A MULTIDISCIPLINARY COURSE IN BIOENGINEERING

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THIS COURSE WAS first taught solely through the chemical engineering department (1985 thru 1987) under the quarter system and was called Microbiological Process Engineering. During semester transition the course was expanded to fifteen weeks, and a six-week laboratory was added. The course was then crosslisted in the departments of civil engineering (as an environmental course) and microbiology, and it was given a truly crossdisciplinary nature with the addition of faculty from those departments. It is presently a graduate course which is taught during the fall semester every year, and it attracts first year graduate students and some seniors from chemical engineering, environmental engineering, and engineering science and mechanics, in addition to life science graduate students from microbiology, ecology, and the Masters program in biotechnology. The course is now part of the required curriculum for the Masters program in biotechnology.

Figure 1 shows where the course (575) fits into the applied bioengineering curriculum at Tennessee. It serves as a prerequisite for courses in environmental engineering, chemical engineering, and microbiology which are offered during the spring semester. ENVR 552 is directed specifically at applications for wastewater treatment; ChE 577 addresses the development of specific models for pure cultures and their applications for producing high value biotechnology products;

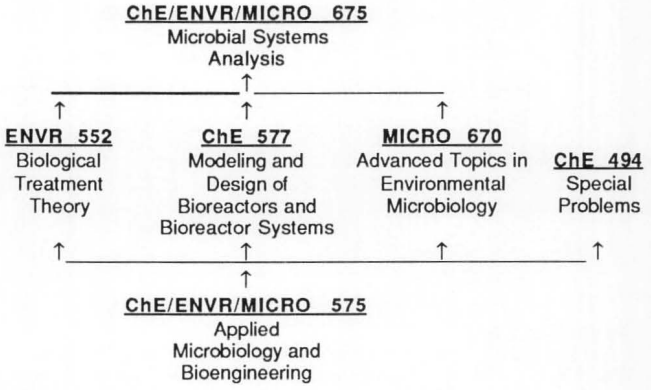
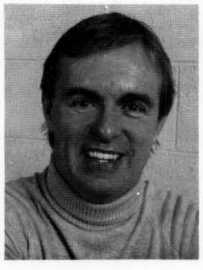
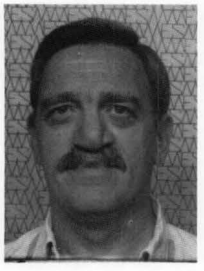


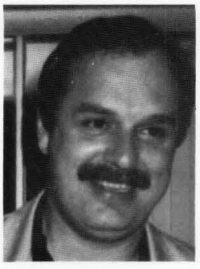
FIGURE 1. Core Courses in Bioengineering



Paul R. Bienkowski is an associate professor of chemical engineering at the University of Tennessee, and is a member of the Center for Environmental Biotechnology. He received his PhD in 1975 from the school of chemical engineering at Purdue University.



Gerald W. Strandberg is a staff scientist in the Chemical Technology Division at the Oak Ridge National Laboratory, and is an adjunct associate professor in the department of Microbiology at the University of Tennessee. He received his PhD in bacteriology in 1966 from the University of Wisconsin.



Gary S. Sayler is a professor of microbiology and ecology, directs the UTK/ORNL Center for Environmental Biotechnology, and is director of research for the Waste Management Institute Center of Excellence at the University of Tennessee. He received his PhD in 1974 from the department of bacteriology and biochemistry at the University of Idaho.

Gregory D. Reed is professor and head of the department of civil engineering at the University of Tennessee. He received his PhD in environmental engineering from the University of Arkansas and has an active research and publication record. He has been active in several professional societies and is currently the Chair of the Environmental Engineering Division of the American Society of Civil Engineers.

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The primary objective of this course is to introduce the engineering students to bioengineering and to allow them to communicate effectively with students in the life sciences. In subsequent semesters the engineering students can develop strong backgrounds in microbiology, biochemistry, *etc.*, by taking courses in the life sciences and by working on crossdisciplinary research projects . . .

Micro 670 is directed at understanding the microbial degradation and effects of toxic waste materials such as PCB's, PAH's, and TCE's. These courses all have direct applications in all three disciplines. What is required is a common starting point, and 575 meets that need. Chemical engineering seniors who take this course may elect to do an undergraduate thesis at the Center for Environmental Biotechnology during the spring semester. ChE 494 is used to give academic credit to these students for their research experience. Usually one or two students can be accommodated on center research projects each spring and/or summer.

ChE COURSE OBJECTIVES

The undergraduate curriculum in chemical engineering is very demanding and does not allow much room for alternate course selection by the student. Many new engineering graduate students with research interests in bioengineering do not have sufficient background and require additional course work before they can begin their research projects. These students could rapidly advance their knowledge base in this area by working with graduate students from the life sciences (in environments like Tennessee's Center for Environmental Biotechnology) if only they could communicate effectively with the life science students, *i.e.*, speak the language of a microbiologist. For example, there are different meanings for CSTR and chemostate, and the different way kinetic data is interpreted (the engineer's dynamic approach vs. the static approach of the life scientist). The primary objective of this course is to introduce the engineering students to bioengineering and to allow them to communicate effectively with students in the life sciences. In subsequent semesters the engineering students can develop strong backgrounds in microbiology, biochemistry, *etc.*, by taking courses in the life sciences and by working on crossdisciplinary research projects or doing a ChE 494 senior research project in this area. ChE 575 provides the base from which to start the educational experience, it provides the basic background to start graduate research, and it feeds into more advanced biotechnology courses in several disciplines.

Most engineering students have no experience in a microbiology laboratory and do not have the time or the background to take a microbiology lab. ChE 575 had a mandatory six-week laboratory which is specifically designed to give engineering students hands-on experience with the basic day-to-day laboratory problems faced by a microbiologist, such as sterilization, culture purity, analytic methods, *etc.* It is much easier to communicate with students and faculty in the life sciences, and to interact in crossdisciplinary research projects, if the engineering students are familiar with the problems faced by their counterparts in the life sciences. The third objective was to improve communications and to gain new insight by interacting and exchanging ideas.

COURSE STRUCTURE

Table 1 gives a detailed outline of the material covered in this course. Basic biochemistry and microbiol-

TABLE 1
Course Outline

Period	*Time (hrs)*	*Topic*
1	1.5	Introduction/Overview of Biotechnology
2	1.5	Biochemistry
3	1.5	Microbiology Physiology
4	1.5	Microbiology Physiology
5	1.5	Stoichiometry (mass and energy balances)
6	1.5	Enzyme Kinetics
7	3.0	*Lab #1: Basic Microbiology Techniques*
8	3.0*	Enzyme Kinetics / *Lab #1*
9	3.0	*Lab #2: Cell Growth*
10	3.0*	Growth Kinetics / *Lab #2*
11	1.5	Reactor Analysis
12	1.5	Continuous Culture
13	3.0	*Lab #3: Enzyme Kinetics*
14	3.0*	Continuous Culture / *Lab #3*
15	3.0	*Lab #3: Enzyme Kinetics*
16	3.0*	Cell/Enzyme Immobilization / *Lab #3*
17	3.0	*Lab #4: Enzyme Immobilization*
18	3.0*	Metabolic Pathways / *Lab #4*
19	3.0	*Lab #5: Continuous Culture*
20	3.0*	Metabolic Pathways/Modeling / *Lab #5*
21	1.5	Sanitary / Virology
22	1.5	Mid Term Examination
23	1.5	Molecular Biology / Recombinant DNA
24	1.5	Molecular Biology / Recombinant DNA
25	1.5	Biosensors
26	1.5	Commercial Processes
27	1.5	Biodegradation / Deterioration
28	1.5	Wastewater Treatment
29	1.5	Wastewater Treatment
30	2.0	Final Examination

*Split period: 1.5 hours of lab, 1.5 hours of lecture

ogy are covered, then reaction kinetics followed by lectures on important specialized topics in bioengineering such as immobilization, biosensors, and recombinate DNA. The course concludes with discussions on specific applications which lead into ChE 575, ENVR 552 and MICRO 670. The text book is *Elements of Bioenvironmental Engineering*, by A. L. Gaudy and E. Gaudy. This book was selected because it gives good coverage of the desired material and is very readable from both an engineering and a life science standpoint (one of the authors is an engineer and the other is a microbiologist). The coverage of biochemistry and microbiology is such that an engineering student can read and understand the material with essentially no background, while the mathematics describing enzyme and growth kinetics and continuous reactors is kept on a level which can be handled by the life science students. Two faculty are present at all lectures, one from engineering and the other from the life sciences. One of the faculty will lecture and the other will be present to stimulate discussion and insure that both engineering and life science viewpoints are taken into consideration when discussing the various topics. Engineers and life scientists frequently look at the same problem from vastly different viewpoints, and combining these approaches frequently gives a better insight into the problem.

TABLE 2
Description of Laboratory Experiments

Laboratory #1: Basic Microbiology Techniques

Students are provided with cultures of *E. coli, Saccharomyces cerevisiae, Bacillus subtilis,* and *Streptomyces phaeochromogenes.* Both live and stained (gram, methylene blue) organisms will be examined microscopically. The students will also do plate counts and sugar utilization tests.

Objective • Teach basic laboratory protocols to the engineering students.

Laboratory #2: Growth and Substrate Utilization

Growth and substrate utilization of *B. subtilis* will be examined in batch culture. Growth will be determined by optical density, dry weight, and plate count measurements. Substrate (glucose) utilization is monitored by dinitrosalycylic acid (DNS) assay for reducing sugars. The cells will be saved for use in Laboratory #3.

Objectives • Determine typical batch growth and substrate utilization curves and teach measurement methods.

Laboratory #3: Enzyme Kinetics

Examine the kinetics of glucose isomerase in *B. subtilis* and *S. phaeochromogenes* using whole cells.

Objectives • Determine the Michalis parameters K_m and V_{max}, the effects of temperature and pH, and substrate specificity.

Laboratory #4: Immobilization/Kinetics of Immobilized Enzymes

Immobilize glucose isomerase (whole cells of *B. subtilis*) using calcium alginate, and perform kinetic studies.

Objectives • Teach a method for immobilization of cells/enzymes and determine the effects immobilization has on enzyme kinetics.

Laboratory #5: Continuous Culture (demonstration)

A continuous culture fermentation system will be set up and operated by the TA. The students will measure optical density, cell dry weight, and glucose isomerase activity.

Objective • Determine μ, μ_{max}, the yield constant, and washout.

LABORATORY

Table 2 gives a brief description of the five experiments which comprise the laboratory. Gerald Strandberg is in charge of the laboratory and is supported by a teaching assistant from the Masters program in biotechnology. The course has the use of the biotechnology laboratory in the Walters Life Science building which is dedicated to the Masters program in biotechnology (experiments do not have to be terminated at the end of a laboratory period). The lab is conducted for six weeks, with four and one-half hours of instruction in the laboratory each week. Extra lab time is available to the students by making arrangements with the teaching assistant. Each lab group is composed of one engineering student and one life science student. Because most of the engineering students do not have experience in a microbiology laboratory, pairing them with other life science students is a most effective way for the engineering student to learn basic laboratory techniques on a one-on-one basis. At the same time the engineering student can assist his/her lab partner in designing experiments and in analysis and interpretation of the experimental data (modeling data and using models for data interpretation).

CONCLUDING REMARKS

This course is very effective in serving as a focal point for bringing people together from different backgrounds and in effectively and rapidly introducing engineering students to the biotechnology area. The microbiology laboratory is a unique addition to a chemical engineering course which allows both first year graduate students and seniors a hands-on experience. The course is an effective vehicle for preparing chemical engineering graduate students for research projects in the biotechnology area. It not only gives them the background to communicate with life science students in collaborating on joint research, but also prepares them for more advanced course work in this area. □