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Project Based Learning of Environmental Engineering: A Case Study

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Abstract

Project-based learning is a comprehensive approach to classroom teaching and learning that is designed to engage students in investigations of authentic problems. This paper presents perceptions and attitudes of students that have participated in a Project-Based Learning (PBL) course in environmental engineering. The course, `Environmental Engineering II', was developed and taught using PBL approach. In this course, 3- or 4-member teams of students carried out two projects that required data collection, literature review, design, and preparation of professional reports. The two projects comprised 50% of the final grade. At the end of the semester, a survey was conducted with seven questions to compare the students' learning environment in the environmental engineering design course, with lecture, exams, and project reports/case studies, with the traditional lecture-centric course. The qualitative paradigm was found to be suitable for studying the process undergone by the students, mainly because the study focused on the materials they learned in a prerequisite course and how outcomes of the projects are used in our daily lives. Required data was collected by means of literature review, laboratory experiments, and field visits. Students' perceptions and attitudes about PBL approach appeared to be favorable and acceptable as a learning environment for future environmental engineering design courses.

Introduction

In project-based learning (PBL), students work in groups to solve challenging problems that are authentic, curriculum-based, and often interdisciplinary. Learners decide how to approach a problem and what activities to pursue. They gather information from a variety of sources and synthesize, analyze, and derive knowledge from it. Their learning environment is inherently valuable because it's connected to something real and involves adult skills such as collaboration and reflection. At the end, students demonstrate their newly acquired knowledge and are judged by how much they've learned and how well they communicate it. Throughout this process, the teacher's role is to guide and advise, rather than to direct and manage, student work. PBL is also a model that organizes learning around projects. According to the definitions found in PBL handbooks for teachers, projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations[1,2]. Other defining features found in the literature include authentic content, authentic assessment, teacher facilitation but not direction, explicit educational goals[3], cooperative learning, reflection, and incorporation of adult skills[4]. To these features, particular models of PBL add a number of unique features. Definitions of "project-based instruction" include features relating to the use of an authentic ("driving") question, a community of inquiry, and the use of cognitive (technology-based) tools[5,6]; and "Expeditionary Learning" adds features of comprehensive school improvement, community service, and multidisciplinary themes[7].

It is believed that the real-world focus of PBL activities is central to the process. When students understand that their work is ultimately valuable as a real problem that needs solving, repeating, or enhancing, or a project that will impact others, they are motivated to work hard. Ed Gragert, director of iEARN, which offers PBL projects that address local, national, and global issues, believes that collaboration, interactivity, and a clear outcome that "improves the quality of life on the planet" really speaks to kids. "By demonstrating that they can make a difference in human lives, students are motivated and empowered to carry their experiences into lifelong community and global service," he says. In addition to teaching core content and raising awareness, PBL trains students to take complex global issues and break them down into specific local action steps. As mentioned by Heitmann[8], PBL may be applied in individual courses or throughout the engineering curriculum. He differentiates between "project-oriented studies" and "project-organized curriculum". According to Heitmann, project-oriented study involves the use of small projects within individual courses, progressing to a final year project course. The projects will usually be combined with traditional teaching methods within the same course. They focus on the application, and possibly the integration of previously acquired knowledge. Projects may be carried out by individuals or small groups. Project-organized curricula use projects as the structuring principle of the entire curriculum, with subject oriented courses eliminated or reduced to a minimum and related to a certain project. Students work in small groups with a project team of teachers who are advisers and consultants. Projects are undertaken throughout the length of the course and vary in duration from a few weeks up to a whole year. In present day engineering, a completely project-organized curriculum does not yet exist, and the closest are programs where projects and project-related courses make up 75% of the program, as at Aalborg University in Denmark. Several examples of PBL used in individual or a few courses in engineering programs are provided in Mills and Treagust[9]. They concluded that PBL is likely to be more readily adopted and adapted by the university engineering programs than problem-based learning. They emphasized that the use of PBL, as a key component of engineering programs should be promulgated as widely as possible, because it is certainly clear that any improvement to the existing lecture-centric programs that dominate engineering would be welcomed by students, industry, and accreditors alike. Another issue in PBL is student motivation and sustaining the motivation once the PBL activities are underway. In a study[10] it was emphasized that project design, teaching, and use of technology all need to be considered as opportunities for marshalling existing student motivation, creating opportunities for motivation, and sustaining the motivation once the PBL activities are underway. The study also argued that motivation and cognitive engagement are iterative – one or other becomes more or less salient during the course of the project work.

Several researchers investigated the use of on-line technology with PBL. Ravitz and Blazevski[11] assessed the role of on-line technologies in PBL. Their study supported many of the predicted relationships, including a direct relationship between online feature use and time spent on PBL for teachers in reform network schools. Outside the reform network schools, however, the path from on-line feature use to PBL use was unclear with only indirect effects. These results suggest areas for further investigation and that we should be cautious not to overstate the role of online technologies. On the technology horizon, there seem to be trends toward virtual reality or game-based learning[12,13], use of online lectures in the flipped classroom[14], and massively open online courses[15]. It is not really known as to what the impact is on use of PBL practices. Lessons learned about student engagement and assessment in games suggest there is room for co-development[13], especially for scaffolding learning and assessment[16], while flipped classrooms may encourage use of PBL as a way to "focus precious classroom time on more interactive problem-solving activities that achieved deeper understanding— and foster creativity".[17]

According to Hanover Research[18], by most accounts, the impact of technology on PBL is only increasing. Although web literacy and digital citizenship can be included in twenty-first-century skills[19], effective PBL does not always have to be "technology accelerated and network-connected".[20]

Kirschner et al.[21] reported on several studies and meta-analyses of PBL, however; they overlooked other reviews that were more favorable to PBL. At around the same time as the Albanese and Mitchell[22] and Berkson[23] reviews that Kirschner et al.[21] cited, there was a third meta-analysis conducted by Vernon and Blake[24]. This analysis found that medical students in PBL curricula performed slightly worse on tests of basic science knowledge but performed better on tests of clinical knowledge than traditional medical students. Unlike the "discovery learning" or minimally-guided instruction[22,25], effective use of PBL requires extensive planning and professional development, a supportive environment, and tool and strategies for effective instruction, including the use of technologies.[26,27,28] After years of research on use of problem-based learning in medical school contexts, evidence was seen that PBL, as adapted for K–12 use, can be effective.[29]

The current study was aligned with the concept of project-oriented studies[8,11] that is recognized to be a part of PBL. The environmental engineering course that was used for this study was the second environmental engineering course in the civil engineering curriculum. The first environmental engineering course and the associated lab are used to expose the importance and use of water and wastewater treatment in our daily lives, as well as the simple unit process design of water and wastewater treatment plants. Two field trips are conducted to local water and wastewater treatment plants to show the extent of the plant layout and processes. Students develop the design concepts and knowledge from the first environmental engineering course. Students also develop relationships with the treatment plants' officials during the field trips and can revisit the plants again from time to time as they need to collect data and/or find a way to collect information for the design in the second course. In the second course, two small projects, one on water treatment plant design and the other on wastewater treatment plant design, were assigned to groups of four to five students. Required data was collected by means of literature review, laboratory experiments, and field visits as was done in a similar study[30]. No individual was assigned to a project due to time constraints. The first project was assigned for six weeks and the second one was for eight to nine weeks for a 16-week semester. The students were required to prepare professional reports and present them in the class at the end of each project. At the end of the semester, a survey with seven questions, as shown in Figure 1, was conducted to gather the data for the evaluation of PBL for environmental engineering. PBL inclusion in engineering curriculum may be well established, but the inclusion of PBL in environmental engineering design courses is a kind of new. This study explores the students' perception and attitude of PBL inclusion in environmental engineering design courses that influence the learning environment.

End of Semester Survey and Data Analysis

There are a total of 55 students that participated in the survey. The analysis of survey data is presented in Table 1 and illustrated in Figures 2 and 3. Some of the responses to questions, as seen in Figure 2, did not sum up to 100% as a few students did not respond to all questions.

Q.1. Please indicate with an "X" where appropriate:

Gender: Male ____________ Female: ______________

Academic Standing: Sophomore: ________ Junior: _______ Senior: __________

Q.2 Have you ever completed a design project or a case study as part of another course in CE?
Yes: _______; No: ________
If yes, please describe nature of the project/case study and the class.

Q.3 Indicate with an "X" your response to the following:

Items	**Strongly Agree (+4)**	**Agree (+2)**	**Neutral (0)**	**Disagree (-2)**	**Strongly Disagree (-4)**
a. Compared to the traditional lecture and exams, two project reports/case studies helped me better understand the basic concepts of the design aspects of the water and wastewater treatment processes.					
b. Compared to the traditional lecture and exams, project reports/case studies helped me better understand the practical applications of environmental engineering.					
c. Compared to the traditional lecture and exams, project reports/case studies helped me better understand how to write a professional report in environmental engineering.					
d. The total credit (50%) assigned to the two projects/case studies does not satisfy the work load.					
e. Working on group project reports/case studies was a good experience.					
f. Four/five member groups were formed for the projects:					
i . Number of group members was too high					
ii. Number of group members was too low					
iii. Number of group members was just right					
iv. Suggest an optimum number of members in a group					
g. Working on an individual project/case study was/will be a good experience.					
h. This kind of design projects/case studies may help me in graduate study.					
i. Two projects/case studies (one for water treatment plant design and the other for wastewater treatment plant design) were good enough for a semester.					
j. Two field trips to local water and wastewater treatment plants enhanced my understanding and learning of the subject matter.					
k. Learning new topics by example during the					

project work was a good experience.				
l. Guest speaker enhanced my interest about environmental engineering.				

Q.4 What did you like most about the inclusion of the design projects/case studies in this course?

Q.5 What did you like least about the inclusion of the design projects/case studies in this course?

Q.6 What suggestions would you give the instructor/students to enhance/improve the experience of writing the project report/case study?

Q.7 Other comments/suggestions/complaints.

Figure 1: Survey questionnaire for PBL of Environmental Engineering

About 89% of the students participating in the survey were male, 11% were female, and approximately 96% were seniors with only 4% juniors. Based on the responses to Q.2, about 85% of the participants had some exposure to design projects in a variety of other civil engineering courses, such as bridge design, steel building design, concrete structure design, hydraulic structure design, etc. before they took the environmental engineering design course and only 15% of participants responded that they did not have any prior exposure to design projects before this class.

Table 1: Analysis of survey data for PBL of Environmental Engineering

Q.1	Male – 49 (89%)	Female – 6 (11%)	Sophomore – 0 (0.0%)	Junior – 2 (3.6%)	Senior – 53 (96.4%)
Q.2	Yes – 47 (85.5%)		No – 8 (14.5%)		
Question No.	Strongly Agree (+4)	Agree (+2)	Neutral (0)	Disagree (-2)	Strongly Disagree (-4)
Q.3a	28 (50.9%)	22 (40.0%)	4 (7.3%)	1 (1.8%)	0 (0.0%)
Q.3b	24 (43.6%)	25 (45.5%)	3 (5.4%)	1 (1.8%)	0 (0.0%)
Q.3c	20 (36.4%)	16 (29.1%)	9 (16.4%)	3 (5.4%)	0 (0.0%)
Q.3d	6 (10.9%)	6 (10.9%)	20 (36.4%)	15 (27.2%)	6 (10.9%)
Q.3e	21 (38.2%)	22 (40.0%)	8 (14.5%)	1 (1.8%)	3 (5.4%)
Q.3f(i)	6 (10.9%)	5 (9.1%)	12 (21.8%)	15 (27.3%)	6 (10.9%)
Q.3f(ii)	3 (5.4%)	3 (5.4%)	13 (23.6%)	4 (7.3%)	1 (1.8%)
Q.3f(iii)	22 (40.0%)	10 (18.2%)	10 (18.2%)	4 (7.3%)	1 (1.8%)
Q.3f(iv)	1-2 = 1 (1.8%)	3 = 15 (27.3%)	4 = 21 (38.2%)	5 = 12 (21.8%)	--
Q.3g	15 (27.2%)	12 (21.8%)	12 (21.8%)	11 (20.0%)	5 (9.2%)
Q.3h	24 (43.6%)	20 (36.4%)	9 (16.4)	1 (1.8%)	1 (1.8%)
Q.3i	34 (61.8%)	17 (30.9%)	2 (3.6%)	1 (1.8%)	1 (1.8%)
Q.3j	34 (61.8%)	16 (29.1%)	5 (9.1%)	0 (0.0%)	0 (0.0%)
Q.3k	28 (50.9%)	16 (29.1%)	8 (14.5%)	3 (5.4%)	0 (0.0%)
Q.3l	22 (40.0%)	26 (47.3%)	7 (12.7%)	0 (0.0%)	0 (0.0%)

As shown in Figure 2 and Table 1, on average, about 90% (about 50% strongly and 40% agreed) agreed that, compared to the traditional lecture and exam approach, two project reports/case studies helped them better understand the basic concepts of the design aspects of the water and wastewater treatment processes (Q.3a), which received an overall score of 2.80 on a 4.0 scale, as shown in Figure 3.

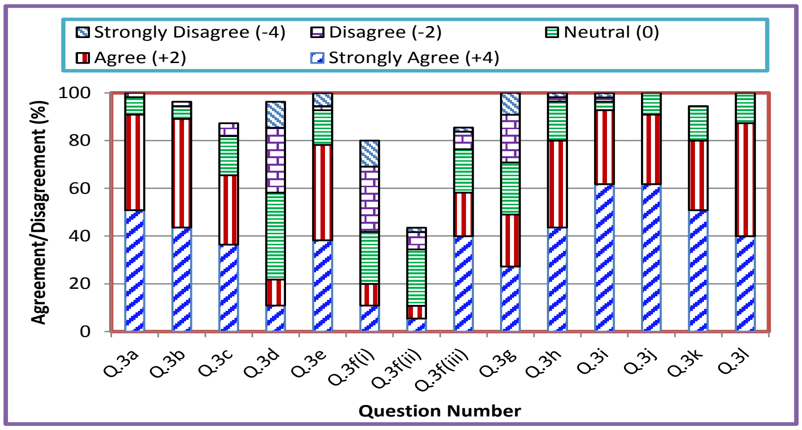

Figure 2: Agreement and disagreement percentage for each question

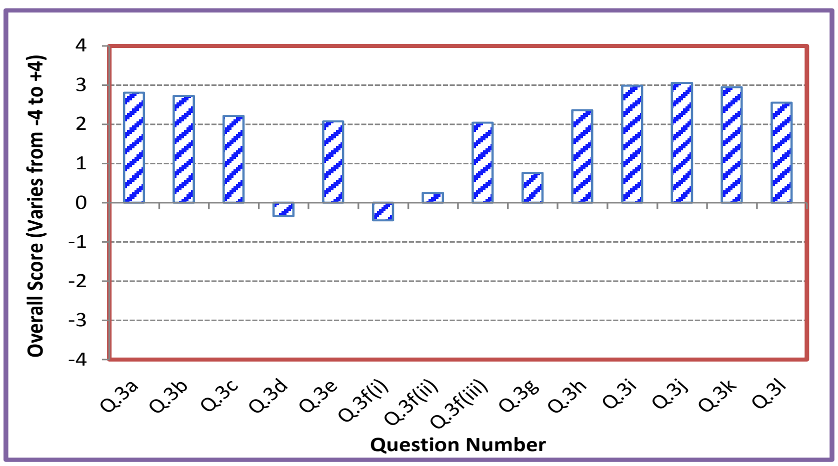

Figure 3: Overall agreement/disagreement

On average, 89% agreed that, compared to the traditional lecture and exam approach, project reports/case studies helped them better understand the practical applications of environmental engineering (Q.3b); with an overall score of 2.72. It appears that project-based learning is desirable to students for understanding of design concepts and practical applications of environmental engineering. About 7 - 9% of participants either did not agree or were neutral and only 1% of participants did not respond to these two questions, which is reasonable, as different people learn different ways. When it comes to report writing, about 65% agreed that, project reports/case studies helped them better comprehend how to write a professional report in environmental engineering (Q.3c); with an overall score of 2.21. About 21% of participants did not agree or were neutral. About 14% of participants did not respond to this question. This outcome reveals that report writing is not a popular item for students, as it is time consuming and thought provoking. About 22% agreed that the total credit of 50%, assigned to the two projects/case studies does not satisfy the work load. About 63% of participants did not agree or were neutral. About 15% of participants did not respond to this question (Q.3d); with an overall score of -0.34. It appears that approximately a majority of the participants were happy with the 50% weight for the projects. About 78% of participants agreed that working on group project reports/case studies was a good experience and about 22% did not agree or were neutral (Q.3e); with an overall score of 2.07. When the question of optimum number of students in a group was posed, 27% voted for 3-member groups while 38% voted for 4-member groups. Only 2% voted for 2-member group and about 22% voted for five- or more-member group (Q.3f (iv)). This question reveals that the optimum number of students in a group would be three or four; four seems to be more desirable.

On average, about 49% agreed that working as an individual on a project/case study was/will be a good experience (Q.3g); with an overall score of 0.76. About 51% of participants did not agree or were neutral. This does not seem to be a good option for projects or case studies. On average, about 80% agreed that these kind of design projects/case studies may help them in graduate study (Q.3h); with an overall score of 2.36. Only 20% of participants did not agree or were neutral. On average, about 93% agreed that two projects/case studies (one for water treatment plant design and the other for wastewater treatment plant design) were good enough for a semester (Q.3i); with an overall score of 2.98. About 90% agreed that two field trips to local water and wastewater treatment plants enhanced their understanding and the learning process of the subject matter (Q.3j); with an overall score of 3.05, while 80% agreed that learning new topics by example during the project work was a good experience (Q.3k); with an overall score of 2.94, and about 87% agreed that the guest speaker enhanced their interest in environmental engineering (Q.3l); with an overall score of 2.55. Learning new topics by example during the project work seems to be more appealing to students. Two field trips to local water and wastewater treatment plants seemed to enhance students' understanding and learning process of the subject matter and received the highest overall score (Figure 3).

The typical comments received for Q.4, Q.5, Q.6, and Q.7 are quoted below. Most of the participants responded to these questions. However, only a few pertinent comments and one of the similar responses are quoted below for each question.

Q.4 What did you like most about the inclusion of the design projects/case studies in this course?

> *"It was application of the real world. Doing problems on the board is all fine and good, but doing something you may actually do later in life is far more beneficial. Even working in a group, having tasks to complete, and relying on your team to get the job done is vital to working in real life. Also, it teaches you to pick your team well. You need to pick people you can rely on, just like in the work place. That may sound cruel, but if I were a manager of an office, I would make sure to higher or add people to the office who know what they are doing and are able to complete the task. Also, if I were preparing a group to tackle a project, I would be sure to pick people who I knew had the strengths needed for the project. I think working in groups for class projects teaches you that very well."*

> *"It gave us the opportunity to research methods of water and wastewater treatment and gave us the chance to put these methods into use in a real world."*

"It increased my interest in the area and made the materials easier to comprehend."

"Working in groups, due to the fact that as soon as you land in a job you will start working with people and be part of a team to accomplish a goal so these projects help you out to bring ideas and opinions together."

"Working with other students really pushed me to perform at my highest level. I had a really smart team. The final product was something I was truly proud of."

"The field trips." "It helped me understand how WTP and WWTP work."

"The research – learning about the process in depth from different sources. The learned approach/method of design."

"It gave us experience in using the design problems we had practiced in class and homework to design an entire treatment plant."

"Solidified knowledge gained thru lectures by applying to real life situations."

"It was practical and helped embrace the concepts learned in the class."

"How it helped to increase my understanding of the subject matter."

"use of everything we have learned, requires you to have organized material in a way that you cannot forget the material."

"Being able to work with a group and 'bounce' ideas off of one another."

Q.5 What did you like least about the inclusion of the design projects/case studies in this course?

"It is hard to get some students motivated and complete their portion of the design. I was not always sure what equation to use in different situations. "

"It's a lot of work, but so is everything that you are going to do in the workplace. I feel that if you were to remove those projects from the class, you would detrimental hinder the class from learning about common things they will be doing in the office. Knowing how to compile a report, explain material clearly and simply, collaborating with fellow colleagues are just a few things that are vital to the workplace that are experienced by having class projects."

"Group sizes were two large, meaning that learning/experience was spread thinly among the four members."

"I liked the projects, but I feel that it would have been better to do the projects first before going to the treatment plants."

Q.6 What suggestions would you give the instructor/students to enhance/improve the experience of writing the project report/case study?

"I would suggest that professional environmental engineers be used as mentors to the different groups. This engineer could also invite the group he is mentoring for an office visit to learn what resources are available to an environmental engineer day-to-day on design projects."

"Treat it as real world as you possibly can. For example, have the company (groups) meet with the client (teacher) individually. The teacher can then share what he would like to have built, and the group would then go and design and present their plan to the teacher. Obviously it won't be perfect. The drawings may look bad and the formatting of the report may be terrible; however, giving students a reality check on what projects are like is really important. Now, don't make things too difficult and don't set unattainable goals. Absolutely they will need to be coached through it. However, make it as close to reality as possible."

"The project was pretty detail intensive and took a decent amount of time; even for what I thought was a very smart team. I had an advantage because I took senior design before Environmental 2. Therefore I was ready to schedule tasks, collect data, iterate calculations and write a technical report from day one. I would explain to the class that these projects are like mini senior design projects. If the students treat it like such, it will not only make for a quality project, but also prepare them for senior design. This project is a challenge. To be honest though, I don't know what would need to be done to improve the experience as I had a good experience."

Q.7 Other comments/suggestions/complaints.

"I have no complaints. I have had the incredible blessing to be an intern/part-time/full-time employ for an amazing engineering firm. There are things that I have learned at the workplace that have made me a better student, but there are things I learned as a student that made a better work person. These projects greatly enhanced by capabilities as an employ for my company. Were they fun to work on? Yes and no. I did not enjoy the late nights of editing material and making sure things looked right, but it taught me so much about how to be an asset to my company. My hope for future students would be that when a company hires them, they would be seen as a vital asset that is needed in their company right out of college instead of being a brand new college graduate looking for a job. The best way we can make a name for SPSU is by producing students who are good at what they do. The best way to do that is to train them hard in college so they'll be ready for the real world."

"Even though getting the river sample for the water treatment plant was a pain in the butt, I liked having real data to use for the project."

Summary and Conclusions

In this paper, an effort was made to assess the perceptions and attitudes, which influence the learning environment, through the PBL approach in environmental engineering. The course, `Environmental Engineering II', was developed and taught using a PBL approach. In this course, 3- or 4-member teams of students carried out two design projects that required data collection, literature review, design unit processes, and preparation of professional reports. For the two projects, 50% of the final grade was assigned. At the end of the semester, a survey was conducted with seven questions to compare the students' learning environment in an environmental engineering design course, with lecture, exam, and project reports/case studies, with the traditional lecture-centric course. The qualitative paradigm was found to be suitable for studying the process undergone by the students, mainly because the study focused on the materials they learned in a prerequisite course and the outcomes of the projects are used in our daily lives. Required data was collected by means of literature review, laboratory experiments, and field visits. Students' perceptions and attitudes of PBL approach appeared to be favorable and acceptable as a learning environment for future environmental engineering courses. Based on the data analysis and specific students' comments, the lesson learned is that any addition of the PBL approach to the existing lecture-centric environmental engineering design course would be welcomed by students. Learning new topics by example during the project work appears to be more appealing to students. However, more data are necessary to confirm the fact that PBL approach is the best option for environmental engineering design courses. Further data are being collected every spring and will be included in the article for journal publication.

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