2006-641: DEVELOPMENT OF AN ENVIRONMENTAL BIOLOGICAL PROCESSES COURSE IN AN UNDERGRADUATE ENVIRONMENTAL ENGINEERING CURRICULUM

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Introduction

Environmental engineering students study a wider variety of scientific subjects than most other engineering students due to the breadth of the environmental engineering field. Traditionally, the biology taught in many environmental engineering programs has been focused on biochemical treatment and transmission of communicable diseases. However, a more comprehensive understanding of biology is now considered necessary to solve emerging problems with pollution, ecosystem destruction, and species extinction.[1] Indeed, genetic engineering and techniques used in the field of medicine are being used to study and solve numerous environmental problems. The ABET criteria for environmental engineering programs state that students must have proficiency in a biological science, e.g., microbiology, aquatic biology, or, toxicology, relevant to the program of study. Unfortunately, students in some environmental engineering programs have not participated in a biology course since their sophomore or junior year in high school.[2] Consequently, a traditional course in biochemical treatment processes (e.g. domestic wastewater treatment) may not satisfy the ABET biological science requirement. There are approximately 50 ABET accredited environmental engineering programs and the number is steadily increasing. An assessment of how these programs are addressing biology in their curricula has not been reported. This work compares the biology component of selected ABET accredited undergraduate programs; identifies common threads among programs and texts; and, presents a course currently taught at the US Military Academy (USMA) as an approach for fulfilling its ABET biological science requirement.

Schemes used to fulfill the ABET biological science requirement

Table 1 presents schemes used by undergraduate ABET accredited environmental engineering programs to address the ABET biological science requirement. These programs were identified via the ABET website and then examined based on information published on their respective program and registrar web sites. Programs were omitted if their information could not be obtained. The courses presented in Table 1 are offered in addition to traditional biochemical treatment courses. In other words, a program that offers only a course on wastewater treatment would not appear in this table. Some of the courses are based on quarters and other on semesters, which could influence the number of topics discussed. Based on this assessment, 81% of the programs evaluated require an additional course in biology. Fifty eight percent of programs require students to take a biology course with another department (e.g. life sciences), and 2% require students to take a hybrid biology course taught within the department (one of those programs also required an external biology course).

Table 1. Biology Courses offered by ABET Accredited Undergraduate Programs.

School	Qtr or Sem	*Hybrid*				*Microbiology*				*General Biology*			
		Req'd		Elective		Req'd		Elective		Req'd		Elective	
		Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext
California Polytechnic State University	S						√						
University of California, Irvine	Q										√		
University of California, Riverside	Q				√						√		
University of Central Florida	S				√						√		
University of Colorado at Boulder	S	√											
Colorado State University	S						√						
Columbia University	S			√									
University of Delaware	S		√		√				√				
Drexel University	Q&S						√						
University of Florida	S	√											
Humboldt State University	S										√		
Louisiana State University and A&M College	S										√		
Manhattan College	S		√										
Massachusetts Institute of Technology	S	√,a		√									
University of Miami	S	√											
Michigan Technological University	S		√								√		
Montana Tech of the University of Montana	S										√		
University of Nevada-Reno	S	√									√		
University of New Hampshire	S	√,b											
New Mexico Institute of Mining and Technology	S		√								√		
State University of New York at Buffalo	S						√						
North Carolina State University at Raleigh	S										√		
Northern Arizona University	S			√							√		
Northwestern University	Q	√											
The Ohio State University	Q						√						
The University of Oklahoma	S	√											√
Old Dominion University	S												
Pennsylvania State University	S			√									
Polytechnic University of Puerto Rico	Q						√						
Rensselaer Polytechnic Institute	S	√											
Roger Williams University	S												
San Diego State University	S										√		
University of Southern California	S										√		
Southern Methodist University	S										√		
Stanford University	Q			√,a									
Stevens Institute of Technology	S												
Syracuse University	S	√											
Tufts University	S										√,a		
Tulane University	S			√									
United States Air Force Academy	S								√		√		
United States Military Academy	S	√											
Utah State University	S						√				√		
Wilkes University	S				√,c								
	Totals	11	4	6	4	0	7	0	2	0	17	0	1
	Percent of Programs Considered	26	9.3	14	9.3	0	16	0	4.7	0	40	0	2.3

a = combined biology and chemistry course; b = course required for Municipal Program, but not Industrial Program; c = can take biogeochemistry or material science; Int = Internally Taught; and, Ext = Externally Taught
NOTE: Four schools have check marks in two required categories

The term hybrid implies that the course could cover a range of topics from microbiology, biology, toxicology, limnology, etc. What is the incentive to offer a hybrid course? One incentive is that many traditional microbiology courses put too much emphasis on topics needed for medical school and include only brief discussions on environmental biological topics. In addition, faculty within an environmental engineering program should be most familiar with areas that are covered in subsequent courses, which could allow a more streamlined presentation of material. Thirdly, this allows the program coordinators to thread this course with other program courses thereby enhancing "higher level" learning in other program courses.

Table 2 presents topics covered in hybrid courses offered within environmental engineering programs (i.e. taught by faculty within the environmental engineering program) to fulfill the ABET biological science requirement. In some cases, assessment is based on very limited information available on the web or additional information obtained from faculty. The majority of these courses include introduction to biochemistry, basic cell structure and cell function. Many also include cell metabolism, energetics, and growth kinetics. The difference between some courses is likely a function of the unique biological science requirement of their programs. Due to the variety of topics that can makeup a hybrid environmental biology course, it may be beneficial to co-teach the course or invite guest lecturers. The course taught at USMA employs at least three guest lecturers.

Hybrid environmental biology courses

Based on the assessment of environmental programs discussed above and selected texts in this area, it was determined that biological topics relevant to the program of study can be grouped in the following categories: fundamentals; biotechnology and wastewater treatment; water treatment; public health; and, ecology and ecosystems. Table 3 presents potential topics that would support a course covering one or more of these categories. The topics presented under each category do not represent an exhaustive list. In addition, topics that could be listed under more than one category were listed once to save space. The topics span a number of disciplines including biology, microbiology, toxicology, colloid chemistry, organic chemistry, epidemiology, etc. Most courses would likely include at least some topics from the fundamentals block and several topics from other categories. Because of the breadth of topics that could be offered in a hybrid course, text selection may be quite challenging. Four environmental biology texts and two microbiology texts were examined to compare their coverage on topics within each category. In-depth coverage of a topic, for the purposes of this paper, is defined as providing enough material and breadth such that additional resources would not typically be needed at the undergraduate level (i.e. the text is self supporting). As expected, none of the texts provided in-depth coverage on all of the topics. It is plausible to assume that faculty might require additional resources to attain sufficient background reading on some topics. For example, the course taught at USMA uses additional resources from two textbooks, an introduction to environmental engineering textbook and a wastewater engineering textbook, required for other courses within the program. These texts support the applied and environmental biology portion of our course.

Table 2. Topics Covered In Hybrid Courses Offered Within Environmental Engineering Programs.

	University of Colorado at Boulder	Columbia University	University of Florida	Massachusetts Institute of Technology	University of Miami	University of Nevada-Reno	University of New Hampshire	Northern Arizona University	Northwestern University	The University of Oklahoma	Rensselaer Polytechnic Institute	Stanford University	Syracuse University	Tulane University	United States Military Academy
Fundamentals of Biochemistry	√	√	√	√	√	√	√	√	√		√	√	√	√	√
Cell Types/Structure/Function	√	√	√	√	√	√	√	√	√	√	√		√	√	√
Epidemiology	√				√			√	√						√
Public Health (e.g. regs, growth of indicator organisms)	√	√	√	√	√			√	√	√				√	√
Reaction Kinetics/Growth Models	√	√	√	√		√	√			√	√	√	√		√
Introduction to Cell Metabolism/Energetics	√	√	√	√		√	√	√		√	√				√
Biochemical/Chemical Oxygen Demand	√	√	√	√		√	√	√		√					√
Limnology & Eutrophication	√														√
Biogeochemistry/ Nutrient Cycling	√		√	√	√	√				√	√	√	√		√
Bioremediation	√	√		√	√	√	√	√		√	√				
Degradation Pathways						√	√			√				√	
Biowarfare/Bioterrorism	√														√
Genetic Engineering								√		√					
Disinfection	√		√		√	√									√
Ecology	√			√	√	√		√							
Methods	√	√		√		√	√			√	√				√
Wastewater Processes	√	√	√					√		√	√			√	
		a	**a**	**b**	**a**		**c**	**d**	**a**			**b,e**	**a**	**a**	

a = limited information available; b = combined biology and chemistry course; c = based on ENE656; d = extensive public health material; and, e = may be an elective

Table 3. Potential Hybrid Course Categories and Topics (left). Coverage Provided by Selected Texts (right).

Unit	Topic Ref.	1	3	4	5	6	7
Fundamentals							
	History of Microbiology			○	●	●	●
	Introduction to Biochemistry	○			○	●	●
	Cell Structure & Function	○	○	○	○	●	●
	Taxonomy & Classification	●	○	○	○	●	●
	Energy & Metabolism Overview	●	○	○	●	●	●
	Genetics	●	○	○	○	●	●
	Cell and Population Growth	●	○	●	●	●	●
	Identification and Quantifying Microbes	●	○	●	○	○	
Biotechnology & Wastewater							
	Advanced Microbial Metabolism	○	○	○	○	●	○
	Microbial Thermodynamics/Energetics	○	○	○	○	○	
	Microbial Kinetics (e.g. Monod Growth Model)	●	○	○	●		
	Mass Transfer & Biofilm Kinetics	○	○	○			
	Contaminate Structure, Toxicity & Biodegradability	●	○	●	○		
	Relationship Between Contaminant Structure, Toxicity, & Biodegradability	●	●	●			
	Degradation of Organic & Inorganic Pollutants (Metabolic & Cometabolic)	○	●	●	○	○	○
	Genetic Engineering	○	○			●	○
Water Treatment							
	Waterborne Pathogens (Bacteria, Parasitology, Viruses)	○	●	●	●	○	○
	Environmental Sample Collection and Processing	○	○	●		○	
	Microbial Enumeration (Cultural, Nucleic Acid Based, and Immunological)	●	○	●	○	○	
	Indicator Organisms and Regulatory Standards	○	○	●	○	○	○
	Disinfection	○	●	●	○	○	○
Public Health							
	Disease Processes	●	○		○	○	●
	Toxicology	●					
	Diseases (Water-, Food-, Air-, Vector-, Sexually-Transmitted)	○	○	○	○	●	●
	Epidemiology	○				●	●
	Public Health Organizations				○	○	
	Identification & Quantification of Microbes in Water/Air/Food/Soil	○	○	○		○	
	Environmental Sample Collection & Processing	○	○	●		○	
	Methods of Limiting Exposure & Controlling of Infection	○				●	●
	Dose-Response Relationships & Risk Assessment	●		●			
	Biowarfare & Terrorism		○			○	○
Ecology & Ecosystems							
	Mass & Energy Flows in Ecosystems	●	○	○	○	○	○
	Biogeochemical Cycling	●	●	●	○	○	○
	Terrestrial, Freshwater, Wetland & Marine Ecosystems	●		●		○	○
	Microbial Transport	●	○	●		○	○
	Streeter Phelps Model of Dissolved Oxygen Sag	○					
	Fate & Transport of Toxins	●	●	○			
	Microbially Catalyzed Pollution (e.g. Acid Mine Drainage)	●	○	●		○	○
	Extreme Environments			●		○	○
	Microbes in Agriculture			●		○	○

● = in-depth coverage of topic and ○ = general overview of topic

Many of the critical thinking skills described in Blooms taxonomy can be accomplished via laboratory experiences.[8,9] And, ABET accredited programs are required to include lab experiences. The objectives of lab experiences include:[8,10] instrumentation, experiment, data analysis, design, learning from failure, creativity, communications, teamwork, and ethics. Table 4 presents laboratory exercises that could be used to support topics in each of the categories. Some of these exercises can be time and resource intensive. Many have been published as microbiology lab course texts.[11] The Association of Environmental Engineering and Science Professors also offers a laboratory manual that includes biological experiments.[12]

Table 4. Hybrid Course Categories and Potential Laboratory Exercises.

Unit	Laboratory
Fundamentals	
	Aseptic Technique and Microscopy
	Staining
	Bacterial Growth
Biotechnology & Wastewater	
	Identification and Quantification of Microbes in Water & Soil
	Chemical/Biological Oxygen Demand
	Genetic Transformations
	Gas Transfer
	Chemostat/Kinetics (Aerobic & Anaerobic)
	Pollutant Detoxification
Water Treatment	
	Indicator Organisms and Regulatory Standards
	Disinfection
Public Health	
	Indicator Organisms and Regulatory Standards
	Identification of Microbes in Beef & Poultry
	Disinfection
	Identification of Unknown Organism
Ecology & Ecosystems	
	Indicator Organisms and Regulatory Standards
	Identification of Microbes in Soils
	Nitrification or Nitrate Reduction
	Winogradsky Column
	Phytoremediation

Hybrid course at USMA

The USMA Environmental Biological Systems course examines biology from a practical environmental engineering and environmental science perspective. This course prepares environmental engineering students for more advanced courses in physicochemical, biochemical, and hazardous waste treatment. The course outcomes are provided below.

a. Discuss phylogeny of the living world.
b. Describe characteristics of prokaryotic and eukaryotic cells.
c. Discuss and evaluate the history, importance, and application of public health microbiology and preventive medicine.

d. Evaluate microbial metabolic processes and microbial energetics with regards to microbial growth and environmental applications.
e. Evaluate biochemical oxygen demand and biodegradation, in engineered and natural systems, and relate to microbial growth.
f. Evaluate of the influence of biochemical oxygen demand on dissolved oxygen in water bodies and the aging of water bodies.
g. Evaluate the efficacy of disinfectants for producing drinking water, treating wastewater, and decontamination operations.
h. Discuss key aspects of applied biological and biogeochemical processes such as eutrophication, biogeochemical cycling of nutrients, limnology, and biowarfare.
i. Recognize common parameters used to establish regulatory standards for indicator organisms.
j. Describe and conduct laboratory procedures that can be used to support evaluation of the topics listed above.
k. Evaluate current environmental biological issues presented in the media.

The course syllabus is presented in Table 5. During the first block, students discuss introductory biochemistry, cell structure, and function. Labs during the first block include aseptic technique and microscopy, and introduction to genetic engineering. The genetic engineering lab, a new addition to our hybrid course, will demonstrate genetic transformation of a non-pathogenic strain of *E. coli* to one that fluoresces and has antibiotic resistance. This lab is easy to set-up and perform with the lab kit provided by Bio-Rad Laboratories, Inc. (catalog # 1660003EDU). The second block of the course provides students with an overview of disease processes and preventive medicine in the Army. Guest lecturers in this block include Dr. Dwight Bowman, a Parasitologist from Cornell University, and Major Tom Timmes, an Army Medical Service Corps officer. This block concludes with students giving a medical threat brief (oral presentation) in preparation for deployment to a developing nation. A senior officer in the department serves as a brigade commander, who is preparing to deploy his troops. During the spring 2005 semester, students gave briefs on Cuba, Honduras, Kosovo, Liberia and Thailand. Block three places an emphasis on the thermodynamics of metabolism including electron donors, terminal electron acceptors, and yield. The students discuss specific examples including methanogenisis, nitrification, and reduction of sulfate. This block culminates with the students conducting a fermentation experiment and predicting the amount of alcohol that can be fermented from a known amount of sugar. The predictions are compared with measured values from specific gravity, refractive index, and, gas chromatography. The final block covers a range of applied topics with a focus on disinfection, biochemical oxygen demand, eutrophication, and, the Streeter Phelps Dissolved Oxygen model. Labs during this block include disinfection and oxygen demand. As part of the disinfection lab, students quantify microbial growth via the membrane filtration technique; quantify log kill for a particular chlorine dose (CT); quantify log kill as a function of UV dose with a collimated beam apparatus; assess the quality of data produced by their peers; and, determine inactivation rate constant using the Chick Kinetic Model. In addition, this lab is threaded into a concurrent disinfection lab in our physicochemical treatment course such that students use the experience and knowledge gained from the hybrid course and apply it to disinfection in plug flow and completely mixed reactors. This is an example of how an internally taught hybrid course can be threaded with other courses to enhance learning. The lab on oxygen demand has students analyze a water sample for COD; nitrogenous and carbonaceous BOD; total coliforms using the MPN method; and, determine if the water sample is safe based on coliform results. The final block also includes a guest lecture on biowarfare, from a Army Chemical Corps Officer; and introductions to nutrient cycling and bioremediation.

Table 5. Hybrid Environmental Biological Systems Course Offered at The United States Military Academy

Block I - Overview	
	Introduction to Environmental Biology
	Fundamentals of Biochemistry
	Basic cell types, structure and function
	Viruses
	Introduction to Taxonomy
	Lab: Introduction to Microbiology
	Lab: Genetic Engineering I
	Lab: Genetic Engineering II
Block II – Preventive Medicine	
	Disease Processes
	Introduction to Epidemiology
	Public Health and Preventive Medicine & Deployment
	Case Study: Outbreaks Involving Parasites
	Lab: Deployment Briefs
Block III – Cell Processes	
	Introduction to Cell Metabolism
	Glycolysis and Fermentation
	Respiration
	Respiration: Thermodynamics & Env Applications
	Photoautotropy
	Growth and Culturing of Bacteria
	Estimating Biomass Yield
	Lab: Fermentation I
	Lab: Fermentation II
Block IV – Applied and Environmental Biology	
	Disinfection and Sterilization
	Disinfection and Sterilization II
	Lab: Disinfection
	Microbial Growth in Batch Systems
	Biochemical Oxygen Demand
	Indicator Organisms
	Lab: COD/BOD and Indicator Organisms
	Biochemical Oxygen Demand: Problem Solving
	Dissolved Oxygen in Natural Systems
	Limnology & Eutrophication
	Introduction to Biowarfare
	Biogeochemical Cycling
	Introduction to Bioremediation

The course outcomes are assessed after each semester that the course is offered. The course director uses student performance on graded events and in-class exercises, student input, and faculty input as a means of assessing the course outcomes. The contribution of the course outcomes to the program outcomes is assessed by quantifying the number of in-class hours dedicated to program outcomes (Table 6).

Table 6. Contribution to Course Program Outcomes.

		In-Class Hours	
	PROGRAM OUTCOMES	**Hours**	**%**
1	Mathematics and Science	17.0	38%
2	Physical and Chemical Processes	0.0	0%
3	Biochemical Processes	3.5	8%
4	Environmental Awareness	6.5	14%
5	Problem Solving	5.0	11%
6	Engineering Solutions under Austere Conditions	0.0	0%
7	Experimental Design, Execution, and Analysis	10.0	22%
8	Written and Oral Communication	0.0	0%
9	Environmental Responsibility	2.0	4%
10	Professional Responsibility	1.0	2%
	TOTALS	**45.0**	**100%**

The majority of the course supports the engineering science (Program Outcome 1) and experimental analysis (Program Outcome 7) outcomes. The broader influence of this course on the environmental engineering curriculum has not been fully assessed. However, immediate benefits include allowance for more design in the biochemical treatment and hazardous waste treatment courses. In addition, by revisiting many of these topics (Table 5) in subsequent courses, students experience a period of growth and reflection followed by a period of learning at a higher level in the cognitive domain.

Because the course is somewhat new (developed in 2003) our assessment reveals that revisions are required. For example, following the spring 2005 semester, course outcome (j) received an assessment score of amber (scale: green, amber, or red) because many students felt lost at the beginning of the lab period and were unprepared for the questions in the lab requirements. Also, many of the students had difficulty applying laboratory concepts in class following a lab experience. Modifications to the laboratory experiences were developed to address these shortcomings. Course outcome (e) was also given a score of amber because the students did not fully grasp the criteria for BOD measurements and its linkage to engineered and natural systems. Additional material was added to the student handout on these topics and more emphasis will be placed in this area on class. The mechanics of the course also require some revision. For example, students struggle with symbology because we use a microbiology text[7] and a biochemical treatment text.[13] We also introduce our students to terminology used on the Fundamental Engineering Exam (FEE), which is different from what is used in these texts. The usage of symbols is being reevaluated to facilitate student learning and help them adapt to the variety of symbols used in the field. The course is comprised of two student populations. It is required for environmental engineering majors, who also take environmental chemistry, and open to environmental science majors, who are not required to take environmental chemistry.

This results in a disparity in background knowledge between each student population. A chemistry review handout on Gibbs Free Energy and Redox chemistry was developed to address this issue. This supplement seemed to help many of the students, especially the environmental scientists. However, some student still perceive this disparity as a bias. Student comments on the course in general include the following.

"Covered broad array of topics, could link class information to other classes"
"Labs added a realistic element to the course"
"It had good ties into the subject material we were learning in EV401 (physicochemical treatment). It built on material leaned in EV Chem."
"The labs helped me learn hands-on techniques that applied my knowledge."

In the development of our hybrid course, our ABET accreditation experience, and, the preparation of this paper, we believe that it will be difficult for many ABET programs to justify meeting the ABET biology requirement with an externally taught basic biology or microbiology course. These courses generally do not spend adequate time on environmental topics to provide students with proficiency in a biological science relevant to their program of study. To supplement this possible shortcoming, some programs cover general environmental biology in other program courses, which may reduce the course hours spent on design. Programs should weigh the advantages and disadvantage of offering their own hybrid environmental biology course to meet their ABET requirements.

Conclusion

A traditional course in biochemical treatment processes (e.g. domestic wastewater treatment) or a general biology/microbiology course may not satisfy the ABET biological science requirement. Eighty one percent of the ABET accredited undergraduate environmental engineering programs assessed in this study require an additional course in biology (beyond the traditional wastewater treatment course). Twenty six percent of these programs offer their own hybrid environmental biology course. The topics that could be discussed in a hybrid course span a number of disciplines including biology, microbiology, toxicology, colloid chemistry, organic chemistry, epidemiology, etc, which might be challenging to teach with one faculty member. Immediate benefits of a hybrid environmental biology courses include allowance for more design in subsequent courses (e.g. biochemical treatment), and integration of the hybrid course with other program courses thereby enhancing "higher level" learning in these courses.

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