Session 2551

DEVELOPMENT OF UNDERGRADUATE LABORATORY EXPERIENCE IN ENVIRONMENTAL ENGINEERING

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Abstract

Currently, undergraduate students in environmental engineering at the University of Illinois and many other schools have very limited laboratory experience. This is a great disadvantage in a profession where field and laboratory techniques are crucial skills for the job market and for graduate school. With the assistance of The National Science Foundation and the University of Illinois for purchase of instruments and construction of a dedicated laboratory, a course has been developed with the goal of involving undergraduate students in significant laboratory and field experience and having them relate that experience to design applications.

This course, which is a permanent addition to the Civil and Environmental Engineering (CEE) curriculum, is a hands-on laboratory course in which students are involved in acquisition of data necessary for the development of environmental programs, design of treatment systems, and evaluation of compliance with regulatory requirements. The students work with the analytical procedures that are used to generate the data used by professionals before they enter the work force. The benefits to the students are:

- Associate abstract concepts taught in traditional lectures with real world phenomena,
- Interrelate classroom approaches to design and operation with actual acquisition of basic data required for design,
- Understanding the limitations of these data and how to work with the data to develop design criteria or regulatory frame works.

The course consists of a series of modules representative of the breadth of environmental engineering: air, solid and hazardous waste, wastewater treatment, water treatment, toxicity assessment, and field ecological assessments. These experimental modules will be described and past experience in conducting the course will be presented.

I. Introduction

Prior to the introduction of the course described in this paper, undergraduates in our curriculum had very few laboratory courses available to them and none in environmental engineering. This was a great disadvantage, especially for undergraduates in environmental engineering where field and laboratory techniques are crucial skills for the job market and graduate school. Our goal was to not only to involve undergraduate engineering students in a significant laboratory experience, but also to relate that experience to design applications.

The development of a significant undergraduate laboratory experience in environmental engineering within a senior level laboratory course was designed to bridge the existing gap between class room theory and practical measurement techniques. The experiments are structured to let the students participate in common field and laboratory measurements that are used in environmental engineering to design monitoring programs and treatment systems in air, water, wastewater, hazardous waste and ecology. The students are directly involved in evaluating data reliability and assessing QA/QC issues as a part of performing the experiments. They make decisions on the use of their data in classroom projects simulating assessment or the development of design parameters for treatment systems.

A series of experimental modules have been constructed that represent the range of sub disciplines within Environmental Engineering such that the students have an exposure to laboratory and field techniques. They are able to use state-of-the-art methodologies representative of professional practice in addition to the research tools they will encounter if they pursue advanced degrees. The combined input of six highly qualified faculty members ensures a broad base of technical knowledge in the overall design of the laboratory and field experience. The course was made possible through acquisition of equipment through assistance from the National Science Foundation. These funds were in turn leveraged into support for a new laboratory in which the course is conducted.

This effort is in line with the engineering accreditation body, ABET, recommendations for laboratory needs in engineering. Thus, CEE at UIUC moved to implement an undergraduate laboratory in environmental engineering as a permanent addition to its curriculum. Although directed at senior engineering students, the course is expected to be attractive and available to non-engineering students in chemistry and related science curricula that also currently enroll in our environmental engineering courses.

A broader underlying objective of the NSF project was the preparation of a course manual containing detailed experiments and required equipment such that other universities can develop similar courses. This paper is a start in that direction.

II. Preliminary Work

CEE has recognized the need for more laboratory experience in the undergraduate curriculum and as a result had initiated development of a course on an experimental basis, CE 398RAM, Undergraduate Laboratory in Environmental Engineering which was taught in the spring and fall of 1998. Enrollment in the course was limited to 12 students because of available laboratory space and equipment restrictions.

The laboratory space was "borrowed" from the research laboratories. To offset this problem, CEE committed to construction of a dedicated undergraduate laboratory space. That laboratory was completed in the fall of 2000.

Previously, equipment for the lab course was also borrowed from research equipment. This temporary solution had to be resolved by acquisition of equipment to be dedicated to the undergraduate laboratory. While the Environmental Engineering and Science Program (EESP) faculty have been generous with research equipment as a means of implementing the course, such contributions were not feasible on a continuing basis and interfered with sponsored research efforts. This was learned first hand in the spring semester of 1998, when scheduling use of equipment made it difficult to complete all the experiments planned for the course. CEE made a commitment to supply matching funds toward acquisition of the necessary equipment to sustain the laboratory course and to maintain the equipment on a continuing basis. This commitment resulted in a successful request to the NSF DUE-CCLI program for equipment.

III. Benefits to Students

It is difficult for students to associate abstract concepts taught in traditional lectures with real world phenomena. In addition, lectures often cannot encourage the development of skills required in the job market and in graduate school. Project simulations, field trips, and experiments can improve instruction by involving students in explorations of fundamental concepts, state-of-the-art methods, and scientific skills. Students learn concepts and methods more readily when they are able to actively participate in the learning process. If the classroom encourages skill development, students will be much more effective in their future careers. Preliminary work to improve the curriculum has sought to provide students with a fundamental education as well as with training in areas not traditionally taught in lecture classes. Most undergraduate classes do not include laboratory experiments. Due to inadequate instructional equipment, most efforts to improve the undergraduate educational experience have been limited to field trips, writing projects, presentations, and project simulations.

The state-of-the-art laboratory course serves as a model for meeting the challenges of linking teaching with engineering practice. Environmental scientists and engineers must understand the basic concepts of many subjects: fluid mechanics, mathematics, computer modeling, measurement techniques, air, waste and drinking water treatment, and ecological assessments. They must be able to recognize the relationship between data acquisition and program operation or system design. They must understand the limitations of data, the uncertainty inherent in measurements and how it affects their ultimate product. The undergraduate environmental engineering laboratory course is structured to bring these elements together as a capstone experience for the students. The modules are structured to provide experience in many of the sub areas of environmental engineering where analytical procedures are required to obtain design data. To summarize, the primary benefits to students from this course are to:

- Associate abstract concepts taught in traditional lectures with real world phenomena.
- Interrelate classroom approaches to design and operation with actual acquisition of basic data required for design.
- Understanding limitations of these data and how to work with the data to develop design criteria

IV. Goals and Objectives

The basic goal was to establish a hands-on laboratory experience as a permanent addition to the civil and environmental engineering curriculum in which students are involved in acquisition of data necessary for development of environmental programs, design of treatment systems, and evaluation of compliance with regulatory requirements. The objective was to have the students work with the analytical procedures that are used to generate the data used by practicing professionals before they enter the work force. The students develop a sense of what the data mean and what the limitations of the data are. The students rely on theory and design concepts learned in prerequisite courses to apply the data generated in the laboratory to solution of design problems or interpretation of specific environmental problems posed to them.

A further objective is to have the students develop an appreciation of how the various analytical procedures function, the underlying principals, the inherent uncertainties, and how these procedures are applied to specific problem solving. Figure 1 presents a conceptual representation of the course structure.

V. Course Description

The course development centered on the assembly of dedicated equipment. The course consists of a series of laboratory modules representative of the breadth of environmental engineering: air, solid and hazardous waste, wastewater treatment, water treatment, toxicity assessment and field ecological assessments. The course is managed by a single faculty member but brings in the special expertise of other faculty and their graduate students in both the lecture and laboratory portions of the course. The course meets twice a week for a three-hour session, which is typically divided into 1 hour of lecture and two hours of laboratory. On occasions, the laboratory experience will be three hours without a preliminary lecture session and certain experiments require involvement outside the formal course hours for maintenance of a reactor or time dependent analytical prcedures.

VI. Course Structure

The current course has the experimental components outlined in Table 1. Following are brief descriptions of each of the experimental modules followed by a list of the equipment that is used for the experiment. Glassware and chemical supplies required for the experiments are supplied in individual laboratory stations and are not included in the lists.

Table 1. Course Outline

Hours(approx)	Lecture Topic	Laboratory Focus
3	Introduction and Procedures	Lab assignments, safety review
6	Survey of analytical methods	No associated laboratory
3	QA/QC, statistical considerations, sampling	Strong acid, strong base titrations, effects of concentration on error
12	Ecological systems	Field assays, toxicology, monitoring
12	Air processes	Particulate assays
15	Water softening	Hardness removal and assays
9	Hazardous Wastes	Vapor extraction design assays
12	Biological processes	Reactor assessment and process design parameter assessment
9	Drinking Water Disinfection with ozone and chloramine	Disinfection kinetics evaluation and organism assays, disinfection by-product formation
6	Term and final examinations	

After an introduction to the range of volumetric, gravimetric, and instrumental based methods used in the environmental field, the students will be engaged in experimental and field experience modules as described below.

<u>Acid-Base and Alkalinity Titrations.</u> The objective is to introduce students to titrimetric analysis procedures used in later experiments and to illustrate precision and accuracy dependence on method design and individual operator skills. Students in Civil and Environmental Engineering have limited prior experience in simple laboratory procedures and data treatment. Emphasis is more on the data reduction rather than the techniques. Lecture and reading materials on QA/QC are taken from Standard Methods[1] and Taylor[2]. Using procedures outlined in Standard Methods[1] and Sawyer et al.[3], a series of strong acid, strong base titrations is done by each laboratory group at successively lower concentrations using an indicators and a pH meter. The resultant data are used to evaluate individual operator precision and inter-group (i.e., inter-laboratory) precision.

Deterioration of precision with decreasing concentration is demonstrated. Deterioration in accuracy is demonstrated by comparison of electrometric (pH) titration curves and color changes with the indicator. This exercise is followed with alkalinity titrations which illustrate end point concentration dependency of weak acid and weak base systems while introducing the students to a water quality variable of considerable importance and which they will use directly in the later water softening experiment.

Equipment Required:

pH meters and electrodes	Titration stands
Magnetic stirrers and magnets	Burets

Hardness and Water Softening. The objective of this module is to have the students be involved in a comprehensive exercise that involves characterization of a water and relating these characteristics to design of a laboratory bench scale assessment of treatment approaches and comparison of their results with a real treatment plant. Reading and lecture material are taken from texts the students have used in prerequisite courses[4,5], Standard Methods[1], and other supplementary readings[6]. The approach is to have students undertake the chemical characterization of the local groundwater as to pH, alkalinity, total hardness and distribution of hardness between calcium and magnesium in order to determine softening dose. The dose is evaluated by jar test softening at a range of lime doses including excess lime. Solids addition, hot lime and split treatment variations are performed. The students visit the local water treatment utility, which practices excess lime treatment with solids addition (recycle) and split treatment with a target final hardness of roughly 80 ppm as $CaCO_3$. The students take samples across the plant and compare their laboratory results with the actual plant operation. They are asked to provide a conceptual design for a water softening plant from their experience. Hardness is determined in the laboratory by EDTA titration (Total and Ca), atomic absorption spectrophotometry (Ca and Mg) and by selective ion electrode for comparison of the techniques. As the local water is also fluorinated, assessment of the fluoride dosing is also included. Carbon dioxide content is evaluated by nomograph[7] using conductivity as a means of estimating dissolved solids content.

Equipment Required:

Jar test apparatus	F electrode (1)
Magnetic stirring Hot plates	Ca and Mg Atomic Absorption lamps

Selective ion meter	Conductivity meter
Hardness electrode	Analytical Balances
Ca electrode	F electrode

Field Water Quality/Ecology. The objective of this module is to provide students with an exposure to ecological assessments and the relationship of water quality variations to aquatic ecology. Three separate activities are contained in this module, all related to the analysis of receiving system response to point and non-point sources. 1. Students participate in a fish population assessment using electroshocking equipment and evaluate the upstream and downstream condition of fish populations in relation to natural variability of water quality in a local waste treatment facility. A qualitative stream ecology is also conducted 2. A second field exercise involves assessing the local stream water quality (The Boneyard Creek, which flows through the UIUC campus) using multi parameter sonde, which is a self contained water quality monitoring system containing multiple physical and chemical monitoring sensors. Stream depth, temperature, pH, dissolved oxygen, redox potential and turbidity, are among the parameters monitored. Diurnal and storm related variations are graphic and challenge the students to interpret and relate the data to water quality management issues. 3. A whole effluent toxicity (WET) test is conducted in the laboratory using *Ceriodaphnia dubia* for both chemical specific and whole effluent samples. Students have the responsibility for toxicity testing design and completionof a test with observations at intervals over a 96 hours. A critical component of the toxicity testing exercise is the analysis of toxic response characteristics as well as calculation of LC/EC_{50} results. Reading material is from prepared notes supplied.

Equipment Required:

Electrofishing equipment	Datasonde unit

Biotreatment Experiment. The main objective of the experiment is to introduce the students to a biological treatability study and to develop a rational design from the kinetic parameters obtained from chemostat data. This module also introduces the students to the range of analytical tools used in waste strength assessment and control of biological treatment systems. Lecture materials and reading materials reference back to prerequisite course texts[4,5], Standard Methods[1], selected references[8,9], and written experimental procedures developed in-house. Dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total organic carbon, filterable and volatile solids are used as part of an experiment designed to obtain rational design parameters (Monod based) for biological waste treatment design by using CSTR bio-reactors. The experimental methodology consists of a system of six reactors to be operated at six different dilution rates that have been running for at least 5 times the longest detention time. Biomass concentrations are determined gravimetrically as the volatile loss upon heating at 550 degrees. Comparison of waste strength measurement methods is included in the experiment by virtue of using BOD, COD and TOC measurements of the influent waste and the effluent waste streams.

Equipment Required:

DO reactors (constructed)	DO meter
Multi-head pump and pump head	DO electrodes (2)
Waste feed unit with stirring motor with stirrer	Dessicators
BOD incubator	Analytical Balances
COD reaction and measurement system for spectrophotometric method	Drying Oven
Spectrophotometer	Muffle furnace

Hazardous Waste Experiment. The objective is to introduce students to the process of vapor extraction of volatile contaminants in subsurface soil systems and the acquisition of pertinent data necessary to design such systems. Lecture and reading materials are prepared specially for the class along with guidance on how data are to be analyzed to obtain the important design parameters. The approach used focuses on the need for soil porosity and vapor migration parameters as these are important in the design of specific vapor extraction units. So the students will use a gas chromatograph to determine the porosity and dispersion coefficients of different soils using methane gas as a tracer through packed stainless steel soil columns attached to a chromatograph system using a flame ionization detector. A volatile contaminant, represented by trichloroethylene (TCE), is then passed through the column and monitored by the flame ionization detector to give information on the soil retardation factor. Soils of differing organic content are used to demonstrate the effect of organic content on retardation of migration of TCE and how this affects the extraction system design.

Equipment Required:

GC-FID with data acquisition linkage	Flow System for TCE/CH_4 feed

Stainless steel columns for Soil	Data Analysis linkage

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Disinfection and Disinfection By-Products. There are two experiments under this module both have as objectives, examination of disinfection kinetics and associated disinfection by-products (DBP). The relationship between dose of disinfectant required for biological safety is contrasted with the production of regulated DBPs and how these tradeoffs vary with different target organisms and different disinfectants. Lectures and reading materials come from the wide experience of several of the faculty in this field, Standard Methods[1], and prerequisite course work[4,5]. The experimental approaches are as follow:

Ozone Related. Disinfection using ozone is simulated in water containing bromide under conditions required for the removal of Cryptosporidium oocysts and is examined for the formation bromate ion, a newly regulated DBP. Students also observe the actual organism disinfection evaluation by demonstration and receive training on how to work with the Cryptosporidium even though they have no direct contact with the infectious organism. Students are supplied with organism survival verses ozone dose and exposure time in order to obtain kinetic design parameters.

Equipment Required:

Spectrophotometer for residual O_3 measurement	Ion Chromatograph
Ozone generator	Microscope

Chloramine Related. In this experiment, the students will actually measure residual chloramine dose and evaluate the viable microorganism concentration with time and with chloramine dose in batch reactors. Kinetic factors will be developed as a base for disinfection design. As real water samples are used for the experiment, DBPs will be measured by gas chromatography to evaluate compliance with regulations.

Trihalomethanes and haloacetic acids are measured at different chloramine doses. If free chlorine is to be used for this experiment, residual chlorine levels cannot be measured with time as the doses required for kill over 10 to 20 minutes are too low low for the analytical methods.

Equipment Required:

Batch reactor/contactor	37° C incubator
E coli analysis system (available directly from scientific suppliers)	Spectrophotometer for residual chloramine measurement (same as for ozone and COD)
Gas Chromatograph	

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Air Quality Experiment. The objective of this experiment is to introduce the students to the principles of ambient air monitoring and the means by which this is achieved, how error analysis is applied for assessment of data reliability, and application of advanced techniques to gain more detailed information from samples collected. Lecture and reading materials consist of specific excerpts from selected reference texts[10-12] plus faculty prepared instructions on procedures. The experimental approach consists of conducting ambient air particulate sampling on the roof top using two different types of samplers, a hi-volume unit with a PM10 head and a dichotomous sampler equipped with both a PM10 and PM2.5 collector. Students disassemble and reassemble both units to aid in understanding the operating principles of the collection devices. Flow calibration and duration of sampling allow the students to assess compliance with air quality regulations. The students then take the filters to a campus electron microscope (EM) facility where they are shown how the EM system works and have their filters examined. They receive photographs and evaluate numbers of particles and size distribution for all three filters. The high-volume filter sample is also extracted with hot water and the atmospheric sulfate and nitrate loads are determined by ion chromatography. Results and data are related to weather conditions as determined by the requested roof top weather station.

Equipment Required:

Hi Volume unit and flow calibration	Dichotomous sample unit and flow calibration
Analytic balance, Cahn microbalance	Weather station unit
Ion Chromatograph	Electron microscope

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VII. Dissemination of Results

The final end product for NSF will be a course manual fully laying out the course structure, lecture material and associated references, the laboratory experiments and guidelines for data analysis and design application. This manual will be made available to all interested colleges and universities at cost.

VIII. Experience to Date

The course has been taught 3 previous times under a special topics listing at UIUC. The experience gain from this has been used to obtain departmental, college, and campus approval as a permanent course. At the time of the paper presentation, we will just have completed teaching the first time as a permanent course and in a new and dedicated undergraduate teaching laboratory. Many students have found the course helpful, especially those interviewing with consulting firms. We have also noted that some students get frustrated when forced to do advanced planning and organization on their own rather than have a complete "road map" laid out for the in advance. This is also true when it comes to data analysis and reporting of results. Formal lab reports are required and when formal examinations are superimposed upon this requirement, some students have felt this was too much work. This feedback is being included in modifications of the course for future offerings.

Acknowledgments

Funding from the National Science Foundation DUE CCLI program through Grant: DUE-9950185 is gratefully acknowledged and made development of the course possible. Without the participation and contribution of fellow EESP faculty, Drs. Edwin Herricks, Susan Larson, Benito Marinas, Lutgarde Raskin, and Charlie Werth, the course and the NSF proposal would not have been possible. Several graduate students have participated in the past course offerings and deserve recognition. They are Ann Dilner, Jaehong Kim, Shinya Echigo, Jason Rennecker, Mark Urban, Jun Li, and Karen Hansen. Recognition is due the Department of Civil and Environmental Engineering and the UIUC College of Engineering for providing funds for the grant matching and construction of a new undergraduate laboratory.

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