NSF CCLI: Developing a Molecular Biology Lab Course in Environmental Engineering and Science

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Abstract.

Using support from a NSF CCLI, a NSF CAREER award, and two NSF workshop grants as well as resources from the Ohio Board of Regents, the Ohio Environmental Protection Agency, and the Department of Civil and Environmental Engineering, we have developed a new course and associated short course to teach molecular biology skills to undergraduate and graduate students in environmental engineering and practitioners of environmental engineering across the state of Ohio and around the world. During the past two years, we have offered a term-long course in molecular biology to undergraduate and graduate students at the University of Cincinnati. In the first three course offerings, enrollment has spread beyond the initial target audience of the Department of Civil and Environmental Engineering and now includes students from electrical engineering, chemical engineering, chemistry, the biological sciences, and the College of Medicine. A unique aspect of this course is that we focus upon an extended problem-based learning example that underlies all course activities. The students select an environmental sample of their own choosing, and the molecular biology procedures employed in the course allow students to systematically identify unknown microorganisms present in their sample. Each week, student teams make progress by completing an additional "step" in the process of identifying unknown microorganisms. The course follows the experimental procedure known as the "full-cycle 16S rRNA-approach" employed in environmental microbiology research laboratories. Because the course follows a problem-based learning approach, the engineering students are not overwhelmed by the unfamiliar vocabulary of molecular biology and the non-engineering students are pleased to have an opportunity for "hands-on" learning of basic molecular biology skills that they may have only been exposed to in a theoretical fashion within their lecture-based coursework. By employing teams of students working together to conduct laboratory assignments, students with strong backgrounds in biology are matched up with students with poor backgrounds in biology. This allows team members to learn from each other, and takes maximal advantage of students teaching students. The initial success of our pilot program is encouraging, and suggests that the format developed at the University of Cincinnati could be exported to other Universities for replication.

Introduction.

Biology has become an important science for engineers. For environmental engineers, biology is important for at least two reasons, namely: (a) environmental engineers need to find ways to remove infectious agents from drinking water; and (b) environmental engineers use microorganisms as biocatalysts to degrade pollutants in sewage as well as in sites undergoing

bioremediation. At the University of Cincinnati, we have developed a series of courses to introduce engineering students to the principles of biology. These courses include, "Introduction to Environmental Engineering," required of all third year civil engineering students. In the senior year, civil engineering students who have opted for a concentration in environmental engineering also take, "Chemistry and Biology of Environmental Systems." Both of these courses are intended to introduce engineering students to basic tenants of biology and to help provide a link between biology courses taken during the second and third years of high school and college-level biology courses. The third course in our series is offered as a split-level to both seniors as well as graduate students. This course is entitled, "Biological and Microbiological Principles of Environmental Systems," and the main emphasis is to introduce microbial biochemistry and physiology. The capstone course, entitled, "Molecular Biology in Environmental Engineering," is a split-level course offered to both seniors and graduate students. Enrollment is not limited to only civil and environmental engineering students, and we encourage the participation of students from engineering, the life sciences, and medicine.

"Molecular Biology in Environmental Engineering," has been supported by funding from the National Science Foundation to Professor Daniel B. Oerther (DUE-0127279). The purpose of the NSF support included the purchase of additional laboratory equipment and the further development of a digital lab manual distributed to students via DVD-ROM.

The success of "Molecular Biology in Environmental Engineering," has been documented previously in a number of refereed publication (1, 2, 3, 4). Rather than repeat the details outlined in those documents, we propose to describe the broader impacts of this course for the education of environmental engineers, in particular, and engineering students, in general.

Details of the NSF CCLI-sponsored project.

Project objective. The objective of our Course, Curriculum, and Laboratory Innovation (CCLI) proposal is the development and evaluation of proof-of-concept educational materials exposing undergraduate students in Civil Engineering to state-of-the-art advances in Environmental Biotechnology research and genome-enabled environmental science and engineering.

Specific aims. To meet the objective of the project, we are addressing six specific aims (SA) over a period of two years, including:

1. We converted preliminary teaching materials from our successful Pilot Course, "Molecular Biology in Environmental Engineering", into a seamless electronic format that is presented to students as an interactive Web-based learning instrument.
2. We utilized existing course content and the new teaching materials developed in SA1 to teach Proof-of-concept Course I in the Spring of 2002 with a mixture of undergraduate students in Civil Engineering and graduate students in Environmental Engineering and Science.
3. We evaluated the success of introducing undergraduate students to genome-enabled research through an inquiry-based laboratory exercise and lecture-discussion sessions.
4. We are in the process of modifying the course content and teaching materials developed in SA1 in response to the student evaluations collected in SA3.

5. We plant to utilize the modified course content and teaching materials developed in SA4 to teach an updated Proof-of-concept Course II in the Spring of 2003 with a mixture of undergraduate students in Civil Engineering and graduate students in Environmental Engineering and Science.
6. We plan to evaluate the success of Proof-of-concept Course II content and teaching materials and determining the appropriate format for local, state, and national dissemination including: continued course development; expansion to include undergraduate students in Biomedical Engineering and Chemical Engineering; commercial distribution of the course content and teaching materials; presentations at national meetings of engineering educators and publication in the archival educational literature.

Broader impacts of this teaching initiative.

Teaching civil and environmental undergraduate and graduate students about molecular biology in environmental engineering is only the starting point for the development of our course. Because biology has become such a pervasive science, a broader education for engineering students is needed. Arguably, all engineering students must be exposed to the basic tenants of biology if they are to function as responsible and informed citizens in a society threatened by bioterrorism and struggling with the ethical issue of human cloning. Although these examples demonstrate the critical need for engineers to understand biology, they only represent the "tip of the iceberg" in terms of the need for engineers to receive formal training in biology.

Nationally, the growth of biology-related job opportunities and biology-related ethical issues has caught engineering curricula flat footed. Today's engineering undergraduate is essentially the same as the undergraduate engineering students trained in response to the 1960's space race. Engineers have strong backgrounds in mathematics, physics and chemistry; practiced analytical skills; and an appreciation for integrated systems. To remain competitive, tomorrow's engineering undergraduate must have a strong background in biology as well. Our long-term objective is the development of a curriculum that integrates biology to a degree comparable to the current integration of chemistry, physics, and mathematics. Ultimately, our goal is to dramatically overhaul existing engineering curricula and integrate biology for engineers within all levels of formal engineering education. Some of the short and long-term benefits of the changes we propose include developing a pool of qualified undergraduate engineering students for biology-related engineering jobs and graduate engineering education and improving the capability of undergraduate engineers to practice informed citizenship in a biology-driven world.

Although one remedy is to simply require engineering students to take courses offered by departments of biological sciences in colleges of arts and applied sciences, we do not believe that existing introductory courses offered by biology departments satisfy the need of introducing engineers to biology. First and foremost, the primary goals of biology courses include serving the needs of the undergraduate biology job market, biology graduate studies, and pre-medicine students. Biology for engineers requires an inherently interdisciplinary approach focusing upon biological principles from an engineering point of view. Biological engineering is an emerging new discipline that interfaces with existing engineering disciplines and the biological sciences. For introductory courses offered by biology departments to satisfy the national need of

undergraduate engineering curricula, faculty in biology departments must understand the "way an engineer learns." For example, introductory biology often emphasizes vocabulary and anecdotes while employing memorization and recitation. In contrast, engineers are taught using problem-based design examples employing derivation of equations from first principles. Biology courses often require students to prepare essays over-viewing research topics or central themes in biology emphasizing learning through synthesis. Engineering courses often require students to complete extensive problem sets emphasizing learning through repetition of analytical procedures. To be successful, biology for engineers must employ widely-adopted engineering learning strategies.

At the University of Cincinnati we have begun to dramatically revamp our curriculum beginning with the emphasis we place on biology in courses offered in the Department of Civil and Environmental Engineering. The development of "Molecular Biology in Environmental Engineering" with support from NSF represents a critical point in our efforts. The next step for our approach is to recruit individuals from other universities with similar interests and a desire to adopt and modify our teaching materials to suit their needs. Dissemination of our pilot-tested teaching materials is the next step in our development of a broadly applicable curriculum integrating principles from biology with classic engineering design.

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Biographical Information.

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