Algal Research – A Case for Teaching Environmental Engineering

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Abstract

Active research provides excellent opportunities for teaching engineering design principles. In this paper, algal research is used as basis to teach environmental engineering concepts and train the emerging civil and environmental engineers is presented. Research focused on algal cultivation, harvesting, processing for biofuel production and beneficial applications to resolve energy-environmental issues has provided opportunities for a number of undergraduate and graduate civil and environmental engineering students at Mississippi State University. Coagulation, flocculation, sedimentation and filtration concepts and design principles were taught through practical demonstrations for the junior and senior civil engineering students in the environmental engineering laboratory. The source water was collected from the algae contaminated ponds at the Mississippi State University campus. The student learning was greatly enhanced by the practical and hands-on research experiences provided to them, and it was evidenced by the number of research excellence awards received at local, regional and national conferences and national level design competitions. This paper discusses the integration of research activities into environmental engineering courses (junior, senior and graduate level courses) and the enrichment of student learning experiences and their success.

Keywords

Environmental engineering, research based instruction, higher order of learning, cognitive skills, project-based learning

Introduction

Teaching engineering courses is a challenging task. The process of understanding scientific principles and applying them in engineering design demands higher order learning and thinking skills from the students. A widely-used classification scheme for different levels of learning, Bloom's Taxonomy[1] defines six levels of learning: (1) Knowledge - to memorize, define, name, state...; (2) Comprehension - to explain, describe, discuss, restate...; (3) Application - to apply, demonstrate, interpret, illustrate...; (4) Analysis - to compare, contrast, question, test, criticize...; (5) Synthesis - to create, design, develop, formulate...; (6) Evaluation - to evaluate, rate, defend, predict. To promote higher levels of learning (or taxonomies), proper instructional strategies should be implemented.

These instructional strategies should include learning elements that provide authentic contexts, opportunities for critical thinking, authentic activities, examinations of multiple roles and perspectives, coaching and scaffolding, access to expert performances and modeling. In addition, these should promote reflection to enable abstraction and articulation[2]. These elements should support collaborative construction of knowledge and the use of authentic assessment techniques. The courses should be developed to provide actual and real world exercises that create a context for activities to promote higher levels of learning.

The students should be allowed to assume multiple roles and share various perspectives that come from basic intuitive (gut) feelings and coach, be coached by others, research expert performances on the given topic and reflect over the content and improve articulation. Laboratory class exercises provide excellent opportunities to implement these elements[3,4]. Laboratory course instruction provides opportunities for teaching various engineering design principles that could not be covered effectively in a traditional classroom teaching environment. Laboratory instruction can be used as a tool to promote cooperative (team learning) learning to teach engineering design. In cooperative learning, students work in teams toward the attainment of some superordinate goal where the labor is divided between team members, such that each individual takes responsibility for a different sub-goal and individual contributions are pooled into a composite product to ensure that the goal is reached. To be successful, there are five factors which are paramount to the cooperative learning process: 1) Positive interdependence, 2) Face-to-face interaction, 3) Individual accountability, 4) Small group and interpersonal skills, and 5) Group self-evaluation. In this paper, we discuss the research-based laboratory teaching exercises that were implemented in a civil and environmental engineering course. The goal of this laboratory session is to introduce some unit operations and processes and analysis commonly applied in water and wastewater engineering.

Illustrations

At Mississippi State University, the civil and environmental engineering department has implemented cooperative learning based exercises in the CE 3801 Environmental Engineering Laboratory course. In this course, student groups were formed to facilitate team-based cooperative learning. The laboratory exercises on physicochemical unit processes included: "Adsorption", "Aeration", "Coagulation-Flocculation-Sedimentation-Filtration", "Chemical Oxygen Demand (COD) and Total Solids Measurement", and "Tracer Analysis".

In these laboratory exercises, environmental samples from authentic sources were analyzed where possible. For example, the water treatment (coagulation-flocculation-sedimentation-filtration) exercise was conducted using algae contaminated pond water from two different lakes on the Mississippi State University campus. Similarly, the wastewater COD and Total Solids measurement characterization exercise used samples of wastewater from various designated process points of the local municipal wastewater treatment plant. Other experiments were conducted using synthetic chemicals such as a dye (i.e., methylene blue) to simulate the environmental pollutants.

Approach

Using engaged learning concepts to design and instruct the CE 3801 Environmental Engineering Laboratory class still required a formal process as a framework of operation and to insure productivity. The activities employed to manage the course involved:

- **A problem set assignment**– Students were collectively instructed on issues of laboratory operation and safety. This was followed by a presentation and classical homework design to provide students with a background in experimental statistics, data regression, and experimental design. All work was completed during the first week. This was followed by establishing teams and assigning teams experiments for which they would be responsible.
- **Laboratory exercises –** these were conducted on a number of selected topics, as outlined above. Student were assigned to teams to work together on each lab exercise. Each student was also assigned a specific experiment in which to serve as **team leader**. The team leaders assumed the responsibility for all aspects of setup and performance of the experiment by their team and, if necessary, coordinated with other team leaders and the instructor or teaching assistant. Student performance as team leader as well as individual participation were considered (assessed by peer ratings) in assigning final grades.
- **Pre-lab calculations** were submitted on an individual basis and are due at the beginning of each lab session. The calculations involved quantitative parameters to be used during the lab exercises, and as such were designed to facilitate execution of the exercise.
- **Lab reports** presenting experimental results and data analysis were prepared and submitted on an individual basis. Reports were expected to comply with the mini-report format provided and were due at the beginning of the lab period one week after the exercise was conducted.
- **Group reports and presentations** were prepared after completion of the lab exercises. Each group was assigned to write a full report and make a presentation on one of the lab exercises performed. Reports were submitted prior to the presentations.
- **Site visits** were conducted at nearby public works facilities to provide students with the opportunity to view equipment and operations. Site visit reports complying with the provided format were due one week after the visit.
- A **final exam** was conducted during the last week of the semester. The exam was administered online and may be taken at the individual students' schedule.

Student Experiences

The water treatment (coagulation-flocculation-sedimentation-filtration) experiments were conducted using actual water samples from two algae contaminated ponds. The students were asked to prepare the samples and plan the experimental procedures to determine the optimum dosage for treating the raw water. In designing these experiments, to maximize the learning potential, the following were addressed:

1. Students must take responsibility for their own learning.
2. Problems should be initially ill-defined and allow for free inquiry by the student.
3. Student collaboration should be encouraged in both group- and self-directed work.
4. Students must constantly re-analyze problems as individuals and as a group.
5. Students must reflect on what they have learned from the problem.
6. Students must take part in self and peer assessment.
7. Problems must have value in the real world.

Fig. 1 shows the sludge volume observations by the students in the laboratory during the experiment. The following illustration describes a research-based laboratory exercise and the student experiences and opinions from the evaluation survey.

Fig.1. Civil and Environmental engineering students performing water treatment experiment (coagulation-flocculation-sedimentation-filtration techniques)

The students were asked to respond to the following simple questions and reflect over their experiences in the laboratory session activities:

As a result of the team based laboratory exercises,

- Q1. My understanding of the environmental relevance of the subject matter is:
- Q2. My interest in environmental engineering discipline and confidence in the subject matter is:
- Q3. My analytical and experimental skills are:
- Q4. My leadership and management skills are:

Response options:

- A. Worse (W);
- B. The same (T);
- C. Better (B);
- D. Significantly better (S);
- E. N/A no opinion (N)

The summary of the students' responses is shown in **Fig.2**. Among the 50 respondents, about 58% (29 out of 50 respondents) of the students have responded that the laboratory exercises have improved their understanding of environmental relevance of the subject matter being taught in the associated classroom and the laboratory classes. 40 percent of the students (20 out of 50 respondents) answered that the laboratory exercises improved their interest in environmental engineering discipline and confidence in the subject matter while 34% (17 out of 50 respondents) of the students mentioned that their interest in environmental engineering discipline and the subject matter were the same after the exercises.

However, it can be noted that about 18% mentioned that the research-based and team-based laboratory exercises have significantly improved their interest in the subject matter and eventually environmental engineering discipline. The majority of the students (60% - 30 out of 50 respondents) agreed that these exercises have improved their analytical and experimental skills, and team work and communication skills. Again, 42% (21 out of 50 respondents) of the students responded that this exercise has improved their leadership and management skills which were the main goals of this assignment.

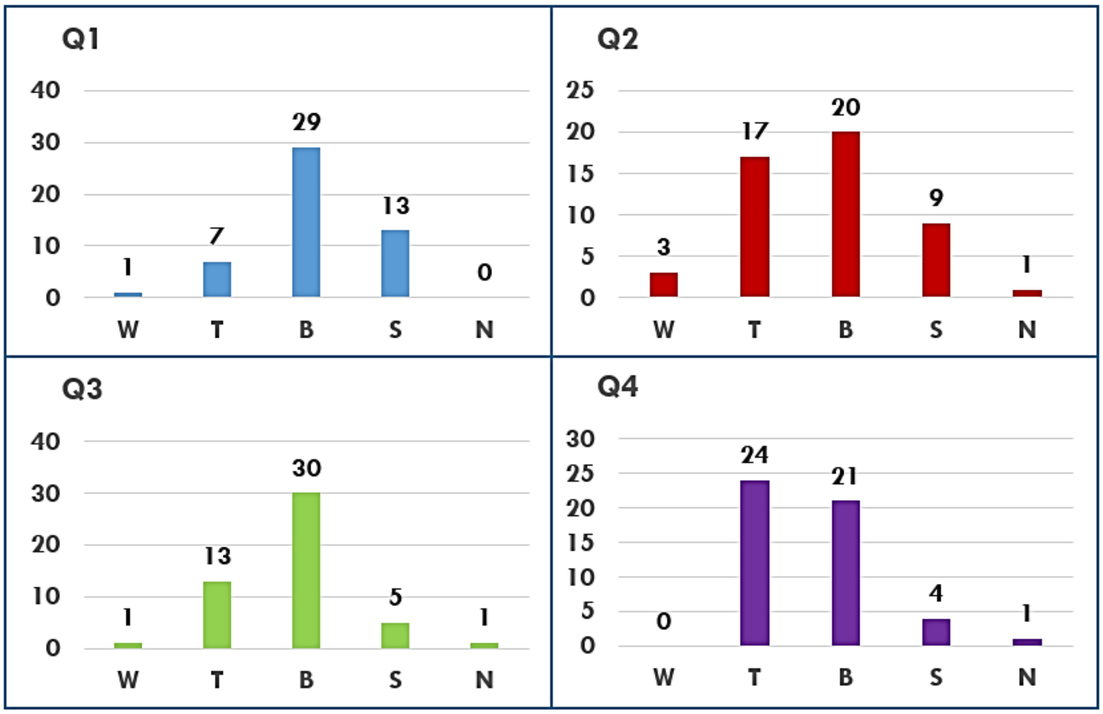

Fig. 2. Assessment of laboratory learning objectives

A few students responded that the cooperative learning methods were not effective in enhancing their learning experience. These students represented less than 10% of the total student population. It should be noted that some students would like to learn independently and are less inclined to work in teams. Typically, these students do not perform in a team-based and research-based learning environment. However, the above team-based and research-based laboratory exercises can be very instrumental in improving the student learning of the subject matter. Especially, the engineering design courses are increasingly being recognized and taught as a team process with multi-faceted socio-technological dimensions[5].

In addition, the ABET general engineering criteria also target the social aspects of engineering education at several levels. For example, criterion 3(c), “an ability to design a system, component, or process to meet desired needs,” and criterion 3(d) addresses the need to function on multidisciplinary teams, criterion, and 3(f) social and ethical responsibilities, criterion 3(g) communication skills, and criterion 3(h) addresses global and social impact. Constructivist theories of learning also recognize that learning is a social activity[6]. This means that the laboratory instruction and project-based design courses can be identified as opportunities to improve students' ability to work in teams, as well as their communication skills. As a result, many civil engineering programs now incorporate many of these dimensions in their design classes, ranging from cornerstone to capstone design courses[5]

Integrating Research into Education

In addition to the hands-on laboratory class activities, a number of undergraduate and graduate students also pursued research projects. Integrating research into education can benefit the students from many perspectives. Bentley described a seven-step procedure to enhance both research and education experiences for undergraduate students. This seven-step includes: (1) select the undergraduate student; (2) define a peer-reviewed reporting opportunity; (3) define a periodic meeting time; (4) select the appropriate graduate student mentor; (5) carefully define the project in terms of overall objectives and specific tasks; (6) execute the project; and (7) evaluate project success upon termination[7].

In our experience, we did not follow any specific procedures to select and recruit an undergraduate research student, instead the environmental engineering faculty were approached by students interested in gaining research experience as a pathway of preparation for their graduate studies or industrial training experiences. These students were assigned a graduate student co-worker and the specific of the details were provided. The students were allowed to work on various research projects related to algal biomass cultivation, harvesting (Coagulation-Flocculation-Sedimentation), algal biofuel production and innovative use of algae for energy production from wastewater treatment.

Simple and results-oriented research tasks were assigned to each of the research students. Students were encouraged to participate in brainstorming, discussions and designing practical solutions to the research problems with their graduate student coordinator and peers in teams. They were required to submit monthly reports, and final project completion reports. These students were encouraged to present and compete in the research symposiums and conferences at the university and national levels. More than 15 students were provided with research and education experiences in these research-based learning projects. **Fig. 3** shows the various environmental engineering projects that the students worked on as directed individual studies or summer internships and research orientation programs over the past two years.

The success of this research-based learning is that the students took pride in their work and this experience helped define their future career path. Research based education serves as a prerequisite for successful, lifelong learning experiences for the environmental engineers to acquire and maintain global competitiveness. The other tangible benefits of incorporating undergraduates into research activities: experience in addressing open-ended nature of research activities; the integration of individuals with differing skills, training and experience; the long-term commitment and teamwork involved in solving research problems; and the continuous learning process in the research environment.

Fig.3. Civil and environmental engineering students working on various research-education based projects (A. Graduate and undergraduate students working on a microbial desalination cell which treats the wastewater and salt water simultaneously while producing electricity; B. High school students learning the biodiesel purification process; C. A graduate student provides educational outreach to the Starkville community in the Water-Energy laboratory of the Civil and Environmental Engineering department)

In this approach, students become involved in oral and written presentations of their work, and, with experience, even formulate and submit proposals[8]. These educational benefits are realized in synergism with research activities, demonstrating the integration of teaching and research in the pursuit of scholarship. Our observations support the position that undergraduate research is a viable approach for enhancing the undergraduate educational experience while promoting the integration of teaching and research.

Conclusion

In addition to the survey data, anecdotal information from students was collected outside of class, either as part of the annual departmental exit survey of seniors or in conversations with students engaged in social settings. It is obvious that the typical student finds creative engagement as provided by this instructional approach as stimulating and rewarding. The instructors involved are perceived as being supportive of the educational process, for which students are appreciative. They also find that their backgrounds are generally superior to other students based on their conversations while at co-operative education work semesters or summer internships. They feel being participants in the learning process makes them stakeholders in the process, and they become vested in class content beyond simply doing laboratory reports and getting a grade.

On the instructional side, this process is rewarding to those willing to invest themselves into the educator role. Time commitment is somewhat greater as this is not a process that can be left to a graduate student to run with any level of acceptable success. It takes a person with a broader understanding of the unit operations and processes, experience with design and analysis, and an interest in student success to make this approach work effectively. However, the authors feel combining engaged students and a committed educator using this format for education will lead to one overall outcome which is successful education of the undergraduate to a level that cannot be achieved by a classical cookbook laboratory instructional approach.

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Biographical Data

Dr. Gude is an assistant professor at Mississippi State University (MSU). He has over 14 years of academic, industrial, and research experiences on various projects related to chemical and environmental engineering disciplines. He has published over 75 scholarly articles, peer-reviewed conference proceedings and invited book chapters. He is a licensed professional engineer (PE) in the state of New Mexico and a board certified environmental engineer (BCEE). His research interests include critical thinking in engineering design, cooperative learning, and reflective learning of water-wastewater treatment. He enjoys teaching environmental engineering courses and mentoring undergraduate and graduate students in research activities at MSU.

Dr. Truax is James T. White Chair, Head and Professor of Civil and Environmental Engineering at MSU. On the faculty for 34 years, he has published over 110 refereed and reference papers, reports and book or book chapters and has made over 170 paper or poster presentations. His funded research has focused on environmental and water resources engineering projects related to modeling of surface waters and pollutant transport, evaluating watersheds and management, managing hazardous wastes, and improving or optimizing physicochemical processes at water and wastewater treatment facilities. He has also worked on curricular development, creative instructional pedagogies, alternative laboratory designs, and student engagement.