

Fostering Critical Thinking Skills in an Environmental Engineering Water and Wastewater Treatment Class Through A Hands-On Semester Project

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Abstract – Students in an undergraduate environmental engineering water and wastewater treatment class were asked to develop and demonstrate a low-cost, energy efficient, simple and reliable system for use in removing silica from brackish water prior to desalination. After performing a literature review, each student team investigated several possible treatment options with laboratory experiments. After designing the system, each team produced a written report. Student groups also produced a poster presentation of their system as well as a PowerPoint presentation. Team members then participated in the WERC Design Contest in Las Cruces, NM. The project was undertaken as part of a university-wide effort to foster critical thinking among undergraduates. To determine the effectiveness of the project on students' critical thinking abilities, pre- and post-project assessments were conducted. Analysis of the results revealed statistically significant progress in thirteen measurements of critical thinking.

Keywords: Critical thinking, environmental engineering.

INTRODUCTION

The Quality Enhancement Plan (QEP) at Tennessee Tech University (TTU) is a five-year project to improve the quality of student learning in all disciplines across campus. The primary goal of TTU's QEP is to improve student's critical thinking and real world problem-solving skills through the use of active learning strategies. Particular emphasis is placed on improving communication skills, teamwork skills, and creative thinking abilities. Active learning means that students are more actively engaged in the educational process, which translates to improved student retention and higher graduation rates. In addition, better critical thinking skills, communication skills and teamwork skills result in greater student confidence and life-long success.

To promote the QEP, each year a request for proposals is made throughout the university. Proposals are evaluated by a committee composed of faculty from various disciplines. In the first year of the QEP, individual projects were funded in engineering, psychology, biology, music, foreign language, earth sciences, history, business administration, sociology and nursing.

One of the objectives of TTU's QEP is to steadily increase the number of projects that are considered successful, starting with a goal that 50% of funded projects would be successful in the first year. To gauge success, student responses on a self-evaluation form that asks for information pertaining to critical thinking skills are compared pre- and post-project. This paper reports on one such successful project, which was intended to foster critical thinking skills in an environmental engineering water and wastewater treatment class.

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SEMESTER PROJECT

Project Background and Administration

The class project required students to develop and demonstrate removal of silica from brackish water as part of a pre-treatment process prior to desalination and/or arsenic removal. This project was selected from among seven different possible projects in the WERC (Waste Management Education and Research Consortium) Environmental Design Contest which is held each year in the Spring at New Mexico State University (NMSU) in Las Cruces, NM. WERC is a consortium for environmental education, public outreach, and technology development and deployment. Consortium members include NMSU, the University of New Mexico, New Mexico Institute of Mining and Technology, Dine College, Sandia National Laboratories, and Los Alamos National Laboratory. Although geographically distant from Tennessee Tech, it is the only contest of its type in the nation. The reputation of the design contest is evident by noting the number and diversity of universities that have competed: The University of New Hampshire, Iowa State University, Clarkson University, University of Waterloo, Oregon State University, Michigan Tech University, Budapest University of Technology and Economics, Universidad de las Americas, and many others. The silica removal project was chosen by the author from the seven possible projects because the subject matter was best suited to an undergraduate class on water and wastewater engineering.

The class project was managed so that it would dovetail with the timeline and requirements of the WERC Environmental Design Contest. The class, CEE 4430, Water and Wastewater Engineering, is a senior-level elective that is offered only in the Spring Semester. Task deliverables for the WERC Design Contest included the following:

- A Safety Summary and Flow Sheet (5% of the total score) of the proposed process including information related to: bench-scale operation, process safety, chemicals used and waste stream emission was due by March 2, 2007.
- A Written Report (30% of total score) was due by March 13, 2007.
- A 15-minute Oral Presentation (25% of the total score) on the proposed design was to be made at the competition on April 2, 2007.
- A Bench-Scale Demonstration (30% of the total score) of the process was to be made at the competition on April 3, 2007.
- A Poster Presentation (10% of the total score) was to be made at the same time as the bench-scale demonstration.

Design considerations required that the treatment system:

- Was reasonably easy to use.
- Was innovative.
- Would not cause new environmental treatment problems.
- Would be applicable to rural systems.
- Was cost effective.

In the Spring 2007 Semester, which began on January 16, nine students enrolled in CEE 4430, Water and Wastewater Engineering. Based on several years enrollment data, this was a typical number of students for the class. Incidentally, in prior years, the course was taught by another instructor and a hands-on project was not required. After learning about the silica removal project, the approach that the students took was as follows:

- 1) Students reflected on the project individually.
- 2) Students formed groups of three.
- 3) Students discussed the problem in groups and formulated an overall approach.
- 4) Students examined the relevant literature individually, including background material to more fully understand the problem.
- 5) Students discussed the literature in groups and formulated a specific approach to follow, including the testing protocol.
- 6) Students initiated testing and analyses.
- 7) Students examined the test results individually and discussed the results in groups. Based on these discussions, new tests were decided on and conducted until the results were acceptable.
- 8) Once an acceptable solution was found, each group documented their project in a written report and prepared a PowerPoint presentation and a poster.

Silica Removal From Inland Brackish Water

Many communities are facing shortages in their fresh water supplies. To meet this challenge, communities have begun using less desirable sources of water, such as brackish groundwater, as a drinking water source. In many instances, however, silica in the groundwater interferes with the most common treatment process, reverse osmosis (RO), by fouling the RO membranes. RO membranes fouled with silica deposits can be cleaned, but only with use of a strong solution which might, in turn, damage the membranes. Brackish groundwater may also contain arsenic. Dissolved silica tends to impede arsenic removal by competing with arsenate ions at the surfaces of arsenic-removing sorption media. As a consequence, it is desirable to remove silica prior to RO treatment or to arsenic removal.

Dissolved silica exists as silicic acids such as metasilicic acid (H_2SiO_3) and orthosilicic acid (H_4SiO_4). Silica is commonly removed from raw water by the addition of metal hydroxides, such as $\text{Al}(\text{OH})_3$ or $\text{Fe}(\text{OH})_3$, to form insoluble metal silicates. Silica is also co-removed with magnesium and calcium in traditional lime-soda softening [Sheikholeslami, 4].

EXPERIMENTAL

Due to the fact that CEE 4430 is only offered in the Spring Semester, students had only eight weeks to complete their projects and send their written reports to WERC. Given this constraint, they decided to explore the conventional treatment processes of coagulation/flocculation/sedimentation using alum as a coagulant, and lime-soda softening, rather than to investigate novel treatment processes. Although this challenged the WERC design consideration that the process be innovative, examining traditional treatment processes was completely acceptable for the purposes of TTU's QEP to enhance critical thinking and real world problem solving. Also, because all three student groups examined the same methods using the same equipment and chemicals, it was easier to manage the laboratory for the class, e.g., providing equipment, purchasing chemicals, etc.

Using a fractional factorial design approach, student groups examined the effect of different concentrations of alum ($\text{Al}_2(\text{SO}_4)_3$), soda ash (Na_2CO_3), lime ($\text{Ca}(\text{OH})_2$) and caustic (NaOH) on silica removal with a six-gang jar test apparatus using 2-L square jars. The recipe for brackish water from WERC was as follows (g per L): NaCl (1.0), Na_2SO_4 (1.0), and sodium metasilicate pentahydrate (0.65). A stock solution containing chemicals at ten times these concentrations was used in the experiments. In each experiment, various volumes of stock solutions (1.0 g/L) of soda ash, lime, caustic, and alum were added to the beakers singly or in combination and rapidly mixed for various periods of time; flocculation was permitted to occur under slower mixing conditions for various periods of time; and finally, stirring was discontinued to promote sedimentation for various periods of time. Following sedimentation, samples were analyzed for silica by Hach Method 8185 using a Hach DR/4000 Series spectrophotometer. As the range of Method 8185 is 0 to 100 mg/L silica, samples were diluted by 50% prior to analysis. The pH was measured with a Thermo Orion model 720 pH meter. Based on experimental results, new combinations of chemicals and/or mixing conditions were investigated in subsequent experiments.

RESULTS

Laboratory Results

Due to limited prior laboratory experience, some groups made simple errors in their first round of experiments. For example, in the first experiment conducted by one group, the control reactor had a silica concentration of only 100 mg/L rather than 184 mg/L. Challenges such as this lead to the type of critical thinking that the project was intended to promote: the students were forced to reexamine the procedure they were using, identify the misstep, and correct it. After several rounds of experiments, the best silica removal was determined to occur using 150 mg/L alum and 200 mg/L lime. This combination resulted in silica removal of 50.0 %.

WERC Environmental Competition Results

An important aspect of the project was the external review of the students' design by the WERC judges. The judges provided the following comments regarding the strengths of their design:

- Strong initial showing for first contest.
- Great experimental effort
- Interesting multi-team challenge on common subjects.

- Worked well together as a team to answer questions.
- Smooth and congenial presentation.
- Use of proven technology resulted in good performance.

The following were noted as weaknesses by the judges:

- Computer based materials.
- Should not use notes during oral presentation.
- Order of materials/inclusion.
- Must address all of design elements for all four scored segments.
- Consider asking for a WERC mentor early to help prepare a full design.
- Use of overheads for oral presentation took away from quality.
- Need to address all aspects required for task.

Some noted weaknesses were a result of misinterpretation of the guidelines. For example, students prepared a Powerpoint presentation, but used overheads during the oral presentation as it was understood that Powerpoint would not be available for the oral presentation. Better communication will avert such missteps in the future.

Critical Thinking Assessments

To determine the effectiveness of the project on students' critical thinking abilities, pre- and post-project assessments were conducted. Analysis of the results revealed statistically significant progress in the following measurements of critical thinking:

- 1) learning to apply material,
- 2) acquiring skills in working with others as members of a team,
- 3) developing skill in expressing themselves orally or in writing,
- 4) learning to separate factual information from inferences,
- 5) interpreting numerical relationships in graphs,
- 6) identifying inappropriate conclusions,
- 7) identifying and evaluating evidence for a theory,
- 8) identifying new information that might support or contradict a hypothesis,
- 9) separating relevant from irrelevant information,
- 10) integrating new information to solve problems,
- 11) learning and applying new information,
- 12) using mathematical skills to solve real-world problems, and
- 13) synthesizing and organizing ideas, information, or experiences into new, more complex interpretations and relationships.

Student Feedback

Student comments on the class included:

- I really enjoyed the experience in CEE 4430. It was the only class in my undergraduate program that took me from the levels of theory and mathematical application to bench-scale laboratory work and all the way to an international competition. As a current graduate student, I now realize how helpful the class was in introducing us to scientific research in academia and clarifying the transition from design to real-world application of environmental engineering solutions.
- Many engineering classes give you basic tools to solve engineering problems. The material covered in CEE 4430 was directly applicable to solving a current problem encountered by some communities.
- It was great because you got some real hands on experience. I felt like our project gave us an opportunity to think outside the box and be a little more creative than other classes.
- I benefited from having an assignment to complete through a team approach. It allowed us to discover and enhance our personal strengths, and see them come together to complete a common goal. Definitely more of a "real world" experience than any other course I have taken.

One other measure of student approval can be observed by the fact that enrollment in CEE 4430 has jumped from nine students when this project was conducted in Spring, 2007, to 23 students for Spring, 2008. This is the largest enrollment in the class for the past ten years.

DISCUSSION

Complications will be encountered with any semester project. One complicating factor of this project was the limited background the students had in water chemistry. All of the students were civil engineering undergraduates with two semesters of undergraduate chemistry. Students were introduced to the applications of water chemistry in CEE 3410, Introduction to Environmental Engineering, a required course, but the only full semester course in water chemistry is taught by the author at the graduate level. Students had previously conducted jar tests in a laboratory exercise in CEE 3410, however, silica removal presents a challenging water chemistry problem. Research on the topic addresses the effect of complexation of various dissolved species, precipitation in various solid forms, sorption to other precipitates, etc. [Foust, 1; Gabelich, 2; Semiat, 3].

Another challenging issue related to the WERC design contest timeline. As mentioned, students had only eight weeks from the start of the class to the due date of their project report. Although the class project could have been conducted without participating in the WERC contest, competing in an international environmental competition was for many students the highlight of the semester and, for some, their undergraduate tenure. Although the timing of this project worked out in an acceptable manner, future WERC projects may present more of a challenge, for example, if the students must solve a problem with which they have no background whatsoever.

The class project was very successful by several measures. Students gained first-hand experience solving a real-world environmental problem and, in doing so, discovered an approach that they can use throughout their lives. The QEP assessments revealed that the project improved their critical thinking skills, their ability to work in teams, and their writing and oral communication skills. Student comments confirmed the value of the project to the students.

CONCLUSIONS

This activity can be replicated in any engineering or science course as long as students have access to a laboratory equipped with analytical equipment. Due to time constraints, it is best if the students have used the analytical equipment in a previous course. The instructor should assign a real-world problem that can be adequately solved in one semester. The general approach to solving the problem would be explained to the class:

- 1) Perform a brief literature review. The instructor might help guide the students to specific literature by narrowing possible solutions, by recommending specific authors, or recommending specific papers.
- 2) Students should read the literature individually and then discuss the problem and various solutions to the problem in groups. Many advocates of cooperative learning recommend that the instructor assign group members to balance the groups.
- 3) Upon consultation with the instructor, each student group would narrow the possible solutions to the problem.
- 4) Students would begin laboratory tests to evaluate their solution and then iterate to find the best solution given the time constraints.
- 5) Each group would then prepare a PowerPoint presentation, a project report, and a poster presentation; and make a class presentation.

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