A Living System for Teaching Engineering Principles

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Abstract

Engineering educators have typically used non-living systems or products to demonstrate engineering principles. Each traditional engineering discipline has its own products or processes that they use to demonstrate concepts and principles relevant to the discipline. In recent years engineering education has undergone major changes with a drive to incorporate sustainability and green engineering concepts into the curriculum. As such an innovative initiative has been undertaken to use a living system such as an aquarium to teach basic engineering principles. This paper describes the activities and course content being developed for a freshman engineering class at Rowan University, the New Jersey Academy for Aquatic Sciences and the Cumberland County College.

Introduction

An aquarium is an exquisite combination of interacting systems which can be analyzed using multidisciplinary engineering principles. Children typically have personal aquariums for their pet fishes and visit some large aquarium as part of a school field trip or as part of their family outing. Movies such as Disney-Pixar's "*Finding Nemo*", *Epcot's Living Seas* also make tremendous impact on a young audience. While these activities apparently raise the knowledge base in terms of nature and the environment, children seldom make a connection to the engineering principles playing out in the maintenance of a natural, commercial or personal aquarium. Thus the idea of using an aquarium to promote engineering concepts for a wide audience is innovative and exciting. A creative initiative between the College of Engineering at Rowan University, Cumberland County College (CCC) and the New Jersey Academy of Aquatic Sciences (NJAAS) to enhance STEM education at all levels has been undertaken by receiving support from the National Science Foundation. There is a growing realization among engineering faculty that a new vision for the education of engineers needs to evolve to keep this country at the forefront of technology. Science and engineering are essential for paving the way for America's future through *discovery, learning and innovation* [1]. A recent report [2] indicates that the United States lags behind the world in technological innovation because of its poor performance in teaching math and science. This eliminates many of the best and brightest schoolchildren from the ranks of future scientists and engineers. Many students who do undertake science and engineering studies in college are unprepared and drop out in frustration, while other potentially capable students never consider these subjects in the first place. In both

cases, precious human and institutional resources are squandered. Enhanced engineering education in our K-12 classrooms can provide students at an earlier age with a more specific understanding of what a technical career entails.

The College of Engineering at Rowan University is always seeking innovative teaching methods to excite freshman engineering students about engineering design [3-8]. The aquarium project was selected to expose K-12 students/educators and freshman students in engineering at Rowan and CCC. Students can easily be introduced to chemical, mechanical, electrical engineering, civil and environmental principles such as mass and energy balances; fluid flow; work, energy, and efficiency; forces and levers; material strength and stresses; water quality and treatment; and electrical signal processing. The aquarium theme also adds to the need for an understanding of biological systems, ecosystems, pollution and sustainable development. These are concepts that have been absent in typical traditional engineering concepts.

Project Partners

NJAAS and CCC were selected as partners for enhancing the broader impacts of the project. Both CCC and NJAAS are located within 30 minutes of the Rowan University campus and both these locations are within the two New Jersey Federal Empowerment Zones (EZ). The EZ programs are designed to empower people and communities across the United States by inspiring communities to work together to develop a strategic plan designed to create jobs and opportunities in the nation's most impoverished urban and rural areas.

The CCC partnership allows us to prepare the community college students for the Rowan engineering program by having direct input on their freshman *Introduction to Engineering* course. CCC is a comprehensive community college that is accessible, learning-centered, and dedicated to serving a diverse community of learners and employers through quality innovative programs, services and the appropriate use of technology for life-long learning [9]. It is accredited by the Middle States Association of Colleges and Schools. Eighty percent of Cumberland's graduates are the first in their families to earn a college degree and a high percent of them are from minority populations. The College offers an Associate's degree in engineering and has partnerships with a number of area engineering colleges. An attractive feature of CCC is their aquaculture certificate program and a fish barn. This fish barn produces 100,000 tilapia per year and serves as an aquaculture training facility for 20 to 40 students per year.

NJAAS promotes the understanding, appreciation and protection of aquatic life and habitats through research, education and youth development programs. This nonprofit organization is a leader in conservation-oriented research, environmental education, and community service both locally and globally. It conducts programs offsite through outreach projects to schools and community-based organizations as well as onsite at the State Adventure Aquarium [10] in a unique partnership to engage aquarium visitors in the wonder of the aquatic world. The Academy delivers a wide variety of classroom lessons, allowing children grades preK-12 to investigate ocean-related topics, from coral reef symbiosis to the sticky tube feet of the sea star. NJAAS also offers 30 minute electronic field trips via two-way videoconferencing technology. All programs are aligned with the New Jersey Core Curriculum Content Standards and National

Science Benchmarks. The Academy further offers an assortment of exciting professional development and interdisciplinary workshops for teachers. The academy has three major community outreach programs: FEST, CAUSE and PISEC [11]. These programs are designed to address the needs to achieve greater participation of underrepresented minorities in the science and education workforce and to provide quality science education through early intervention to underserved K-12 youth. The NJAAS serves a total of 50,000 students and educators via its programs every year.

Our three-way partnership is summarized in Figure 1.

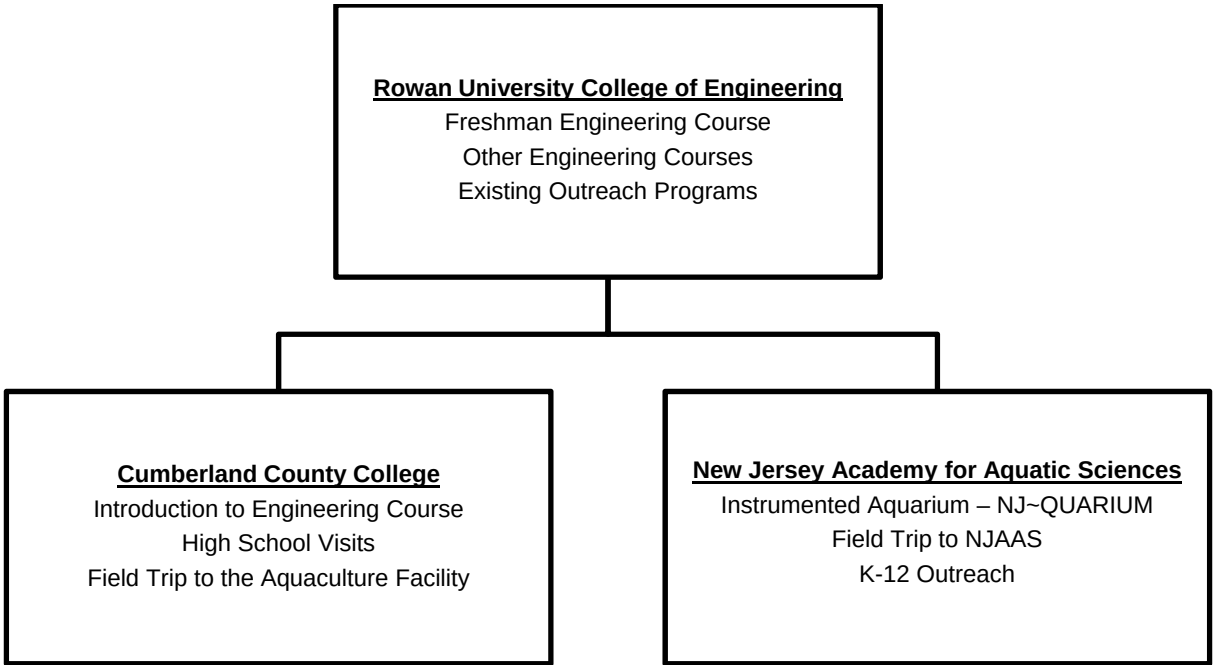

Figure 1: Chart Indicating Partners and their Respective Roles

Project Activities

Project activities include the development of hands-on activities, implementation of the activities in courses, workshops and in outreach activities, dissemination via a dynamic website and other traditional mechanisms.

Hands-on Activities

Twelve hands on activities have been developed to expose students to the engineering principles behind the operation of an aquarium. Activities have been developed to address a broad group of K-12 and college students. These include:

Water Quality Testing: This module introduces students to basic water quality parameters (such as pH, Conductivity, Hardness, Dissolved Oxygen, Temperature, Nitrate, Ammonia, Chlorine)

that are important to support freshwater and marine aquatic life. Students learn to measure water quality parameters using various probes and wet chemistry methods.

Water Treatment Processes: Students observe demonstrations of various water treatment processes such as Sand Filtration, Reverse Osmosis, Ultrafiltration and Ion Exchange. Specifically they work on an experiment on determining the adsorption coefficient of activated carbon in removing organic pollutants.

Gas Transfer –Aeration: Aeration of aquariums to maintain safe dissolved oxygen content is crucial to the successful design of an aquarium and survival of aquatic life. This module exposes students to the fundamentals of gas transfer and gas transfer kinetics. Students work on an experiment to evaluate the gas transfer rate of commercial gas transfer products such as diffusers, bubbling stones, and membranes.

Material Testing: This module focuses on material properties such as stress, strain, hardness, density, refractive index, insulation, and even toxicity as some materials may have additives that are toxic to aquatic and marine life. Students specifically focus on acrylic (commonly used for aquariums) and compare it to glass. Students also work on material properties of aggregates, sand, concrete and wood which are typically used for construction of a solid foundation to hold the weight of an aquarium.

Hydraulics: Water pressure in an aquarium is a major parameter in design considerations. Students conduct experiments to determine the pressure distribution and net forces on the aquarium walls using conventional hydraulics equipment. They also conduct experiments on head losses in pipes and porous media such as sand.

Temperature and Heat Transfer: This module introduces students to basic concepts of heat transfer. Students work on experiments to determine the overall heat transfer coefficient of water.

Robotics: This module introduces students to basic concepts in robotics. Students use a robotic fish that has been developed to take underwater pictures using a digital camera. The pictures allow the scientific community to learn about the surroundings of the aquatic habitat.

Data Acquisition and Remote Control: This module exposes students to data acquisition techniques. Students' prototype a relatively simple but representative example of a technologically complex feedback control system to monitor water quality parameters (e.g., aquarium temperature, pH, Conductivity, and Dissolved Oxygen). Students also identify all relevant electronic components (e.g., sensors, amplifier, A/D, and D/A, etc.) and their interrelations.

WWW and Networking: One important feature of the aquarium project is the on-line real-time data acquisition. This module focuses on the basic networking technology in support of this theme. Students are introduced to a seven-layer networking model, distributed systems as exemplified in the Internet, and database fundamentals with emphasis on their application to the aquarium.

Ethics and Sustainability: The aquarium theme is extended to investigate ethical, social and environmental issues through classroom and homework activities. These additional topics bring tremendous strength to the theme as engineers of the future must have a fundamental understanding of their role in the design and analysis of complex interacting systems, as well as the relevance of ethical and social issues. These modules specifically focus on the impact of engineered activities on the environment. Students learn about the effect of pollutants on receiving waters, the benefits of alternate energy and watch videos on marine pollution and protection. Typically engineering students are never exposed to experiments dealing with toxicity measurements of pollutants. Ironically most engineering facilities contribute to pollution of water via industrial, municipal or accidental discharges. Students use the HACH BOD Trak Equipment [12] to determine the toxicity of synthetic wastewaters typically generated from Chemical, Electrical and Mechanical Manufacturers. Students also use solar panels to deliver energy to run a small aquarium pump and compare the energy costs to traditional delivery methods. Students also work on a simple experiment on making biodiesel from vegetable oil and methanol [13]. In order to emphasize the role of environmental ethics and environmental justice issues, students watch videos and discuss specific case studies. Specifically students watch the impact of the Exxon Valdez Spill on the fishing community in Cordova, Alaska [14] and the impact of technology on driving species to extinction [15].

Each experiment has been developed such that it has broad appeal to different learning styles, is simple, cost effective and allows students to see applications of their math and science courses. Gender sensitive information is also provided such as contribution of male and female scientists to the specific topic. The contributions of Rosalind Franklin [16] to the structure of activated carbon, the contribution of Stephanie Kwolek for the development of Kevlar [17] and the contributions of Rachael Carson [18] to environmental protection and regulations are specifically discussed in the water treatment, materials and ethics modules.

Implementation of Activities

The hands on activities that have been developed have been implemented in the Freshman Engineering course at Rowan University. Both NJAAS and CCC allow the Rowan University students to visit the state aquarium and the aquaculture centers as part of their engineering course. These field trips allow the students to connect concepts learnt in the classroom to the real world. Apart from the above experimental experiences, students are also exposed to traditional experiences such as engineering drawing using software (AutoCAD, PCAD and Solid Works), technical report writing and oral presentations.

Hands on activities are will also be used in different workshops offered for teachers and K-12 students at Rowan University. Some of the developed experiments are also used in our upper level engineering courses such as Water Treatment and Chemical Processing.

Dissemination

The aquarium project has disseminated in a variety of ways. A dynamic website has been established to disseminate our Aquarium Project [19]. All laboratory activities, handouts, experimental methods, quizzes and exams are posted on this website.

We are working with NJAAS personnel to instrument an existing 100 gallon marine aquarium as seen in Figure 2 in their distance learning classroom to provide real time images and water quality data that will be posted on their website and titled the NJ~QUARIUM. This is a unique opportunity for NJAAS as currently none of the NJ State Aquarium exhibits have real time data and images online. The NJ~QUARIUM site will also generate excitement among students of all ages. Students will not only visualize activities of different living organisms in the aquarium, they will also see values of water quality parameters such as pH, dissolved oxygen, conductivity and temperature in the aquarium. Educators will be able to download data and help students plot and conduct statistical analyses of the data.

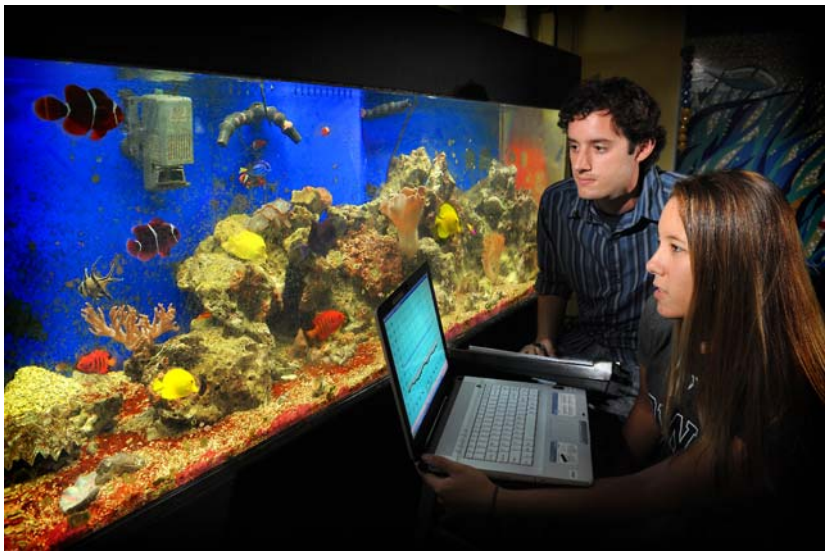

Figure 2: Instrumented marine aquarium at the NJAAS

Impact of the Project

We are in the first year of completing the project. The impact of the project has been excellent so far. The project is very appealing to students of all ages. This is evident from the number of Rowan students that want to be a part of this project. It had also been noted that the project is very appealing to our female students. A mid-term assessment of the freshman engineering students at Rowan University indicated the following responses to the questions below:

Question	Yes	No	Maybe	Don't Know
Do you believe that the aquarium project is untraditional for teaching engineering principles?	21	0	0	0
Does the presence of live fish make the project exciting and fun?	21	0	0	0
Does the project provide a better overview of a system using various types of science and engineering applications?	20	0	1	0
Does this activity enhance your understanding of ethics?	18	0	2	0
Does this activity enhance your understanding of sustainability?	18	0	2	0

Surveys and assessments will also be conducted at the end of the semester for Rowan and CCC students. They will also be used for the outreach workshops at Rowan and NJAAS.

Conclusions

The aquarium project generates a lot of enthusiasm and excitement in our freshman class. While the course assessments are incomplete, the overall impact of the projects appears to be positive and exciting. The theme is also extremely useful for outreach activities that range from K-12 education through college students. The three-way partnership has also added great value to the project. Initial responses to the project from female students have also been positive. This project can be a national model for other institutions and aquariums for adoption.

Acknowledgement

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Biographical Information

Dr. Kauser Jahan is Professor and Chair of Civil and Environmental Engineering at Rowan University, Glassboro, New Jersey. She completed her Ph.D. studies in the Department of Civil and Environmental Engineering at the University of Minnesota, Minneapolis in 1993. Dr. Jahan is a registered Professional Civil Engineer in Nevada and is actively involved in environmental engineering education and outreach for women in engineering. Her research interests include biodegradation of petroleum compounds and surfactant enhanced remediation of slightly soluble organic compounds.

Dr. Jess W. Everett is a Professor Civil and Environmental Engineering at Rowan University, Glassboro, New Jersey. He has extensive experience in supervising undergraduates in project-based learning, extensive experience in project management, and a proven publication record (46 refereed journal publications and over 100 conference proceedings and reports), and significant experience creating and managing both static and dynamic websites. His research interests include sustainable engineering and teaching pedagogy.

Dr. Gina Tang is an Associate Professor of Electrical & Computer Engineering at Rowan University. She worked as a research assistant at the Multi-lifecycle Engineering Center at New Jersey Institute of Technology. Since then she has been actively conducting research on modeling and scheduling computer-integrated manufacturing /demanufacturing systems. Her work has led to over 25 articles in journals, conference proceedings and book chapters within the last three years.

Dr. Stephanie Farrell is an Associate Professor in the Department of Chemical Engineering. She has been involved with several pre-engineering programs for high school students and college freshmen. Through these programs, she has focused on informing students about engineering careers and stimulating their enthusiasm for engineering education. Outside the classroom she has worked extensively to encourage the participation of underrepresented groups in engineering by participating in programs such as The Alliance for Minority Participation, University Research Experiences for Undergraduates and Exploring Career Options in Engineering and Science.

Dr. Hong Zhang is an Associate Professor in the Department of Mechanical Engineering. His primary expertise is Mechatronics systems, robotics and automation. He also conducts research on autonomous mobile sensors and thermo-image based Non-Destructive Evaluation systems. Dr. Zhang is an active mentor for Rowan's CHAMP program which provides outreach to regional high schools with high a minority population. Dr. Zhang has had tremendous success in motivating undergraduate students to work on projects for national competitions sponsored by ASME and SAE with successful outcomes.

Angela Wenger is the Executive Vice President & COO of the New Jersey Academy for Aquatic Sciences. Ms. Wenger has extensive science teaching and research experience and holds B.S. and M.S. degrees in biology (specialty: physiology) and marine science (specialty: malacology and aquaculture). During her tenure with the Academy, she has been involved with all facets of the organization, particularly exhibit design; public programming; family and classroom workshops; staff and teacher training courses; and programs for underserved audiences. Ms. Wenger is a member of the Committee on Conference Planning of the Association of Science and Technology Centers (ASTC).

Majid Noori graduated from the University of Maine in 1987 with a Ph.D. degree in Physics. Dr. Noori taught Physics and Astronomy at Towson University in Maryland for ten yours followed by a five year appointment at Seton Hall University in South Orange, New Jersey. He is currently an Assistant professor of Physics/Engineering at Cumberland County College. During his academic career, Dr. Noori has taught many graduate and under graduate courses in physics and astronomy and several undergraduate courses in Engineering technology. His current research activities at CCC include promotion of science and engineering among minority high school students with participation in a Cumberland County College grant for STEM careers.