AC 2007-614: ACHIEVING GRADUATE COMPETENCIES THROUGH AN AUTHENTIC DESIGN EXPERIENCE IN A WASTEWATER TREATMENT COURSE

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Abstract

Developing professional competencies require learning experiences that simulate authentic practice. A wastewater treatment course at a large, research university converted a portion of its traditional lecture and homework model of instruction to a challenge-based model of instruction culminating in a redesign project. The course used a series of challenge-based modules as a precursor to learners' synthesis of a design report and presentation to a corporate client. A nearby pharmaceutical company acted as a "perspective client" and issued a formal request for proposal (RFP) to the students, who were organized into "consulting companies." In addition to fundamental learning objectives related to wastewater treatment, opportunities to develop and demonstrate professional competencies were integrated into all aspects of the problem-based learning experience. Learners made gains in their knowledge about wastewater and demonstrated excellent professional skills in their written and oral reports.

Introduction

Graduates of our engineering programs are lacking the professional skills that are highly desired by employers. Industry-based surveys appear to indicate that engineering graduates, in the United States, are technically savvy; however, they are concerned with professional competencies of the students coming from our engineering colleges and universities. In 1993, Todd, Sorenson, and Magleby[1] presented the results of a nation-wide survey of industry perceptions of engineering graduates. The weaknesses identified in their survey included:

- Lack of design capability and creativity,
- Lack of appreciation for considering alternatives,
- Poor perception of the overall engineering process,
- Weak communication skills, and
- Little skill or experience with working in teams.

Sageev and Romanowski[2] conducted a survey to evaluate the impact that communication skills had on the professional careers of engineering graduates. Their survey of 208 individuals indicated that 32% of the engineer's work time is dedicated to written communication, 10% oral presentations, and 22% other forms of oral communication. That amounts to 64% of the engineer's time relating to communication activities. Also of note, is that the survey respondents reported that they spent 32% of their time working in teams. Their survey results also showed a strong correlation between communication skills and career performance (promotions, salary, etc.). Sageev and Romanowski[2] summarize their investigation with the following statement:

> *"Students need to learn basic people skills combined with technical communication skills or they will fail horribly when they enter the real world and have to compete with their peers."*

The message appears to be clear; engineering graduates lack the professional skills desired by industry and the skills necessary for career advancement. To address this, there are a variety of methods for integrating professional skills into a crowded engineering curriculum.

Seat, Parsons, and Poppen[3] discussed a minor in Engineering Communication and Performance offered to engineering undergraduates at the University of Tennessee. While attempting to answer the question, "Can the ABET Professional Skills be Taught?," Shuman, Besterfield-Sacre, and McGourty[4] stated:

> *"Although not necessarily taught in the traditional lecture format, these skills can certainly be mastered as part of a modern engineering education format that utilizes active and cooperative learning, recognizes differences in learning styles, and is cognizant of teaching engineering in its appropriate context."*

Shuman, Besterfield-Sacre, and McGourty[4] discuss the ability to incorporate professional skills in such broad programs as Engineering Projects in Community Service (EPICS) and Engineers without Borders, as well as several university specific initiatives.

This paper discusses an authentic problem-based learning (PBL) experience applied to an existing wastewater treatment course. PBL environments continue to grow and many investigators are illustrating its potential for developing technical skills and problem solving skills. In this paper we also explore the potential of PBL for integrating professional skills into a technical course.

We begin with a short description of generative learning environments followed with a short description of the refinements to the course.

Generative Learning Environments

Constructivist's theories of knowing guide the design of instructional methods for learning with understanding in an increasing number of engineering classrooms. Research indicates that learning environments that provide opportunities for students to activate their prior knowledge, also allow the student to further build and refine their knowledge in novel contexts. The use of activities that encourage students to articulate or demonstrate what they know and refine their thinking through self guided learning activities, interactions with their peers and instructors are components of a generative learning environment. Bransford, Brown, and Cocking's[5] text How People Learn (HPL) provides a framework for such learning environments. This framework emphasizes the importance of not only centering on the formalism of the knowledge to be learned, but also on factors centering on the learner, how they learn the specific content, assessments (both formative and summative) and issues of community (e.g. in undergraduate education this could include the classroom, department, university and specific profession)

The general instructional design principles governing problem-based learning are:

- Provide a context for knowing (conditions of when and how to use the knowledge)
- Encourage reflection, refine and reapplication of knowledge
- Continual test of knowledge (formative assessment)
- Encourage synthesis and integration of ideas in multiple and similar contexts.

A more detailed description of the actual activities is reported in the methods section.

Background

At Purdue University, in West Lafayette, Indiana, the water and wastewater treatment course is an upper-level, undergraduate technical elective in School of Civil Engineering. The course is also offered for graduate credit (with additional requirements). The course catalog describes the class as:

> *"Fundamental concepts and design procedures for the treatment of municipal and industrial wastewaters. Problem assessment; determination of effluent quality; preliminary treatment; biological physical and chemical treatment methods; and utilization and disposal of residues."*[6]

The intent of the semester-long course is to provide students with the fundamentals necessary to design both water and wastewater treatment facilities.

Like many engineering courses, this course has traditionally been instructed using what Raju and Sankar[7] describe as "teaching by telling" methods. During the fall of 2006 the course was divided into two sections; water treatment and wastewater treatment. The water treatment section of the course (approximately seven weeks) was taught using only traditional instruction methodologies. Subsequently, the wastewater treatment section of the course (approximately eight weeks) was instructed utilizing the principles of problem-based learning and challenge-based instruction.

A total of fifteen students registered for the course. Eight of the students were undergraduates and the remaining seven students were graduate level (masters and doctoral). Four of the students were female and five of the students held international status. Prior to the first day of class, students were not aware that a portion of the course would be instructed using PBL. The class is not a senior design or capstone course.

Anticipated Outcomes

Several outcomes were anticipated as a result of implementing the PBL. We hypothesized that the students would perceive an increase in their knowledge of wastewater treatment as a result of the innovative teaching/learning methods. Further, as a result of the PBL experience, students would perceive an increase in their written and oral communication skills, as well as teamwork skills.

Design of a Problem-Based Learning Experience

The primary objective of the PBL-course was to create an active learning environment to develop learners' content knowledge and skills related to wastewater treatment. The secondary goal of the PBL-course was to the integrate professional skills into their learning process. This was accomplished by simulating a common practice in the wastewater industry (and other industries), obtaining input from outside consultants to assist with design or redesign of facilities. In this situation, the consult must develop a viable solution and persuasively defend it in front of the client. Achieving this ability requires the combination of content knowledge and skills for evaluating and analyzing a system for opportunities to improve, and professional skills to effectively communicate and persuade the client that the design is effective. With this approach we were able to effectively achieve one of the fundamental principles of PBL - the problem should be authentic in nature. Several specific efforts were made to design a course with a degree of authenticity, while at the same time integrating methods for developing and assessing the desired professional skills.

Credibility of the PBL experience was greatly enhanced by the opportunity to design the project around an existing wastewater treatment facility. A major pharmaceutical company operates a manufacturing facility near the Purdue campus. Their manufacturing facility includes an industrial wastewater treatment plant. The pharmaceutical company has a long standing relationship of collaborative educational activities with the university. The company graciously offered to act as a corporate partner for the PBL.

The pharmaceutical company took an active role in defining the problem statement such that it addressed real issues facing the company. The PBL was designed around the reality that the existing treatment facility is oversized for the current volume of manufacturing. Thus, one of the goals of the PBL experience was to evaluate the existing treatment facility and consider options for altering the facility.

As in industry, the problem was presented to the students in the form of a Request for Proposal (RFP). With the assistance of our corporate partner, the RFP was written to include information and language typical of those issued by the pharmaceutical company for engineering services. The RFP was addressed to a series of fictitious consulting companies and included a discussion of the facility, identification of the project goals, a listing of possible design alternatives, and data regarding the facility operation. Our corporate partner is respected for its commitment to sound environmental practices. A history of effluent discharge, well below required limits, was detailed in the RFP. The RFP clearly stated the company's desire to adhere to ethical and environmentally responsible practices. Lastly, the document issued to the students also included an eight week schedule with dates for required deliverables.

The RFP was prepared to contain extraneous information, while at the same time it was missing critical information that the students would need to complete the PBL. The extraneous information required the students to thoroughly review the RFP and understand which information was necessary to address the project. A minimum level of wastewater treatment knowledge was required to identify information lacking from the RFP. Questions raised by the students provided evidence of learning to the course instructors. In keeping with the authentic nature of the PBL, students issued formal Requests for Information (RFI) to obtain additional project-related information. RFIs were addressed through a series of addendums issued to the students.

Students were organized into "consulting companies" to address the PBL and respond to the RFP. Rather than allowing students to self-assemble, the students were assigned to a particular "consulting company." An attempt was made to assemble well-balanced teams with a mix of gender, international/national status, and undergraduate/graduate standing. In total, four teams were created; three teams of four students and one team of three students.

By using the consulting company scenario, a sense of competition was created in the classroom; with individuals contributing to the team's effort to produce a top quality set of deliverables. While the learning process was common amongst all the students, each consulting company developed a unique approach to responding to the RFP. Teams were not competing for course grades. Thus, the competition was only artificial in nature.

The pharmaceutical company remained involved throughout implementation of the PBL, acting as the perspective "client" from whom "consulting companies" were seeking a contract. A representative of the corporate partner made a presentation to the students (one of many guest lectures utilized during the project) related to the original design and current operation of the existing wastewater treatment facility. The representative also discussed the alternatives for altering the existing facility, as identified in the RFP. The PBL deliverables (discussed in greater detail subsequently) included preparation of a formal report and delivery of a presentation detailing the "consulting companies" recommendations to the "client." Multiple representatives of the pharmaceutical company attended the presentations made by the student teams and reviewed the reports.

A unique aspect of problem-based learning is that the instructor, at times, becomes less of a teacher and more of a facilitator and coordinator. Students are encouraged to advance their knowledge through peer instruction within the team setting. During the early portion of the project, each consulting company received coaching from the instructors on methods of developing teamwork skills. The application of the PBL in this course did not fully rely on self-directed student learning. The problem-based learning experience was delivered using "traditional" lectures during approximately half of the scheduled meeting times.

Learning Assessment Instruments

A variety of assessment activities were employed to evaluate student learning. The assessment activities were designed in general accordance with challenge-based instruction (CBI) methods, while at the same time adhering to the desire to integrate opportunities to promote and develop professional skills.

Students completed a pre-assessment designed to evaluate their knowledge of wastewater treatment concepts prior to seeing the RFP. The pre-assessment consisted of a flow diagram consisting of nodes and link, but without the links. Multiple boxes (nodes), each labeled with the name of a unique and discrete wastewater treatment process, were randomly scattered around a single page. The students were asked to independently use a series of arrows (links) to connect each box to represent the series of flow encountered in a wastewater treatment facility. At the end of the course, students were asked to complete the same assessment (post-assessment). A comparison between the pre- and post-assessment results should demonstrate an aggregate increase in learning.

The primary learning assessment, implemented in this PBL, was preparation of a technical report and presentation of recommendations. The report and presentations were executed by the "consulting company" teams. As a team, each company was required to issue a formal report to the "client" that included a discussion of alternatives, considerations used in evaluating the alternatives, decision model employed, and well defended recommendations. Preparing the report and presentation required the teams to evaluate the alternatives for altering the existing treatment facility and other requirements of the RFP. Addressing all the requirements of the RFP during a short schedule and preparing the report required the students to exercise significant teamwork and written communication skills.

The formal presentations, lasting 20 minutes, were evaluated for technical content, ability of team members to speak beyond the slides, confidence of the team, public speaking aptitude, and professional demeanor. The "consulting companies" were also evaluated on their ability to address technical questions raised by the instructors and representatives of the pharmaceutical company in attendance during the presentations.

Quasi-weekly assessments were made through a series of assignments issued to the "consulting companies." Each of these assignments were designed to test broad knowledge of concepts, as well as the team's ability to perform calculations specific to the course content discussed during the prior week. The weekly assignments required the teams to synthesize data presented in the RFP and consult multiple external references (not just class notes). Completion of the weekly assignments contributed to the ability of the teams to address the formal report and presentation. The weekly assignments required teamwork and written communication skills to accomplish the requirements and prepare a deliverable. Each assignment included a combination of calculations and open-ended questions that required the "consulting companies" to prepare a unique and well defended response. The weekly assignments were graded on technical merit and professional presentation.

The final assessment implemented into this PBL was an oral defense. Unlike the other PBL activities that were performed as a team, the oral defense was performed on an individual basis. Each oral defense lasted approximately 10 minutes and was conducted in a closed environment with only the student and instructors present. Students were asked to describe the process that their team used to reach the recommendations made in their report. Students were asked to describe and defend the team's recommendations or discuss why they personally believe their company may have proposed the wrong design recommendations.

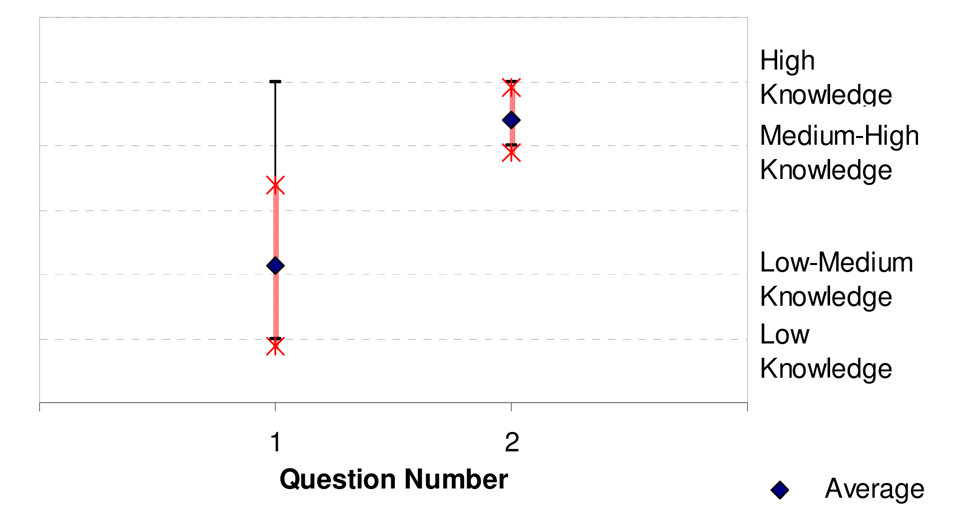
Results

An exit survey was designed and administered with the intent of evaluating students' perceptions of the PBL experience. Students were asked to evaluate various aspects of the PBL and how each aspect contributed to their individual learning. Students completed the survey on a voluntary basis during the final course meeting and after all assessments had been completed.

A portion of the exit survey questions have been analyzed and the results are graphically presented herein. In the case where a range of responses were possible, the data was analyzed by assigning number values across the range (e.g. strongly disagree = -2, disagree = -1, agree = 1, and strongly agree = 2). The results are presented graphically, but without the associated numeric values. It should be noted that the graphic presentation assumes an even distribution between each response.

Questions #1 and #2 of the exit survey asked the students to evaluate their own knowledge of wastewater treatment prior to and after completion of the PBL. The results indicate that the students reported a wide range of perceived initial knowledge (Figure 1). While at the end of the PBL, the students consistently rated their knowledge as “High” or “Medium-High.” It is also encouraging to note that the results indicate an increase in the average class wastewater treatment knowledge.

As noted previously, the secondary learning objective of the PBL (wastewater treatment learning being the primary learning objective) was to integrate opportunities for students to practice specific professional competencies. The target competencies included those areas identified as weakness among engineering graduates in various industry surveys. Seven questions on the exit survey were designed to evaluate the students’ perceptions of the effectiveness of integrating professional skills in the PBL (Figure 2).

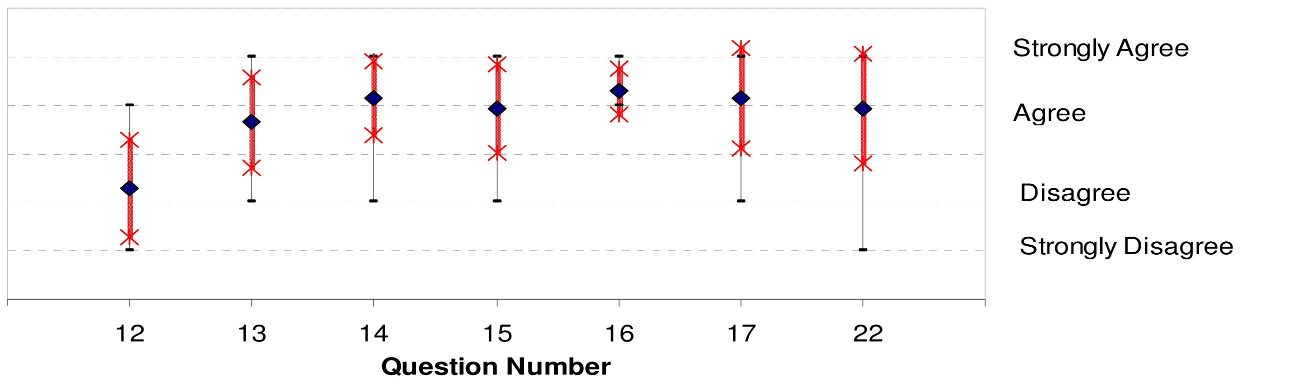


Questions:

1. Rate your personal knowledge of wastewater treatment prior to the project-based learning experience.

2. Rate your personal knowledge of wastewater treatment after the project-based learning experience.

Figure 1. Student perceptions of wastewater treatment knowledge prior to and after the project-based learning experience. Average response, response range, and standard deviation shown.



Questions:

12. Before the project I did not understand that wastewater treatment is a series of processes in a particular order.
13. I think the RFP increased my awareness of how business is conducted in the wastewater industry.
14. This project increased my awareness that there can be multiple solutions to address an engineering problem.
15. This project strengthened my written communication skills.
16. This project strengthened my oral communication skills.
17. This project strengthened my ability to perform work as part of a team.
22. I learned more about solving complex problems in this course compared with other courses I've taken in engineering.

Figure 2. Student perceptions of professional competencies within PBL. Average response, response range, and standard deviation shown.

On average the students reported that prior to the PBL they understood wastewater treatment was a series of processes in a particular order (question #12).

There was a range of reported responses to question #13, which evaluated if the students believed that the use of the Request for Proposal (RFP) increased awareness on how business in conducted. However, the average results were positive, indicating that this attempt to make the PBL authentic was useful. When this data was sorted based on graduate versus undergraduate, it was interesting to note that the graduate students were unanimous in their belief that the use of the RFP increased their business acumen.

Question #14 evaluated if the students believe that the PBL increased their awareness that there can be multiple "correct" solutions to engineering problems. While the responses range from "Disagree" to "Strongly Agree" the average response for the class correlates to slightly better than "Agree."

Questions #15 - #17, relate to the PBL's ability to strengthen the written communication, oral communication, and teamwork skills, respectively, of the students. The results are encouraging. All students reported positive results for these questions. Notably, the reported range for the oral communication skills (question #16) was small and the average was high (between "Agree" and "Strongly Agree").

Question #22 indicates that on average the students believe that they learned more about solving complex problems from the PBL course than other engineering courses they have been exposed to. However, this question also had the largest range of responses.

Eight of the fifteen students completed the pre-assessment flow diagram correctly. Whereas, a total of eleven students completed the post-assessment correctly. The fact that eight of the students completed the pre-assessment correctly appears to be consistent with question #12 (Figure 2) of the exit survey. The results of the exit survey indicate that on average, at the start of the course, the students believed that they understood wastewater treatment was a series of processes in a particular order.

Upon closer inspection of the completed pre- and post-assessments, advanced knowledge of wastewater treatment concepts was illustrated by students who created loops in the system to indicate wastewater recycling (e.g. denitrification with mixed liquor and activated sludge). An indication of advanced knowledge was observed in one pre-assessment and two of the post-assessments.

Discussion

The survey results and assessment tools appear to provide positive responses to the anticipated outcomes. Specifically, the students self-reported an increase in wastewater treatment knowledge. Additional survey questions probed the student learning deeper to evaluate the depth and breadth of learning resulting from the problem-based learning versus the level of learning that students perceive resulted from more traditional instructional methodologies. The authors are currently assessing those results and anticipate that information will be released as part of a separate publication.

The instructors noted that the quality and professionalism of the team deliverables was considerably better during the PBL than the individual student work performed during the non-PBL portion of the course. The assignments submitted during the first half of the semester (non-PBL and non-team based) lacked clarity and organization. Whereas the PBL assignments were prepared and presented in a highly professional manner. Treating the students as professionals appears to have resulted in the students producing better technical and skilled work.

The survey results clearly indicate that the students believe that the PBL was successful in strengthening their written, oral, and teamwork skills. Further, the PBL increased the students' understanding of how business is conducted in the wastewater treatment industry. Lastly, the students developed an understanding of wastewater treatment as a series of processes, each with a critical role. These are the types of professional skills that industry has been looking for in engineering graduates and the type of requested skills that Todd, *et. al*[1] and Sageev and Romanowski[2] identified in their respective publications.

There are limitations inherent to this study that we readily identify and offer comments on. The study evaluated a small group of students who received a PBL treatment. There was no true control group for us to compare our treatment against. However, we intentionally designed the study such that the water treatment portion of the course via traditional lecture methods and the wastewater treatment portion of the course via PBL (same group of students throughout). Therefore, we have a within-subject comparison of students' perception of traditional versus PBL approaches to instruction within a specific course.

The majority of the students had not previously been enrolled in a course that used a problem-based learning approach. Four of the students were enrolled in a problem-based senior design course, concurrent to the PBL course. Accordingly, the novelty of the PBL experience may have produced a slight Hawthorne effect among the students. However, we also see that students value this experience as an important part of their educational experiences; therefore, their sustained motivation is more than just the novelty of the experience and more a factor of their intellectual engagement in a worthwhile learning experience.

Conclusion

A common criticism received from industry surveys and advisory committees is that graduates need to be equipped with better professional skills. We have developed a problem-based learning experience around the simulation of a consulting contract commonly used in industrial practice. We blended this project experience with didactic lessons on specific content related wastewater treatment to create a learning environment that achieved both content knowledge and professional skills. Evidence from this study indicates that by selectively utilizing principles of problem-based learning, opportunities were presented for students to develop and demonstrate the professional skills desired by industry. The course maintained some of the common components of an academic undergraduate experience (regular class session, mini lectures, and assessments). The project-based experience provided a level of synthesis that engaged the learners in an authentic professional practice. As a result, students were required to go beyond computations, to a much higher process of problem solving and communication. The project gave them an opportunity to evaluate a complex challenge, generate questions and communicate a persuasive argument to "sell" their design ideas to a client. We believe providing this level of instruction to juniors, seniors, and graduate students is appropriate and feasible within specific domains. The level of support and overhead to accomplish this corporate simulation of the RFP process is manageable with a small class size and wholly appropriate with the developmental level of the students.

We anticipate the opportunity to conduct further studies on student learning in a PBL environment like the one we have implemented and described herein.

Acknowledgement

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