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Hands on an Aquarium

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ABSTRACT: An aquarium is an excellent demonstration of interacting systems that can be used to illustrate fundamental engineering principles. Children are typically familiar with aquariums from an early age, worldwide. This can be either through their personal aquariums or a local public aquarium. While these aquariums expose children to ecosystems and pollution prevention concepts, it is seldom that a connection to engineering and scientific principles behind the design, operation and maintenance of an aquarium is made. In this paper, the authors describe their efforts in engaging freshman engineering students to discover the science and engineering behind the design and operation of an aquarium. Students are introduced to common engineering principles, such as mass and energy balances, fluid flow, work, energy, and efficiency, forces and levers, material strength and stresses, water quality and treatment, digital imaging, and electrical signal processing. Topics on microbiology, pollution prevention and sustainable development are also an integral part of this project. Class assessment indicates that students enjoy the use of a live aquarium to be exposed to basic engineering principles. The use of a familiar object also enhances student participation and learning.

INTRODUCTION

The *Hands on an Aquarium* project at the College of Engineering at Rowan University, Glassboro, USA, is implemented in a freshman engineering class titled *Freshman Engineering Clinic*. This class is team taught by engineering faculty to a class that has students enrolled from various engineering disciplines. The College of Engineering curriculum at Rowan University seeks innovative ways to excite and enhance student learning. Faculty are constantly seeking ways to use simple cost effective methods to motivate students to enjoy their engineering coursework. As such, the *Freshman Engineering Clinic* was designed to expose students to the creativity of engineering design.

In their first semester of this class, students learn basic engineering skills (problem solving, teamwork fundamentals, engineering measurements) [1][2]. Students are introduced to a variety of activities that are relevant to the four engineering disciplines. This is followed in the second semester by intense study of engineering design through reverse engineering (*dissection*) and competitive assessment (instrumentation, testing and side-by-side comparison of technical performance) of a consumer product. Products examined include hair dryers, water filters, electric toothbrushes, beer brewing processes, electronic mouse and remote-control cars [3-8]. The chemical engineering programme has also used the *human body* for the reverse engineering module [9-11]. Students investigate various parts of the human body and discover the science and engineering applications that are intimately associated with respiration, blood circulation, bone strength, etc.

An aquarium was recently introduced for the reverse engineering module [12][13]. An aquarium is an exquisite combination of interacting systems that can be analysed using multidisciplinary engineering principles. Children typically have personal aquariums for their pet fishes and visit some large aquariums as part of a school field trip or as part of a family outing. Movies, such as Disney-Pixar's *Finding Nemo* and *Epcot's Living Seas*, also make a 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. Therefore, the idea of utilising an aquarium for a reverse engineering activity is innovative and exciting. The idea also has a broad appeal to a wide audience ranging from young children to engineering students. Educators are always being challenged to develop teaching tools that engage students' imaginations and provide a platform for integrating state-of-the-art modern technology into the undergraduate curricula. MIT's *iquarium* project and Georgia Tech's *NSF Funded Aquarium Project* are two excellent examples of aquariums being used to enhance the quality of science and engineering education at all levels, including K-12 education [14][15].

Figure 1 indicates the impact of the aquarium project on many core engineering and science courses. Most of the experiments developed for the freshman class can easily be used in the upper level engineering/science courses. For example, an experiment developed to demonstrate oxygen transfer from air to water in an aquarium can easily be used to demonstrate gas transfer in water treatment or reactions kinetics in chemical processing. Water quality parameter measurements can be an integral part of an aquatic chemistry course. The developed experiments are simple to adopt and use standard laboratory equipment available at any traditional engineering school. In fact, many of these experiments can easily be carried out at K-12 educational institutions to expose engineering to school and pre-college students.

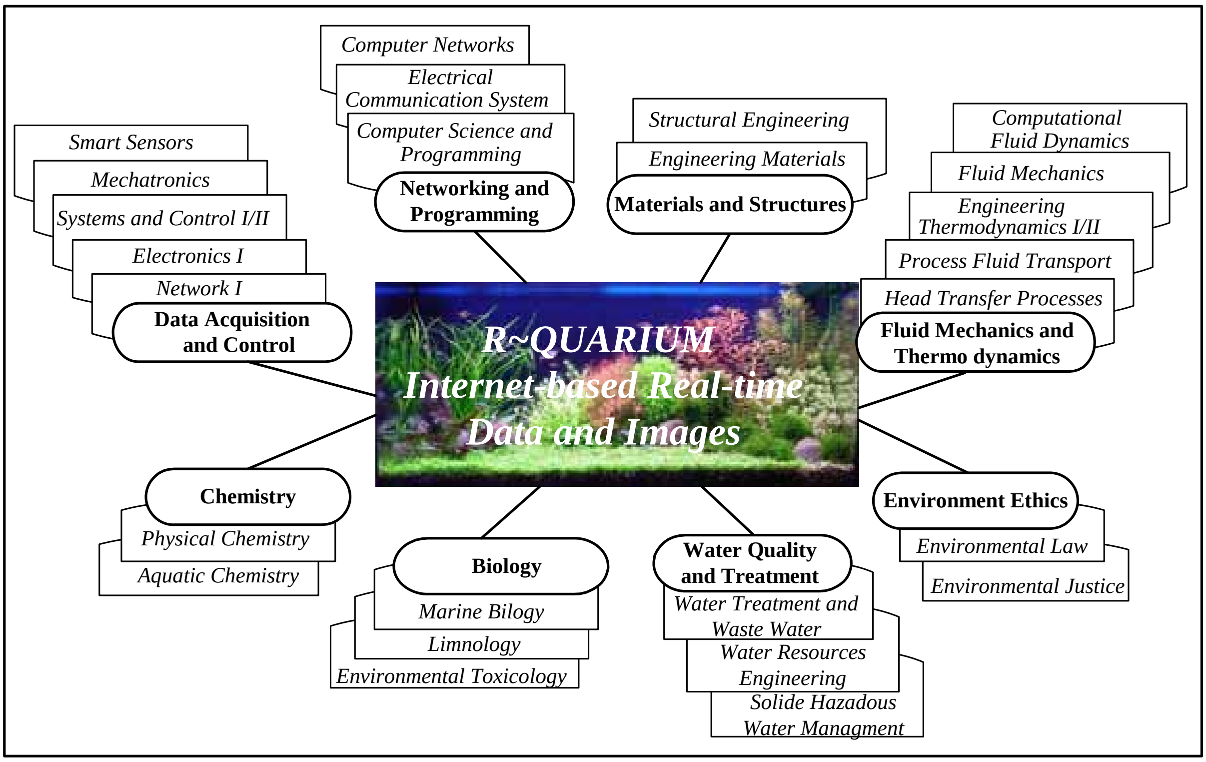

Figure 1: Relevant topics and impacted courses.

AQUARIUM PROJECT DETAILS

The *Freshman Engineering Clinic* course is a 2.0 credit class with a 50-minute lecture and a 2.5-hour laboratory session every week. The class size is typically 20 students from various engineering disciplines. Students are divided into multi-disciplinary teams of four or five. Eight hands-on activities were developed for the laboratory sessions while lectures focused on the relevant engineering principles behind each experiment. All experimental methods and laboratory/ lecture handouts are available at the course Web site [13].

All experiments require some form of data acquisition (manual and automated) and the use of the *Excel* software for plotting and data analyses. Students are required to write technical reports for each laboratory experiment. This report includes a letter of transmittal, experimental summary, and data analyses/ interpretation. Mid-term and final team presentations using *PowerPoint* software are also required.

Apart from the laboratory experiments, students visit the New Jersey State Aquarium and view the documentary film, *Empty Oceans, Empty Nets*, as part of their learning activities [16]. The field trip allows students to observe many engineering activities that are in place for the successful maintenance and operation of an aquarium. Students are allowed to observe the *behind the scene* operations, such as water treatment, remote water quality sensing and data acquisition.

The documentary focuses on global marine fisheries crisis and is an excellent tool to increase general awareness of the global issues involving the fishing industry and its impact on science and society. It focuses specifically on the increased mechanisation of the fishing processes by use of ocean floor bottom trawls and global positioning systems (GPS). It highlights how informed consumers and citizens can make a difference in restoring and maintaining healthy oceans for generations to come.

The class schedule, by lecture topic and laboratory session, is presented in Table 1.

Table 1: The hands-on an aquarium project schedule.

Lecture Topic	Laboratory Session
1. Introduction to Water Quality	Measuring common water quality parameters
2. Unit Operations in Water Treatment	Water treatment techniques
3. Introduction to Gas Transfer	Oxygen transfer mechanism and rate measurement
4. Ethics and Sustainability	Ethics Video: *Empty Oceans, Empty Nets* by Bullfrog Films
5. Heat Transfer	Experiment on heat transfer (evaporation and convection)
6. Biology: Micro-organisms; Nitrification and Denitrification	Enumeration and identification of microorganisms (bacteria, algae, fungi)
7. Materials	Material properties and testing (stress and strain; modulus of elasticity; refractive indices)
8. Statistics	Material testing
Data Acquisition and Instrumentation	Data acquisition: remote sensing of pH, dissolved oxygen and temperature
9. Economics	Field trip: New Jersey State Aquarium
10. Digital Imaging	WWW live feed of the Rowan Aquarium

EXPERIMENTAL MODULES

As mentioned earlier, eight experiments were developed to illustrate common engineering principles. Short descriptions of the experiments are provided below.

Water Quality Testing

The Water Quality Testing module introduces students to basic water quality parameters (such as pH, density, specific gravity, conductivity, hardness, alkalinity, 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. They also compare the differences between the water quality of freshwater and marine environments.

Water Treatment Processes

Students observe demonstrations of various water treatment processes such as sand filtration, adsorption, reverse osmosis, ultrafiltration and ion exchange. Column experiments using sand and activated carbon are utilised to demonstrate filtration versus adsorption processes.

Gas Transfer: Aeration

The proper 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. Students are also exposed to reaction kinetics theory via this experiment.

Material Testing

This module focuses on material properties such as stress, strain, modulus of elasticity, hardness, density and the refractive index. Students specifically focus on acrylic (commonly used for aquariums) and compare it to glass. Students also work on the material properties of aggregates, sand, concrete and wood, which are typically used for the construction of a solid foundation to hold the weight of an aquarium.

Temperature and Heat Transfer

Water losses via evaporation are important for an aquarium’s operation. This module introduces students to the basic concepts of heat transfer. Students work on experiments in order to determine the overall heat transfer coefficients of various materials.

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 (eg aquarium temperature, pH, conductivity, and dissolved oxygen). Students also identify all relevant electronic components (eg sensors, amplifier, A/D, and D/A, etc) and their interrelations.

WWW and Networking

An important feature of the aquarium project is the online real-time data acquisition. This module focuses on basic networking technology in support of this theme. Students are introduced to a seven-layer networking model, plus distributed systems as exemplified on the Internet, as well as database fundamentals with an emphasis on their application to aquariums.

Biology

The Biology module focuses on using microscopes to identify different microorganisms. Standard bacterial enumeration techniques are also taught. Typically, engineering students are never exposed to experiments that deal with the toxicity measurements of pollutants. Ironically, all engineers somehow contribute to the pollution of water via industrial, municipal or accidental discharges. Thus, students are allowed to conduct toxicity experiments using the *MICROTOX*™ apparatus.

As mentioned earlier, most of these experiments expose students to engineering fundamentals. For example, the gas transfer module exposes students to the following standard gas transfer equation:

$$\int_{Co}^{Ct} \frac{-dC}{C^* - C} = K_L a \int_0^t - dt \qquad (1)$$

where C* = saturation concentration of oxygen in water (mg/L), K_La = overall gas transfer coefficient (sec^{-1}), t = time (sec) and C = actual concentration of oxygen (mg/L).

Students also have to utilise their integral calculus skills to integrate the above equation and develop a relationship to determine the value of K_La. This relationship is as follows:

$$\ln(C^* - C_t) = \ln(C^* - C_o) - K_L at \qquad (2)$$

During the experiment, students measure the value of C_t versus time. An experimental set-up is shown in Figure 2. A glass beaker is filled with tap water and the oxygen in this vessel is brought down to 2.0 mg/L by the addition of sodium sulfite. Cobalt chloride is added as a catalyst to speed the reaction. When the oxygen concentration is around 2.0 mg/L, a common diffuser is used to add air to the water. Students record oxygen concentrations with time using a DO meter and a stopwatch.

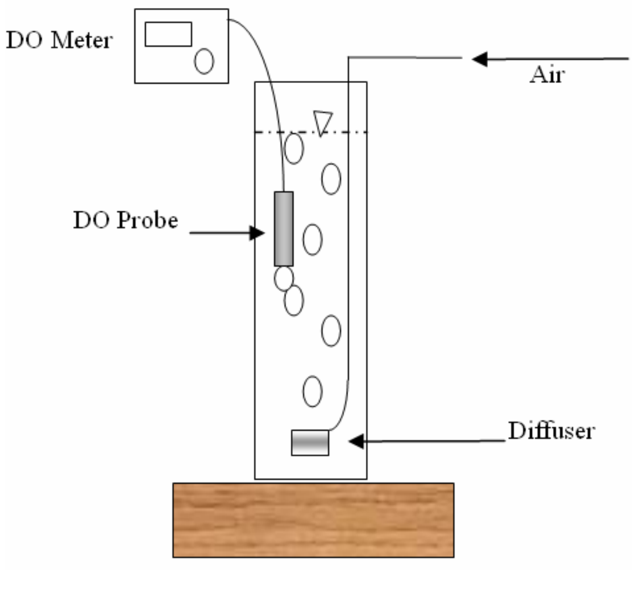

Figure 2: The gas transfer experiment set-up.

Students note the water temperature and determine the corresponding oxygen saturation concentration from a standard engineering handbook. Using an *Excel* spreadsheet for calculations, they can plot their experimental data and obtain the value of K_La. A typical plot is presented in Figure 3.

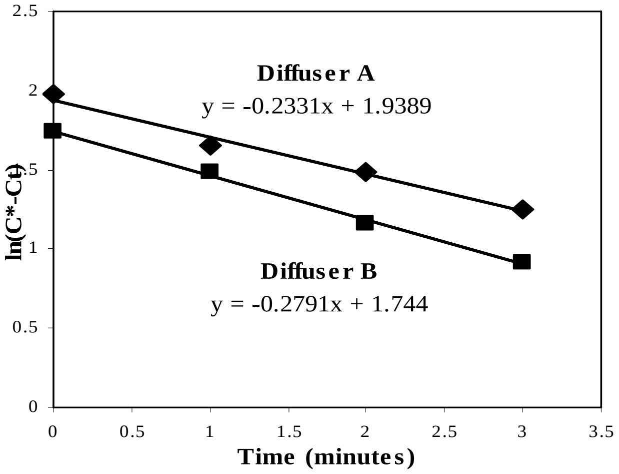

Figure 3: The determination of K_La.

The gas transfer experiment is a simple, visual, yet powerful learning exercise. Students are exposed to an equation that requires them to use their integral calculus skills. Next, the equation exposes them to reaction rates and reaction kinetics. Students also strengthen their data analyses and graphical representation skills.

CONCLUSIONS

The *Hands on an Aquarium* project has been highly successful at Rowan University. Course assessment results indicate that all students believe that the aquarium theme brings excitement to the learning process. Students are engaged in the scientific discovery process utilising exciting hands-on activities that introduce them to chemical, mechanical, electrical engineering, civil and environmental principles. The aquarium theme also adds to the need for an understanding of biological systems, ecosystems, pollution prevention and sustainable development. These 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. Finally, the experimental modules that have been developed can easily be adopted by other institutions as they are simple and cost-effective and all course material has been posted on the Web for rapid dissemination.

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