Sustainable Engineering, while utilizing a student outreach organization (Engineers Without Borders, EWB) to mobilize the resulting efforts to engage developing coastal communities with the assistance of practicing engineers. To meet these goals, we aim to integrate our research programs, courses, and the local student chapter of EWB. This paper describes progress in the first year of the program with the initiation of a sustainable water treatment project in the island community of Roatán, Honduras, through the development of a new course in Ecological Engineering.

Project Location

Located 40 miles off the north coast of mainland Honduras (Figure 1), the island of Roatán is home to a diverse set of ecosystems, socio-economic conditions, and immersive learning opportunities. The key facets which justify the launch of this initiative in Roatán include:

- **Favorable conditions for success**: Isolated from complex economics of larger countries, island communities possess "micro grids" of energy, water, and economic infrastructure and offer excellent opportunities to engage in the deployment of sustainable and resilient technologies;
- **Unique setting for sustainable technology deployment**: The warm temperatures and coastal wind/solar availability of Roatán offers a perfect setting for the proposed technologies. The local community is politically stable, English speaking, close in proximity to the US, and economically and socially diverse – factors which enable rich and fulfilling contributions by student teams;
- **Enhances and strengthens multiple existing and diverse activities**: Introduces a global engineering component into existing courses and research infrastructure in sustainable energy and water technologies that can serve as a foundation for the engagement of further disciplines in the future.

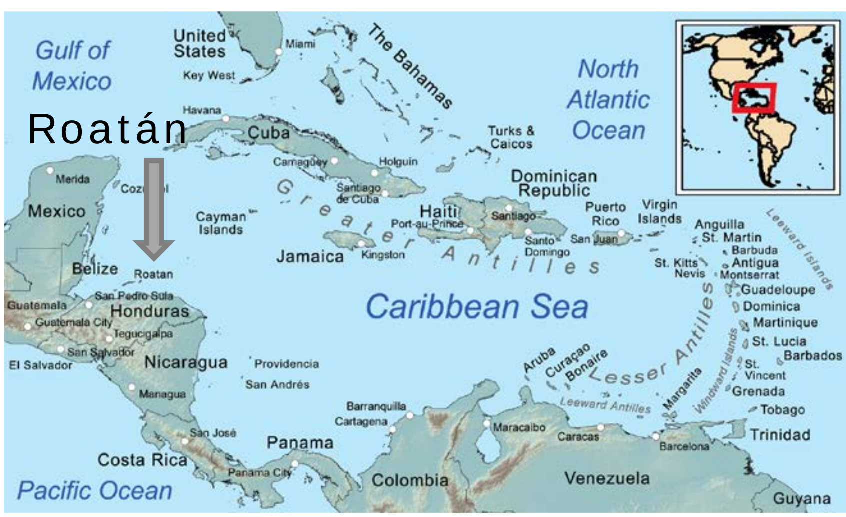

Fig. 1. Map of project location (Roatán, Honduras) in the Central Equatorial Atlantic (Wikipedia).

In future years, this initiative is expected to expand to enrich an existing university program in Mona, Jamaica. As the initiative gains momentum, we envision even broader partnerships with faculty and organizations working in other coastal communities to pursue further sustainable engineering applications.

Course Integration

As part of our new program in Sustainable Engineering, a senior-level, elective course in Ecological Engineering was offered for the first time in fall 2014 with a focus on empowering real coastal communities in the Caribbean to improve their quality of life and protect their natural resources. In this course, undergraduate and graduate students worked in multidisciplinary teams to design ecological wastewater treatment systems with an emphasis on producing beneficial byproducts of food, income, and/or education for the targeted community. The team project was strategically designed as a training and recruitment tool to help identify and prepare student leaders of Engineers Without Borders (EWB) for the project.

The class of 23 undergraduate and graduate students was divided into four teams based on their background and interests, and half of them were tasked with designing a sustainable solution for restoring and protecting the Pensacola estuary on the island of Roatán, Honduras, while the other half were tasked with a similar project for a community in Jamaica. In Roatán, wastewater from individual homes is currently being dumped into the Pensacola estuary, where it flows untreated out to sea damaging the nearby coral reef. The instructor of the course (lead author of this paper), traveled to Roatán with one graduate student from her research group to survey the site and collect water quality data to support the project. Multidisciplinary teams of students then worked to design a passive, wetland-based treatment system to remediate the area. They took advantage of proven ecological technologies and natural tidal forces to remove contaminants from the wastewater so that surrounding habitats are not further damaged.

The goals of this student design project were to: 1) reduce contaminant concentrations within the estuary to Honduran regulations; 2) provide beneficial byproducts from within the treatment system; and 3) educate the local community on the importance of treating wastewater and protecting their environment.

After completing a Site Investigation and evaluating potential technologies, the students formalized their strategies through a comprehensive Design Plan. Both Roatán teams converged on similar engineering solutions for treating the wastewater, including the construction of a septic tank, horizontal subsurface flow (HSSF) wetland, free water surface (FWS) wetland, and a stormwater channel. The two teams differed, however, in their development of value added projects for the community. The leading team proposed a variety of features for the site, including a bridge made out of locally recycled materials to traverse the estuary, an educational sign to describe the water treatment system, and an oyster aquaculture system at the mouth of the estuary to provide additional water quality polishing, as well as a protein and income source for the community. This leading design now serves as a template for EWB to remediate this and other estuaries with similar detrimental impacts in Roatán.

Assessment

In an optional online survey conducted at the end of the semester, students in the new Ecological Engineering class were asked to reflect on their learning experiences in the course compared to other courses taken throughout their time at university. The survey consisted of 50 randomized multiple choice questions, provided in both positive and negative voice, with five possible answers to select from: strongly disagree (SD), disagree (D), neutral (N), agree (A), and strongly agree (SA). Survey participants (n = 21 out of 23 enrolled) overwhelmingly liked the real-world application of the design project (76% SA; 24% A), felt that it enhanced their fundamental technical skills (29% SA; 67% A), inspired them to learn more than if it had been a theoretical problem (38% SA; 62% A), and believed that it was a better learning experience than a typical classroom activity (45% SA; 50% A). Working with a team made students more effective collaborators (14% SA; 71% A), contributed to their learning in the course (19% SA; 48% A), and enhanced their leadership skills (19% SA; 62% A). The international aspect of the project enhanced student learning (19% SA; 62% A), encouraged them to think about social impacts while creating engineering solutions (38% SA; 52% A), and inspired them to deliver a quality design for the community (33% SA; 62% A).

Significance

This work is significant because it is one of the first international, multi-disciplinary programs in Sustainable Engineering at our university to leverage a student outreach organization (EWB) to engage both developing communities and fundamental research activities. The program provides students with challenging, hand-on experiences that augment their research and education in sustainability. The program also provides an immersive learning experience including cultural, technological, collaborative, and leadership components, and demonstrates a scalable approach to the globalization of existing courses and research initiatives. The very nature of this project helps cultivate the characteristics of a World-Class Engineer, which requires that students be: solidly grounded; technically broad; globally engaged; ethical; innovative; excellent collaborators; and visionary leaders.

In future semesters, the Ecological Engineering course will include optional travel to Roatán for students to help build the water treatment systems that they collaboratively designed with oversight by practicing engineers. The longevity of this program will be supported by a team of faculty committed to cross-disciplinary research, course development, and mentoring of EWB projects containing interdisciplinary, multi-component systems.

Acknowledgements

Funding for development of this new program was supported in part by a grant from the College of Engineering Global Engineering Leadership Program and by the Harry West Teaching Award for the Advancement of Civil Engineering Education. Both of these grants are gratefully acknowledged.

Bibliography

1. United Nations Development Programme. 2006. Human Development Report 2006: Beyond Scarcity: Power, Poverty and the Global Water Crisis. New York: Palgrave Macmillan.
2. National Academy of Engineering (2008). Grand Challenges for Engineering. Washington, D.C.