Using Phosphorus Recovery from Wastewater as a Context for Teaching Sustainable Development with USEPA P3 Support

Daniel B. Oerther
Missouri University of Science and Technology, oertherd@mst.edu

Cinnamon Carlarne

Eric Maurer

Regina Lamendella

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/civarc_enveng_facwork/530

2006-92: USING PHOSPHORUS RECOVERY FROM WASTEWATER AS A CONTEXT FOR TEACHING SUSTAINABLE DEVELOPMENT WITH USEPA P3 SUPPORT

Daniel Oerther, University of Cincinnati

Associate Professor of Environmental Biotechnology, University of Cincinnati. Dr. Oerther teaches graduate and undergraduate courses in biology and molecular biology as applied to natural and engineered environments. His research focuses upon microorganisms in wastewater treatment plants, drinking water treatment plants, bioremediation field sites, and natural surface watershed.

Cinnamon Carlarne, University of Cincinnati

Assistant Professor, Environmental Studies Program, University of Cincinnati. Dr. Carlarne teaches graduate and undergraduate courses in environmental policy and law. Her research focuses the role of international law in sustainable development.

Eric Maurer, University of Cincinnati

Director, Environmental Studies Program, University of Cincinnati. Dr. Maurer teaches graduate and undergraduate courses in biology and sustainable development. His research focuses upon sustainable biological systems.

Regina Lamendella, University of Cincinnati

Graduate Research Assistant and doctoral candidate, University of Cincinnati. Ms Lamendella completed her MS degree with Dr. Oerther. She was a student in the original offering of this course, and participated as a teaching assistant for the second offering of the course.

Sarah Pumphrey, University of Cincinnati

Graduate Research Assistant and MS candidate, University of Cincinnati. Ms. Pumphrey worked with Dr. Oerther as an undergraduate work study student and is continuing her MS degree. She was a student in the original offering of this course, and participated as a teaching assistant for the second offering of the course.

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Abstract

Phosphorus is an essential element required for agriculture. Current practices include "one-way" use of phosphorus: that is mining; production of fertilizer; land application; and ultimately loss to aquatic sediments. Once in the aquatic environment, phosphorus stimulates eutrophication resulting in the "death" of water bodies. With financial support from a People, Prosperity, and Planet program grant of the U.S. Environmental Protection Agency, an interdisciplinary team of faculty at the University of Cincinnati used phosphorus recovery from sewage and re-utilization as a struvite fertilizer as the context for a year-long course of study integrating graduate and undergraduate students in Environmental Engineering and Science as well as Environmental Studies. This presentation will highlight the original course format, results of student assessment from the 2004-2005 academic year, modifications incorporated for the 2005-2006 academic year, and the subsequent findings of student perceptions and learning. The challenge of integrating across two colleges within a comprehensive university system will be discussed, and our approaches for meeting the learning needs and course expectations of a diverse student population will be included.

Introduction

Environmental policy-makers, ecologists and engineers have been dealing with the problem of soluble bioavailable phosphorus as a component of wastewater since the 1960s. Originally cited as the cause of eutrophication of drinking water reservoirs in South Africa, the increased use of phosphorus-based detergents and industrial chemicals ultimately lead to a dramatic deterioration of the quality of fresh water bodies in the United States, including the Chesapeake Bay and the Great Lakes. To combat phosphorus pollution, stringent controls were put in place to limit phosphorus use in commercial chemicals. Nevertheless, phosphorus pollution remains a significant problem because: (i) phosphorus is used as a fertilizer to encourage intensive agricultural practice; and (ii) phosphorus is released in excrement in the form of sewage. A comparison of agricultural phosphorus use published by the U.S. Department of Agriculture with phosphorus discharge from municipal sewage calculated from U.S. Environmental Protection Agency data indicates that approximately 10% of the phosphorus released to the environment is from sewage while 90% is from agriculture.[1] Thus, while the discharge of phosphorus from agriculture is the most significant contributor to eutrophication, phosphorus recovery from sewage represents a significant opportunity to increase the sustainability of the phosphorus nutrient cycle.

Because phosphorus discharge to the environment represents a significant concern; and because solutions to environmental discharges of phosphorus require technical as well as policy efforts the topic was selected to serve as the theme for a People, Prosperity, and the Plant (P3) grant from the U.S. EPA. The objective of the P3 program is to provide seed funds for teams of faculty and students to tackle complex, globally relevant environmental challenges in the context of sustainable development. Because phosphorus is a growth limiting nutrient required for intensive agriculture, and because discharge of excess phosphorus stimulate severe environmental degradation the problem fits within the mandate of the P3 program to tackle a significant, complex environmental challenge. Furthermore, to select a program of study that would most significantly address the issue of global sustainability, the project team elected to use a scalable approach (e.g., with a range of scales of technology from individual approaches to approaches suitable for large municipalities) to recover phosphorus from sewage using Tanzania as a model developing country.

Course Format

The year-long P3 project was performed under the umbrella of existing courses offered at the University of Cincinnati, namely CEE 600/601 Chemistry and Microbiology of Environmental Systems/Lab and the Environmental Capstone course, EVST 501.

CEE 600/601 Chemistry and Microbiology of Environmental Systems/Lab brings together undergraduate and first year graduate students from the Department of Civil and Environmental Engineering as well as senior students from the Environmental Studies Program. As an interdisciplinary course involving environmental engineers and scientists, CEE 600/601 facilitates the commencement of a year-long independent study by the student design team using proven approaches of team-based learning.[2, 3, 4] The course provides the basic scientific background needed to tackle the problem as well as a hands-on understanding of the unit operations available for phosphorus recovery. Lecture/discussion sessions cover the basic principles of chemistry (e.g., acid-base; precipitation/complexation; and redox) and microbiology (e.g., Monod growth rate; stoichiometry of biomass yield; and microbial diversity) as applied to the design and operation of drinking water and sewage treatment plants. Students work in teams to perform team-directed laboratory exercises performed to provide authentic learning by facilitating the work of the students as active learners. For example, the course instructors help the students to plan team experiments that are self-selected and ultimately designed and performed by the teams with a significant degree of autonomy. In particular, to complement the P3 project the course emphasizes the acid-base and precipitation chemistry of phosphorus recovery as struvite and the microbiology of enhanced biological phosphorus removal for activated sludge sewage treatment systems.

The format for EVST 501 is significantly different from CEE 600/601. Students are provided with reading assignments and an opportunity for self-paced, monitored, independent study. Reading assignments are selected to stimulate Socratic discussions of sustainability where the instructors facilitate an open-ended discussion within the classroom among the students to self-define common vocabulary and critical concepts. Along with the readings, each team of students continues to perform necessary laboratory work to complete the P3 project.

For the 2004-2005 academic year, an interdisciplinary team of Co-Advisors from environmental engineering and environmental studies was formed to oversee the courses and the P3 project. The team included Dr. Oerther, Environmental Engineering, Dr. Maurer, Director, Environmental Studies, Dr. Cinnamon Carlarne, Environmental Studies, Dr. Paul Bishop, Environmental Engineering, and Dr. Brian Kinkle, Biological Sciences. For the first offering of the course, the original content of CEE 600/601 was significantly modified. Originally, water treatment focused upon the chemistry of lime/soda ash water softening, and the wastewater treatment focused upon the microbiology of nitrification. To match the objective of the P3 project, the chemistry component of the class was refocused to tackle struvite precipitation while the microbiology component was refocused to tackle enhanced biological phosphorus removal.

Initially, a team of twelve students was assigned to complete the P3 project. The team included an equal mix of environmental engineers (both seniors as well as first year graduate students) and seniors in environmental studies. The team was asked to self organize to tackle the P3 project. Without interference from the instructors, the students self-organized into four sub-teams of three members each. The four sub-teams were arranged to study: (1) enhanced biological phosphorus removal; (2) struvite precipitation; (3) crop production using struvite fertilizer; and (4) economic analysis for sustainability. The engineering students formed groups (1) and (2) while the environmental studies students formed groups (3) and (4). Although this self-selection was clearly based upon the students' level of comfort with the perceived technical details of reactor design and operation, it was clear as the class progressed that the artificial separation into discipline-oriented sub-teams was detrimental to learning as the students did not invest time to learn about projects outside of their primary sub-topic.

As part of EVST 501, the students extended their learning through a year long process which offered an opportunity for a long-term learning experience. The students experimentally evaluated if the phosphorus recovered from artificial sewage was bioavailable and capable of stimulating plant growth. In addition, as art of EVST 501, each students invested significant time developing social and economic analyses to evaluate the costs and benefits of scaling-up phosphorus recovery from sewage throughout the developing world.

Course Schedule

The P3 project commenced in September when the autumn quarter started and ended in May when the final project was presented on the National Mall in Washington, D.C. CEE600/601 is an autumn course that runs from mid September through early December, 2005. CEE600 is a 3 credit hour course and CEE601 is a one credit hour lab; therefore students had six hours of scheduled time each week to work on this project. The first two weeks of the course introduced students to the concept of sustainability and endeavored to build student interest in becoming part of the student design team. In the following eight weeks, the students designed, assembled, and operated laboratory-scale bioreactors for enhanced biological phosphorus removal as well as a laboratory-scale reactor for phosphorus precipitation as struvite. Students lead the laboratory work with faculty available as active advisors. At the end of CEE600/601 course, the student design team developed a schedule of activities to perform over winter break, including initiating plantings using the phosphorus recovered from sewage as a fertilizer. Available green house facilities in the Department of Biology were used to grow appropriate plants to evaluate the bioavailability of phosphorus.

During the winter quarter in the EVST 501 course, the student design team evaluated the laboratory-scale data collected in the autumn, continued the greenhouse experiments, conducted the research necessary to complete their social and economic analyses of phosphorus recovery from sewage, and developed applications of phosphorus recovery technologies applicable to the developing world. This part of the project was lead by Drs. Maurer and Carlarne who supervised the design team's on-going research as well as provided relevant seminars on ecological, economic, legal and political issues associated with water pollution, nutrient run-off, and phosphorus recovery. In this way, the students were prepared to analyze the results of their research and to place it in the political and social context necessary to analyze the sustainability of the technology and its benefits for people, prosperity and the planet.

During the spring quarter, in the EVST 502 course the student design team evaluated the data collected from their study of struvite bioavailability as a fertilizer for plants and incorporated this information with the overall design developed from the laboratory-scale data, the socioeconomic analysis, and the ideas for transferring phosphorus recovery technology to the developing world. The students integrated these components of the design into the final project report and presented the results at the P3 Award competition in Washington, D.C.

Course Modifications

Although the first year could be considered a success, a number of critical observations were noted. First, the self-selection of sub-teams prevented appropriate interdisciplinary mixing of environmental engineering and environmental studies students. Second, without a focus on a country of interest, it was difficult to provide an appropriate context for agriculture or economics. Third, because the course sequence is required for the seniors in environmental studies – but merely an option for the engineering students – only a limited cadre of students continued throughout the full year.

To address these concerns, the course was modified for the 2005-06 academic year. First, student sub-teams were assigned by the instructor based upon students backgrounds as presented by their transcripts and self-proclaimed interests. This allowed engineering and environmental studies students to be distributed into each of the four teams. Second, the students selected Tanzania was as a model country of interest and the students decided to tackle the problem of scalable phosphorus recovery by simultaneously examining struvite precipitation as well as wetlands recovery and the use of drip bucket irrigation of source separated urine. Third, a greater emphasis was placed upon encouraging the engineering students to consider participation in the year-long course, and two engineering students were provided as teaching assistants for the course. At the end of the 2005-06 academic year, the value of these course modifications will be assessed.

Challenge of Interdisciplinary Learning

Clearly, sustainable development is an area that requires significant interdisciplinary skills. One of the outcomes of the P3 project at the University of Cincinnati was the establishment of a strong interdisciplinary cadre of teachers willing to work together to present students with multiple facets of a complex environmental challenge. Never the less, integration of students with diverse backgrounds in the natural and social sciences was difficult. At times, it was evident that the level of the scientific content for the course was too remedial for the engineering students, and the discussions of social justice and environmental law were often of little interest. In stark contrast, many of the environmental studies students struggled with the quantitative aspects of the course while thoroughly enjoying the Socratic discussions.

Unfortunately, a drawback for the format of this course is the unequal requirement for year-long participation. It was observed that the engineering students were less interested in aspects of the project that were not unfolding during the academic term in which they were enrolled. Also, it was observed that the environmental studies students were willing to sacrifice involvement in the early portion of the course and apparently to wait for their opportunity to participate during the second and third academic terms. Thus, future efforts to integrate students with diverse training and background must also remain cognizant of the exterior motivations of the students towards to the course. It would be beneficial to contrast the findings of this effort with similar capstone experiences undertaken at institutions which operate a campus-wide center for the environment or equivalent. Under a campus-wide umbrella, perhaps student participation would be more evenly distributed among diverse disciplines. Unfortunately, we are unaware of any such program currently.

Conclusions

A one-year-long learning exercise was undertaken wherein a student team tackled the complex problem of recovering phosphorus from sewage and using the recovered phosphorus as a fertilizer. The student team consisted of undergraduate and graduate engineering students as well as seniors in environmental studies. The major hurdle to the success of this course was a result of the diverse backgrounds of the students and may be reflective of an underlying need for improved interdisciplinary training. Although the faculty members participating in the course were capable of providing a highly interdisciplinary environment for learning, it appears that the discipline-specific bias of the student participants may have impeded the abilities of the students to learn as a team. Future efforts for a year-long course of this type may be best undertaken at an institution where a strong campus-wide center for the environment or equivalent exists. This umbrella organization could provide the needed incentive for students to fully participate in the course despite their affiliations with specific departments or programs.

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