A New Program in Sustainable Engineering: A Platform for Integrating Research and Service into the Classroom through Global Engagement.

Dr. Rachel A Brennan P.E., Pennsylvania State University, University Park

Rachel Brennan, Ph.D., P.E., is an Associate Professor of Environmental Engineering at Penn State University, a Senior Consultant with Golder Associates, and a Faculty Advisor to Engineers Without Borders. She has over 16 years of practical experience in environmental remediation, with expertise in the development and application of enhanced bioremediation technologies for treating contaminated soil, groundwater, surface water, and wastewater. She has developed innovative strategies for treating a variety of hazardous compounds, including chlorinated solvents, hydrocarbons, explosives, pharmaceuticals, pesticides, and acid mine drainage (AMD). Her current research efforts focus on ecological wastewater treatment, enhanced nutrient removal, and beneficial reuse of aquatic biomass for sustainable fertilizer and biofuel production.

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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, 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 or fossil-fuel-based energy systems. In high-poverty equatorial coasts, the stable temperatures, steady winds, and predictable solar input greatly facilitate sustainable practices for water treatment and energy production.

We have recently begun to develop a new cross-disciplinary program in Sustainable Engineering at our university that empowers coastal communities in the Caribbean to improve their quality of life and protect their natural resources. In this program, senior-level engineering courses train undergraduate and graduate students to design and deploy ecologically-designed wastewater treatment plants with renewable energy systems in collaboration with faculty-led research teams and community participants. These courses are strategically designed to be training and recruitment tools to help prepare the local student chapter of Engineers Without Borders (EWB) for the project, and to provide students at all levels with challenging, immersive, hands-on experiences that augment their research and education in sustainability.

This work is significant because it is one of the first international, multi-disciplinary programs in Sustainable Engineering in North America, and utilizes a student outreach organization (EWB) to mobilize the resulting efforts to engage developing coastal communities with the assistance of practicing engineers. The longevity of this program is supported through cross-disciplinary research, course development, and mentoring of EWB projects containing interdisciplinary, multi-component systems. Future partnerships in the areas of wind energy, coral reef resilience, food systems science, economic development, and eco-tourism are planned to further enhance the program.

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 or fossil-fuel-based energy systems. In high-poverty equatorial coasts, the stable temperatures, steady winds, and predictable solar input greatly facilitate sustainable practices for water treatment and energy production. These issues show a present and growing need for engineers trained in a broad suite of sustainable water treatment and renewable energy technologies, and with an ability to work in interdisciplinary teams in complex international settings.

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; making solar energy affordable; 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 (of which the authors are advising). 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, coupled with high energy costs, 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.

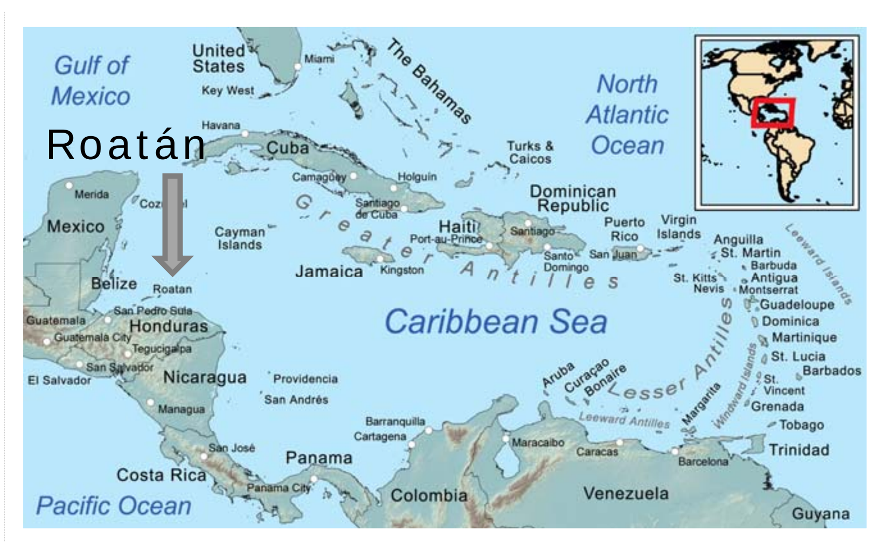

Fig. 1. Map of project location (Roatán, Honduras) in the Central Equatorial Atlantic (Wikipedia).

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, organizations, and industry partners working in other coastal communities to pursue sustainable engineering applications that address critical energy and water challenges.

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 the first half of the semester, the class was taught in standard lecture format to cover ecological engineering design principles for treating domestic wastewater and mining impacted water. Lectures were augmented with three field trips to natural and engineered wetlands, and six guest lectures by ecologists and professional engineers who specialize in wetland design and/or sustainability. During this initial stage of the course, students were allowed to work together, but were required to individually complete a series of three homework assignments, four quizzes on relevant TED Talks, and a closed-book exam. After the exam, the course transitioned into the design stage, and students were grouped into multidisciplinary teams to develop ecological wastewater treatment systems for real communities with an emphasis on producing beneficial byproducts of food, income, and/or education for people in the targeted location. Lectures during the design stage were targeted to address the specific needs of each project location, and were offset with open work sessions to provide additional opportunities for the teams to meet and discuss their progress with the instructor.

The class of 23 students consisted of 9 undergraduate (UG) and 14 graduate (GR) students, in the following majors: Environmental Engineering (10 GR); Civil Engineering (6 UG); Water Resources Engineering (2 GR); Plant Pathology (1 GR); Agricultural and Biological Engineering (1 GR); Chemical Engineering (1 UG); Environmental Resource Management (1 UG); and Petroleum and Natural Gas Engineering (1 UG). Based on their majors, backgrounds, and interests, the students were divided into four teams and half of them were tasked with designing a sustainable solution for restoring and protecting the Pensacola estuary on the island of Roatán (2 teams of mixed UG and GR), while the other half were tasked with a similar project for a community in Jamaica (1 team of UG and 1 team GR). Water quality characteristics for the Jamaica site were previously collected and available to the class. Comparable data for the selected estuary in Roatán was not available, however, so 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 (Figure 2). In this location, wastewater from individual homes is currently being dumped into the estuary, where it flows untreated out to sea, damaging the nearby coral reef.

Provided with water quality and surveying data for each location, the students in each team worked together to design passive, wetland-based treatment systems to remediate their sites. They took advantage of proven ecological technologies and natural site characteristics to remove contaminants from the wastewater to prevent further damage to surrounding habitats. The primary goals of the design project were to: 1) reduce contaminant concentrations within the impacted water bodies to meet local 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. 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. Throughout the assignment, social and political challenges for each location (Honduras and Jamaica) were discussed with the students.

Fig. 2. Water quality sampling performed at an estuary receiving raw wastewater in Roatán, Honduras (Oct. 2014). The collected data was utilized by students in the described class to develop preliminary designs for an ecological wastewater treatment system to remediate the site and protect the local coral reef.

The design project consisted of five graded components:
1) **Project Plan** (summary of targeted technologies and division of labor);
2) **Site Investigation Report** – a compilation of relevant site data, including geology, hydrology, native vegetation, climate, contaminant concentrations, local effluent requirements, etc.;
3) **Design Plan Report** – a review of feasible technologies and the team's design strategy;
4) **Final Project Report** – a full design report, including revised elements from the Site Investigation and Design Plan (following the instructor's graded recommendations), combined with detailed design calculations, schematics, and a cost estimate;
5) **Design Presentation** – a formal presentation by all members of each team to describe the main points of their Final Report in the style of a consulting firm bid.

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) (Table 1).

Table 1. Online survey questions and responses (n = 21 out of 23 students) at the conclusion of the course. The questions were automatically randomized for each student by the survey software.

Question	Strongly disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)
The design project was a good learning experience.	0.00	0.00	4.76	42.86	52.38
I liked that the design project focused on a real-world problem.	0.00	0.00	0.00	23.81	76.19
The international aspect of the project enhanced my learning.	0.00	0.00	19.05	61.90	19.05
The design project was a better learning experience than a typical classroom activity.	0.00	0.00	5.00	50.00	45.00
The topic of the project encouraged me to contribute to my team's design.	0.00	0.00	19.05	42.86	38.10
I would recommend that the design project be used in a senior-level capstone course.	0.00	0.00	19.05	42.86	38.10
I wish I had more time to work on the design project.	0.00	0.00	33.33	33.33	14.29
I would have preferred to have typical homework in this course, rather than an applied design project.	28.57	52.38	19.05	0.00	0.00
The real-world application of the design project inspired me to learn more than if it had been a theoretical problem.	0.00	0.00	0.00	61.90	38.10
I did NOT learn as much as I wanted to in the course because of the design project.	42.86	57.14	0.00	0.00	0.00
I felt we spent too much time on the design project.	9.52	71.43	14.29	4.76	0.00
The design project was too technically demanding.	9.52	71.43	19.05	0.00	0.00
The design project was appropriately challenging.	0.00	0.00	0.00	80.95	19.05
Interacting on a team contributed to my learning in the course.	0.00	0.00	33.33	47.62	19.05
If possible, I would have liked to travel to the site and help build the design.	0.00	4.76	9.52	33.33	52.38
The design project helped me be a more effective collaborator on a team.	0.00	0.00	14.29	71.43	14.29
The design project enhanced my communication skills.	0.00	0.00	28.57	61.90	9.52
The design project broadened my technical skills.	0.00	0.00	9.52	71.43	19.05
The design project helped me learn how to formulate sustainable solutions to complex problems.	0.00	0.00	9.52	57.14	33.33
I learned about other technical disciplines while working on this design project.	0.00	4.76	4.76	66.67	23.81
My ability to formulate creative solutions to open-ended problems was enhanced by working on the project.	0.00	0.00	0.00	71.43	28.57
The design project encouraged me to be innovative.	0.00	0.00	9.52	42.86	47.62
The design project inspired me to deliver a quality design for the community.	0.00	0.00	4.76	61.90	33.33
Working with a team on the design project enhanced my leadership skills.	0.00	0.00	19.05	61.90	19.05
I became more aware of ethical issues encountered around the world while working on the design project.	0.00	4.76	9.52	76.19	9.52
The design project inspired me to learn more about sustainable engineering.	0.00	0.00	14.29	47.62	38.10
The design project helped me develop my fundamental technical skills.	0.00	0.00	4.76	66.67	28.57
After working on the project, I have LESS desire to learn about other cultures.	52.38	38.10	9.52	0.00	0.00
Working on a team diminished my learning in this course.	23.81	61.90	9.52	4.76	0.00
I did NOT get an opportunity to use my technical skills on this project.	38.10	52.38	9.52	0.00	0.00
The design project encouraged me to think about social impacts while creating engineering solutions.	0.00	0.00	9.52	52.38	38.10
The design project raised my awareness of global environmental issues.	0.00	0.00	9.52	61.90	28.57
The design project raised my impression of Engineers Without Borders.	0.00	0.00	28.57	52.38	19.05
The design project was too open-ended.	14.29	52.38	28.57	4.76	0
The College of Engineering should offer more courses which focus on international engineering design.	0.00	0.00	14.29	42.86	42.86
The design project stifled my creativity.	35	60	5	0.00	0.00
Ethical considerations were NOT important for the design project.	28.57	61.90	4.76	4.76	0.00
After working on the project, I have LESS desire to work on global engineering problems.	61.90	38.10	0.00	0.00	0.00
The nature of the project discouraged me from collaborating.	38.10	52.38	4.76	4.76	0.00
I did NOT learn about sustainability while working on this project.	42.86	52.38	4.76	0.00	0.00
My communication skills suffered while working on this project.	23.81	71.43	4.76	0.00	0.00
The College of Engineering should NOT support courses like this in the future.	85.71	14.29	0.00	0.00	0.00
Working on the design project encouraged me to learn more about other cultures.	0.00	4.76	28.57	52.38	14.29
Working on this project has inspired me to work on other global problems in the future.	0.00	4.76	19.05	38.10	38.10
I was NOT concerned about the success of the project for meeting the needs of the community.	55.00	45.00	0.00	0.00	0.00
The project is NOT appropriate for a senior-level capstone course.	45.00	50.00	5.00	0.00	0.00
Overall, the project was a poor learning experience.	61.90	38.10	0.00	0.00	0.00
I did NOT learn about global environmental issues while working on this project.	42.86	47.62	0.00	4.76	4.76
After working on the project, my impression of Engineers Without Borders has decreased.	52.38	42.86	4.76	0.00	0.00
The design project was too prescriptive.	9.52	71.43	19.05	0.00	0.00

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, hands-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 (for both authors collaboratively) and the Harry West Teaching Award for the Advancement of Civil Engineering Education (for the lead author). Both of these grants are gratefully acknowledged.

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