2006-988: A NEW PILOT COURSE: BIOLOGY AND CHEMISTRY APPLICATIONS FOR ENGINEERS

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A New Pilot Course: Biology and Chemistry Applications for Engineers

Abstract

A new pilot course, **Biology and Chemistry Applications for Engineers**, was developed for first-year engineering students. The fundamental concept of this course was to provide these students with a basic background in focused areas of biology and chemistry as it applies to engineering. The emphasis of the course was a hands-on experience with biology and chemistry applications in engineering. Applications in the areas of bioengineering, material science, nanotechnology, medicine, energy, and the environment could be selected, depending on faculty expertise, and appropriate biology and chemistry content taught in support. Topics for this pilot course included microbial processes, cell chemistry and biology, rates of reaction, chemical equilibria, acid-base chemistry, and reduction-oxidation reactions. These topics were demonstrated using fresh-water aquarium microcosms and field studies in the La Ballona Wetlands as a focus. The engineering content at this level served to broaden engineering student understanding of science, stimulate interest in technical careers, and attract under-represented populations into technical fields. It is expected that the course will ultimately become part of the science sequence for all first-year engineering students.

Introduction

The interrelationship between the sciences and engineering is especially significant as the role of biological systems and chemistry in engineering are growing areas of opportunity for engineers and as the sciences are often treated as distinct entities in engineering curricula. In most cases, engineering students at the university level never take a biology class. Furthermore, most engineering students who take a chemistry class learn chemistry in isolation with no articulation with engineering coursework. At Loyola Marymount University, first year engineering students take a one semester introductory chemistry class that addresses atomic theory, stoichiometry, properties of gases, solids and liquids, periodic law, solutions, thermochemistry, and redox equations. This new course added biology topics, addressed more advanced chemistry topics and integrated these biology and chemistry topics with engineering in a new and innovative way. To our knowledge, few if any institutions offer a course like it. Few examples were found based on an internet search. Few engineering biology courses existed that were not associated with a biomedical program. Some evidence of similar courses was found at the Universities of Toronto, Maryland, and Washington, Princeton University, and the Massachusetts Institute of Technology. A textbook, *Biology for Engineers*, was found in draft form on the internet by Johnson (1). The course presented in this paper was initially tested as a pilot course targeted to incoming first-year engineering students who have had Advanced Placement Chemistry in high school as they would initially have the free units in their first year schedule to take the course. It is thought that the introduction of biology and chemistry applications in the engineering curriculum may improve first-year student interest and motivation as well as broaden the scope of and improve their preparation to study in the various fields of engineering.

A number of publications have addressed the need for an interrelationship of the sciences and the opportunities associated. Nerem (2) stated that the biological revolution (referring to advances in biology) would define scientific progress in the 21st century. Nerem also states that a biology course needs to be added to chemistry and physics as a core science course for engineers (2). Panitz (3) indicates that bioengineering may be the next major engineering discipline. He cites the development of an implantable pump that uses a biosensor to measure blood insulin levels and dispense insulin as needed. Panitz believes that engineers with strong chemistry skills will be needed for drug production, prosthetics, transportation of the infirmed and handicapped, gene therapies, agricultural and ecological systems. Bruce Hamilton (4), Division Director, Bioengineering and Environmental Systems, National Science Foundation (NSF) points out that the NSF has integrated engineering and biology since the 1970s. The NSF's enzyme engineering program is a stated example. Hamilton has indicated that biology should be added to foundational engineering education. Jeffrey Schloss, Program Director, Technology Development Coordination, National Human Genome Research Institute, National Institutes of Health (5) presented a recommendation in a NIH Bioengineering Consortium (BECON) symposium, that interdisciplinary teams of researchers will make the most rapid contributions in the field of nanotechnology. In addition, he stated that the new generation of students needs training with rigorous disciplinary depth and the ability to reach out to other disciplines. Mihail Roco, Senior Adviser for Nanotechnology, NSF, in a presentation to the ASEE (6) defined current primary areas of investigation as biosystems at the nanoscale, nanostructure by design, device and system architecture, and environmental processes. All include biology and chemistry components. Dr. Timothy Fitzimmons of the Division of Materials Sciences and Engineering, Department of Energy (7) defined four major research and development priorities. These included research and development concerning antiterrorism, nanotechnology, network and information technology, and climate change. These areas require core competencies in materials sciences and engineering, chemistry, geosciences, and physical biosciences. Dr. Fitzimmons (8) also defined ten areas of research interest. Among these were materials research to transcend energy barriers, energy bioscience, research towards the hydrogen economy, energy storage, novel membrane assemblies, heterogeneous catalysis, energy conversion, energy utilization efficiency, nuclear fuel cycles and actinide chemistry, and geosciences. These areas were identified as "multi-disciplinary in nature" and certainly blend engineering and chemistry.

The National Council of Examiners for Engineering and Surveying (NCEES) has also begun the process of incorporating elements of biology into the Fundamentals of Engineering Exam.

In summary, the rationale for this class falls into the following categories:
1) Advances in biology will require engineering expertise to implement associated technologies.

2) Current chemistry applications in engineering are numerous and advances will further expand the demand for engineers.

3) A biology component needs to be added to the engineering curriculum's core science requirements.

4) The student understanding of chemistry will improve due to this applications-based course.

5) An application-based biology and chemistry course will improve first-year student interest and motivation as well as broaden the scope of their preparation to study in the various fields of engineering

In sum, it is expected that growing opportunities exist for engineers in technologies related to biology and chemistry. It is imperative that universities "step up to the plate" to establish supporting curricula for the current generation of students.

Course Goals

In addition to teaching engineering applications based on biology and chemistry principles, this new course was designed to address the following goals with particular respect to the need for engineers to function in interdisciplinary teams. The following goals are consistent with the rationale addressed previously.

1) to help the student to become cognizant of the changing needs of humankind while interpreting and implementing biology and chemistry principles in engineering applications;
2) to encourage the student to recognize the wide applicability and interrelationship of the sciences (specifically, biology and chemistry) and engineering practice and to become skillful in their use;
3) to prepare the student for a world of accelerating scientific and technological change; and
4) To impress upon the student that education must be a continuous process throughout one's professional career.

Course Content

NTLS 120, a pilot course entitled **Biology and Chemistry Applications for Engineers** was offered to incoming first-year engineering students who have had advanced placement or honors chemistry in high school. In its present form, the class was offered as a 4-unit class offered twice per week for 3 hours. It was a combined lecture and "hands-on" experience for the students allowing access to classroom, field and/or laboratory facilities as necessary. Initial enrollment was 14 students.

Biology and Chemistry Applications for Engineers presented students with fundamental biology and chemistry concepts in the context of engineering and science applications. Based on the expertise of the two faculty teaching the course (a chemical/environmental engineer and a biologist and wetland ecologist), the class focused on the study of a freshwater aquatic microcosm. Based on the expertise of the faculty, this course offering was focused in civil/environmental engineering. Skills developed in the class are appropriate for the study of environmental impact of engineering decisions. Utilizing nearby Ballona Wetlands, a state-owned nature preserve, the students created their own freshwater microcosms using water, sediments, and plants from the freshwater portion of the marsh. Additionally, field trips to the salt water marsh allowed students to study ecosystem functioning and species diversity. Appropriate biology and chemistry principles as well as instrumentation were taught in order to support the students' hands-on lab and field work in these areas. Note that this is a first-year science course. As such, it is an introductory science course intended to provide the student with a stronger science background than he/she would have had otherwise. The biology is more focused and in depth than that encountered in a typical survey course. The chemistry presented is more advanced than that encountered in the LMU engineering core chemistry class. Both are applied and integrated into a more complete applied science and engineering experience. The course focused on four areas of microcosm function: key components, energy flow, ecosystem functions, and biodiversity.

Key Components of Aquatic Microcosm. This portion of the class began with basic chemistry concepts including the elements, molecules, chemical bonding, stoichiometry, molarity, and normality. Dissolved oxygen measurements were made within the microcosms and the concept of photosynthesis was introduced. pH measurements within the microcosms were used introduce acid-base chemistry. Acid-base chemistry was further demonstrated and equilibrium was introduced using alkalinity titrations. Salinity in the saltwater marsh was measured using a Mohr titration in order to demonstrate precipitation. The concept of solubility and its temperature dependence were studied in the lab. To this end, students measured dissolved oxygen concentrations at several temperatures. Oxidation-reduction reactions were demonstrated using anoxic sulfide rich sediments from the saltwater marsh. Finally, the students learned about more complex molecules (carbohydrates, proteins, and lipids) that make up cells and living organisms that were integral to their microcosms and Ballona Wetland.

Energy Flow within Aquatic Microcosm. In this area of study, photosynthesis and nutrient uptake were studied using spectroscopy to measure nutrient and chlorophyll concentrations in the aquatic microcosms. These measurements were used to introduce the concept of chemical kinetics and limiting reactants. Oxidation-reduction potential within the sediments was measured and studied as it applies to ecological oxidation-reduction reactions and the corresponding microbial communities in the marsh sediments. Students used enzyme test kits to study differing metabolic pathways within microbial communities. They compared the species diversity between healthy and unhealthy environments.

Ecosystem Functions and Biodiversity. Finally, with an understanding of the chemical processes and energy flow within the microcosms, students studied benthic infauna in the saltwater marsh as they apply to trophic levels and species diversity. Students collected sediments samples removing aquatic organisms for identification and study. Students used sulfur the create sulfur dioxide and studied the effects of acid rain on microcosm water quality and toxicity effects. This section of the class illuminated the impacts of the industry on the environment. Students studied first-hand the effects of acidity on microcosm function. The students were very interested in this cause-effect relationship.

During the semester, each student studied an environmental, industrial, or biological process or instrument of their choice with an emphasis on engineering. Each student researched his or her topic and presented the biological and chemical principles behind each process to the class. Topics included: catalytic converters, melatonin functioning, gene therapy, dissolved oxygen probes, drinking water fluoridation, and fecal bacterial indicator testing.

Course Goals Addressed

1) to help the student to become cognizant of the changing needs of humankind while interpreting and implementing biology and chemistry principles in engineering applications;

This goal was accomplished throughout the course as students learned about water quality indicators and the biology and chemistry-based methods used to measure these parameters. For example, students learned about the sources and impacts of salinity on natural waters. They measured salinity using traditional titration methods as well as more recently-developed conductivity probes.

2) to encourage the student to recognize the wide applicability and interrelationship of the sciences (specifically, biology and chemistry) and engineering practice and to become skillful in their use;

Throughout the course students were presented with basic chemistry and biology concepts which were then demonstrated in the laboratory or in the field. Whenever possible, the chemistry and biology concepts used in the engineering application were presented. For example, dissolved oxygen probes are based on oxidation-reduction reactions at the cathode and anode. These basic chemical reactions are used to generate electrical energy (e.g. batteries) for many engineering applications.

3) to prepare the student for a world of accelerating scientific and technological change; and

This goal was met as students studied many water quality technologies. They used enzyme test kits which are based on the chemical reactions mediated by metabolic pathways. The students created acid rain in the lab and then studied the impacts on their microcosms. They learned about changing technologies as well as the environmental impacts that may result from these technologies (e.g., coal-burning).

4) To impress upon the student that education must be a continuous process throughout one's professional career.

This is likely the most challenging goal to demonstrate; however, it can be said that the experimental nature of the course demonstrated the importance of information gathering and hypothesis testing. Throughout the course of the semester, microcosm observations were made and causes for these observations were hypothesized and tested when possible.

Conclusion

The first offering of Biology and Chemistry Applications for Engineers allowed for first-year engineering students to learn biology and chemistry principles in the context of engineering and science applications. Long-term assessment is difficult to address immediately following a class. On a short-term basis, student comments about the class can be collected and analyzed. The students in the class were surveyed concerning their opinions of the class. Overall, the students were very positive about the field work in the Ballona Wetlands, the "hands-on" elements of the class and the linkage of the lecture and lab material. As a first attempt, it can be concluded that the class was successful. It is expected that the course will ultimately become part of the science sequence for all first-year engineering students.

Bibliography

(1) Johnson, A.T., "Biology for Engineers," http://www.agnr.umd.edu/users/bioreng/predbiol.htm

(2) Nerem, R. M. "The Biological Revolution: Too Important to be Left to the Biologists, Too Important to be Left to the Bioengineers," http://www.asee.org/about/events/conferences/edi/upload/2004-EDI-Nerem-PDF.pdf, 2004.

(3) Panitz, B. "Bioengineering: the Next Major Engineering Discipline?," http://www.asee.org/about/publications/prism/upload/Panitz%201996.pdf , 1996.

(4) Hamilton, B. "Engineering, Biology, and NSF," http://www.asee.org/about/events/conferences/edi/upload/2004-EDI-Hamilton.pdf, 2004.

(5) Schloss, J. "Nanotechnology at the National Institutes of Health," http://www.asee.org/about/events/conferences/erc/presentations/upload/Nanotechnology-at-the-National-Institutes-of-Health.pdf, 2001.

(6) Roco, M. "NSF and Nanotechnology Update," http://www.asee.org/about/events/conferences/erc/presentations/upload/NSF-and-National-Nanotechnology-Update-2004.ppt, 2004.

(7) Fitzimmons, T. J. "The Office of Basic Energy Sciences and New Research for National Defense and Homeland Security," http://www.asee.org/about/events/conferences/erc/presentations/upload/The-Office-of-Basic-Energy-Sciences-and-New-Research-for-National-Defense-and-Homeland-Security.ppt, 2002.

(8) Fitzimmons, T. J. "Budget Priorities and Opportunities for the Office of Basic Energy Sciences and the Office of Science for FY 2004," http://www.asee.org/about/events/conferences/erc/presentations/upload/Budget-Priorities-and-Opportunities-for-the-Office-of-Basic-Energy-Sciences-and-the-Office-of-Science-for-FY-2004.ppt, 2004.