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Implementing Project-Based Learning in a Civil Engineering Course: A Practitioner's Perspective*

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Project-based learning (PBL) promotes development of critical thinking and problem-solving skills by allowing students to work in teams on real world projects. However, in spite of its effectiveness, the use of PBL in engineering classrooms has been limited due to the challenges associated with its design and implementation. Instructors have reported concerns regarding the amount of time required in administering PBL and difficulty in aligning projects with student workload preferences. While several studies have been conducted to examine the effectiveness of PBL in engineering courses, minimal research attention has been devoted to finding effective strategies for using PBL. Most recommendations in the literature have been primarily anecdotal. In this practitioner-focused study, we present an examination of a PBL engineering course and explicate techniques for implementing PBL. Using classroom observations, instructor interviews, student focus groups and surveys, we examine instructional approach and students' response to PBL. The findings offer several strategies for designing project tasks, sequencing projects, assigning presentation topics, and selecting readings in PBL course.

Keywords: project-based learning; instructor strategies; active learning

1. Introduction

Project-based learning (PBL) allows students to enhance their technical and practical skills by working in teams on real world projects [1, 2]. Several engineering education researchers and faculty developers have recommended the use of project-based learning in engineering courses [3–7]. PBL involves students working in teams on assignments or projects to "carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation" [3]. The result of a project is commonly a written or oral report describing the process used for completing the project tasks. The key emphasis of PBL is the end product which students create by applying their previously acquired knowledge and techniques under the guidance of an instructor [8].

PBL falls under the umbrella of student-centered teaching methods in which the students play an active role in the process of acquiring knowledge rather than being passive recipients [9]. The inherent structure of PBL involves working in teams to find optimal solutions to real world projects and thus promoting development of critical thinking and problem solving skills [10]. PBL leads to development of several abilities in students—formulate objectives, analyze problems and criteria for solution, organize and plan the process, formulate solutions, collaborate with team members, and present results in the form of written reports and presentations [11]. However, in spite of learning gains, the implementation of PBL "remains a challenging task for instructors and students" [12]. In this study, we focus on addressing the challenges associated with the implementation and use of PBL.

While researchers have reported the effectiveness of PBL in achieving better learning outcomes at both engineering program [13] and course level [14, 15], the adoption of nontraditional teaching methods including PBL in engineering classrooms has been slow [16, 17]. In order to facilitate the implementation of nontraditional teaching methods in engineering classrooms, it is necessary to shift research focus from finding more effective instructional strategies to promoting the use of already known effective strategies [18]. Recent calls from the National Science Foundation have further emphasized the importance of research focusing on adoption of research-driven teaching practices such as PBL [19]. However, there is a lack of research attention on how engineering instructors can facilitate successful use of PBL. In this practitioner-centered study, we examine a PBL engineering course with emphasis on instructional approaches and techniques. The purpose of this study is to provide support to instructors with empirically-supported strategies for using PBL to facilitate its widespread adoption in engineering courses.

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2. Literature review

Project-based learning (PBL) falls under the broad category of inductive teaching and learning. Usually, the teaching approach in engineering is deductive, involving an introduction to topics and underlying principles through lecture, then derivation of mathematical models and finally application of these models in homework problems [3]. On the other hand, the inductive approach begins with a set of observations or a real-world problem. In the process of solving the given problem or analyzing the observations, the students themselves generate procedures and guiding principles [3].

The focus on PBL has been driven by the need to ensure alignment between student learning outcomes and performance characteristics needed in future engineers [20]. Along with disciplinary knowledge and competence, engineering graduates should possess skills that allow them to work effectively in workplace environments [21].

The National Academy of Engineering (2005) has recommended key elements for inclusion in an engineering education system, such as, application of engineering processes to define and solve problems, engagement of engineers in multidisciplinary teams and interaction of engineers with customers and with the public. The report also emphasized the importance of aligning engineering curricula and experiences with future workplace challenges.

However, despite this emphasis, even though engineers are hired for their ability to solve problems, most engineering graduates lack the skills to solve complex problems that often feature conflicting goals, and multiple solution methods [22]. Engineering as a discipline undergoes continuous evolution as it adapts to new knowledge, technology and needs of society. In order to meet the demands of this rapidly evolving field, future engineers need to possess attributes like analytical skills, creativity, ingenuity, professionalism and leadership [23].

PBL involves students working in teams to complete projects tasks including but not limited to problem analysis, delimitation, problem solution, reporting and implementation [11]. This process of creating a design, simulation or an end product to meet the requirements of the assigned task gives students an opportunity to think through the process steps and learn workplace-related skills such as problem solving and teamwork [11]. Thus, the congruence between PBL's instructional design and real engineering practice makes it a natural fit for engineering education.

2.1 Existing research

Due to its numerous advantages, PBL has gained significant attention in higher education, particularly in the engineering discipline [13]. In their systematic literature review on PBL in higher education, Helle, Tynjälä [8] reported that the majority of the published work has been limited to course descriptions reported by instructors. While several authors provided detailed description of their 'successful' courses, most of the studies were either anecdotal or lacked any attempt to evaluate the described PBL approaches. In addition, although few studies have reported positive impact of PBL on student satisfaction, enjoyment, interest or motivation, no rigorous attempts were made to examine these student motivation-related issues with respect to the used PBL technique in detail.

With increased awareness about engineering education research, in addition to descriptive accounts of PBL implementations, several authors have presented assessment and evaluation data in support of the PBL approach they used in their engineering courses. However, the majority of these studies have focused on evaluation of student learning and/or gathering general course-level student feedback [2, 14, 24–29]. Furthermore, although few researchers have gathered student feedback about specific course components, they have been examined in isolation with specific instructor techniques used in PBL implementation [30, 31], offering limited empirically-supported recommendations for direct applicability to practitioners. In other words, while practitioners have presented anecdotal descriptions of their PBL use, most of the empirical work has paid limited attention to developing resources for practitioners.

2.2 Challenges and recommendations

The use of PBL is challenging for both instructors and students [12]. For instructors, some of the most frequently reported challenges are the amount of time required in administering PBL, aligning projects with student workload preferences, integrating supplementary material and managing student team dynamics [8]. Specifically, in engineering, time constraints has been identified as major barrier towards the adoption and continued use of PBL [32].

In addition, concerns about student response to the PBL approach has restricted increased adoption [32]. Student perceptions of PBL have not always been positive in engineering. For example, evaluating the implementation of PBL in civil engineering course, Gavin [33] reported students concerns about the time required to complete the projects. In another example, Stolk and Martello [14] reported that students' felt that there was a lack of knowledge in the implemented PBL approach. In addition, there have been student concerns regarding the workload and complexity of projects [4, 34, 35]. These findings indicate that students often perceive

PBL as overwhelming due to time constrains and complexity of projects, which leads to discomfort among students [12].

Although often lacking empirical support, existing literature offers several recommendations for implementing PBL. Describing PBL-inspired aspects of undergraduate curricula for materials engineering, Savage, Chen [12] suggested: (1) composing student teams to cover a breath of skills and backgrounds, (2) clearly identifying the problem and making sure students develop sufficient background knowledge to work on the problem, (3) encouraging students to brainstorm ideas with their teammates, (4) requiring students to summarize results through both written reports and presentations, (5) allowing opportunities for teams to communicate their results with the entire class, and 6) designing projects that are not too complex. Other researchers have placed emphasis on the design of projects. Projects used in PBL should be feasible and manageable for both instructors and students [27]. In order to motivate students, attention should be paid to the structure and scalability of the projects [26]. Projects should be selected and designed such that there is match between student capabilities and task requirements, but are "complex enough in order to induce students to generate questions of their own" [8].

In summary, there are several challenges that engineering instructors might face when implementing PBL in their classrooms. Research has shown that a significant percentage of instructors have tried evidence-based teaching methods such as PBL and then discontinued their use [36]. Although the literature offers several tips for engineering instructors seeking to implement PBL, most of these recommendations are based on personal experiences and lack minimal empirical support. Existing engineering education research has focused on providing support for the use of evidence-based teaching methods. However, limited research attention has been devoted towards examining evidence-based techniques for implementing PBL, making its examination a logical step towards bridging the gap between research and practice. In this study, in the context of a PBL engineering course, we explicate techniques for implementing PBL by examining students' and instructor's responses to the used PBL approach and its constituent components.

3. Methodology

The study was conducted in an upper division undergraduate construction engineering course at a large research university in US. The class was held twice a week with a 75 minute lecture and a 165 minute lab session, with a total enrollment of 21 students. The instructor of the course was a recipient of a university-level teaching award and had taught the course three times before the current offering.

A case study approach, using multiple data sources (classroom observations, instructor interview, student focus groups and survey), was used in this study [37, 38]. Classroom observations were conducted for the entire semester to document student engagement to different instructional components using observation protocol to measure engineering undergraduate students' resistance to active learning [39]. Student focus groups were used to validate observation findings and gather students' feedback [40, 41]. Twenty-one students participated in 4 separate focus group sessions at the end of the semester. In addition, student survey [42] was used to gather student response to classroom instruction and instructional preferences (n = 18). Lastly, an instructor interview was conducted at the end of the semester to examine instructor's PBL course design and implementation experience.

4. Findings

4.1 Course background

The course was divided into four cycles catering to construction engineering topics: Model-based Cost Estimating, Project Scheduling and 4D Simulation, Design Coordination and Construction Progress Monitoring. Each cycle included a lecture session, hands-on lab, question and answer lab, and a presentation session. Table 1 presents a description of the course components. In the lecture session, the instructor taught the content related to the specific topic, provided industry specific examples and used online videos. In addition, the lecture session included active learning exercises in which the instructor engaged students in group discussions.

The lecture session was followed by two lab sessions. In the hands-on lab session, the students

Table 1. Description of course components

Course Component	Description
Hands-On Lab Session	Students follow demonstrations to familiarize with different software tools needed for the project.
Question and Answer Lab Session	Students work on their projects in groups under the instructor's guidance.
Student Presentations	Students give group presentations for their projects and case studies.
Course Readings	Students are assigned readings for discussion in class.

Table 2. Instructor approaches

Course	Instructor Approach
Project design and implementation	• Optimize the complexity of the projects by adjusting their based on student feedback • Sequence complex and time-consuming projects earlier in the semester • Use demonstration sessions to train students and impart required knowledge needed to complete project tasks
Student Presentations	• Assign projects which are common to all the students as presentation topics to create student interest • Use student-initiated questions to encourage student participation
Supplemental Material	• Use white papers or other simpler articles rather than journal articles as reading assignments • Provide assistance to students in understanding the complex readings

were taught the material using software demonstrations by the instructor and her teaching assistant. In the question and answer lab session, they worked on their assigned group projects under the guidance of the instructor. Lastly, the students reported their project results through group presentations. Classroom participation counted towards 10% of the final course grade. Students were assigned to groups by the instructor based on their responses to a survey asking them about their background knowledge and content-related experience. Overall, a positive student response was received for the course and PBL approach. In the next sections, we describe the approaches used by the instructor in detail and corresponding student response. A summary of instructor approaches is presented in Table 2.

4.2 Hands-on lab session

Instructor approach

The hands-on sessions lasted for approximately 120 minutes. The instructor frequently intervened during the demonstration to explain critical concepts and clarify students' doubts. A total of four hands-on lab sessions were held in the semester. For every session, the instructor demonstrated high levels of engagement by circulating around the room, monitoring students' progress and answering students' questions.

In the interview, the instructor explained how she designed the course so that students are able to understand the basics of using the software during the hands-on sessions and then went to work on the project in later sessions. The hands-on lab sessions involved an introduction to the software tool needed for completing the assigned project. Specifically, the session included a demonstration about the functionality of the tool using a sample problem. Throughout the session, the students followed along on their own computer. In addition, in few instances, the instructor also asked the students to "play around with the software" and work on a sample problem which was part of the project assignment.

Student response

High levels of student engagement were observed for the hands-on sessions for the entire semester. More than 90% of the class was observed to be engaged in the activity for almost every hands-on session. The students worked individually on their computers familiarizing themselves with the various software tools by following along the procedural steps demonstrated by the instructor. In the focus groups, students provided positive feedback about the hands-on session. Students reported that the design of the hands-on sessions in which a big problem was presented as a sequence of smaller sample problems allowed them to better understand the material. For example, expressing satisfaction with the design of the hands-on session, one student said, "I think I was fine with following along because it was like a lot of steps in such a short amount of time . . . we really needed the time to be able to understand each step to move on to the next one. Because then it would've been confusing if we did not understand the full process". Overall, students reported that performing the demonstrated steps on their computers assisted in understanding the process and performing the project tasks.

4.3 Question and answer lab session

Instructor approach

The question and answer Lab session allowed students to work on their projects in groups during class time under the instructor's guidance. The project deliverables were due a week after the question and answer session. A total of four question and answer lab sessions were held in the course. The sessions lasted for approximately 120 minutes. During the session, the instructor consistently encouraged the students by circulating around the room, monitoring students' progress and clarifying doubts. The instructor also encouraged interaction by asking students in one group to explain procedural steps and other project details to their neighboring groups.

During the class session, at multiple instances, the instructor sought feedback from students about each project. Specifically, the instructor asked about the complexity of the project and the number of hours students worked to complete the project. The instructor used this feedback to design the projects, explaining, "I had to be a lot more careful about the size of the homework assignments as well. I try to keep them around 10 hours. That is why I always ask the students how long did you all take to do this".

In the interview, the instructor highlighted two factors that she considered while designing the projects. First, the instructor reported that she included complex and time consuming projects earlier in the semester, which led to high engagement. The instructor mentioned, "All of my classes tend to be front loaded. It's really heavy in the first half of the semester. They got to get all that work done while I have their energy. And in the second half of the semester, its natural, everybody is going to be exhausted". Furthermore, the instructor reported that she used student feedback about the projects for designing the project sequence for next semester. Referring to the last project which she implemented in this class for the first time, she stated "For the last one, I did not know that it would take so long for them to do it. So the next time we do the class, that's going to be the third assignment."

Second, in response to questions about the process behind the design of the projects, the instructor underscored the importance of scaling the complexity of the projects to align with students' level of understanding. Reflecting on her first experience teaching this course, the instructor reported that she did not appropriately choose the complexity of the project which led to students being overwhelmed with the project. Consequently, in the next course offerings, she scaled down the complexity of the project by minimizing the scope of work.

Student response

Overall, high student engagement levels were observed during the sessions with almost every student working with their assigned group members. The students were engaged in the exercise almost for the entire session throughout the semester. During the sessions, students frequently raised their hands to ask the instructor questions. Students' questions primarily involved clarifications about project deliverables, scope of the project and assumptions that they are allowed to make for modelling. In addition, students also engaged in questions inquiring about the specifications and models, indicating active involvement in understanding the project rather than only completing the assigned tasks. The instructor acknowledged this engagement and further encouraged students to ask such questions. At one such instance, the instructor announced, "Good you are asking these questions. It shows you are not just believing the numbers you are seeing".

Student focus group findings indicated positive response to the projects and question and answer lab sessions. Specifically, students reported that they benefitted from working on the projects under the guidance of the instructor, as one student stated,

> This is my last semester now. In terms of homework, these are the most beneficial homeworks I have had. In terms of comparison with other courses, like these homeworks are much more beneficial than the other courses. You learn a lot. The homeworks are better put. In other homework, they will give you something and just do it. Here she was guiding us in some way. After the homework you would learn the objective.

Another student echoed,

> I think that it's good to have the exercises. If you run into any problem, you can ask. In any case, in any course, if you give us the lecture and slides, we can do them without the instructor. But, at the end of the day, you want some integration within the course. Or having your thoughts put in there or you doing an exercise in class for it to be more engaging.

Student focus group findings underscored instructor's approaches towards the sequencing and complexity projects as the reasons behind high engagement. First, students highlighted the timing of the projects based on complexity as a reason for their success. Particularly, students appreciated that the complex and time consuming projects were introduced early in the semester. Commenting on the structure of the course, one student mentioned, "I am kind of glad the order that they have gone so far. I can't imagine now going up against cost estimating and doing some of the things that were more time intensive. These now are less difficult seeming. I think she structured this in a way it's not overwhelming". Reflecting on the time constraints prevalent at the end of semester, one student stated, "Complex projects should be as early as possible". Another student reiterated, "During this time it's like finals, everything is due in these last few weeks. It's more difficult to meet with your partners".

Second, the students reported that the level of complexity of the projects was appropriate for them to remain encouraged and engaged in the project, as evident in this student comment: "I think it's just the way professors integrate and hold the attention of their students ... find that balance of challenging them enough so they learn the material but not so much that they are freaking out that it's so hard and complex".

4.4 Student presentations

Instructor approach

Student presentations required students to present their group project results to the entire class. Two student groups presented for each of the four course projects, totaling eight project presentations in the semester. Two presentation sessions were held in a class session and each presentation lasted for approximately 20 minutes. This allowed student groups to present on topics that were common to students in the audience without being repetitive, as explained in this instructor comment: "You need to understand that everybody did that same assignment as you did, so they will be able to understand all that you are talking about . . . They understand everything in detail. So, they are expected to chime in their thoughts". At the beginning of presentation sessions, the instructor announced that she expected the students to ask questions because all the students have worked on the same project problem.

For the presentation, the instructor provided the presenters with few pre-specified points and questions that they were asked to address in their presentations. Such questions led to high engagement from the audience during the presentation. For example, in one such instance, under the instructor's direction, the presenters posed a question to the audience which could be answered in multiple ways. This led to increased engagement with several students contributing and expressing their ideas about the posed questions. During the class session, the instructor mentioned that she included this question so that she "can pick your brains".

In addition, the instructor asked the presenting students to engage students in the audience by posing questions to them, she mentioned,

> The presenters have to understand that it's part of their role, and I tell them when they are presenting, you have to prompt the audience to participate. It's your job as a presenter to ask those questions . . . It's not graded. I just informally, like the class before they are presenting, I usually walk up to the group and say 'You are presenting in next class, try not to have slides that are wordy and try to engage your audience'. I just informally chat with them about that.

Lastly, during the presentations, the instructor interrupted at multiple instances, posing questions to the whole class, commenting on key points presented by the students, asking how other groups approached the problem and suggestions for improvements.

Student response

Overall mixed level of engagement was observed with approximately 60–70% students engaging in the presentation discussions. In the focus groups, students provided positive feedback to project presentations and echoed support for instructor's design and implementation approach. First, students underscored the commonality of the presented project topic to the students in the audience as a reason behind higher engagement. For example, one student said, "Everyone's done it. It's not like someone is coming with a specific topic assigned and they are trying to teach the class something and you are just kind of zoned out because it means nothing to what you have done. Everyone has done it, you feel like you have something to contribute." Another student mentioned, "For me it was nice because I could actually see what other groups did and compare what they did to yours."

Second, students acknowledged the contribution of instructor questions asking other students about their approaches and tips for improvements in increasing student engagement, as evident in this student comment: "It's also about questions. How did you do this and is there a better way to do it? Everyone wants an easier and better way to do something. So, when it's that type of discussion, I think more people want to participate because you are getting something out of it". Underscoring the advantages of knowing how other students performed the project task with focus on future work responsibilities, one student commented,

> I think it was good because that just like the extra information that we don't get directly from like the actual assignment. Because we collaborate when doing the assignment but not to a point where it's like specific improvements on how to like be more efficient in the assignment. For some people we might actually be using it after this class if we go into construction engineering. So, I would want to know what other people did so that way if I ever have to use this program again, I can actually know of a shortcut.

Third, students recognized that the effectiveness of questions posed by presenting students in fostering engagement in the audience. The students reported that they felt more comfortable answering questions posed by students when compared to the instructor. As one student mentioned,

> I would say I feel more comfortable responding to a question posed by a student because if you are asked a question by a teacher and you get it wrong, it's really embarrassing. But, if you are asked a question by a student, you kind of know, like, 'I can answer because neither of us are perfect because we both are still learning'. So it's just more comfortable way of opening up the classroom for discussion I suppose.

Also, students expressed that they felt more responsible to answer student-initiated questions rather than instructor-initiated questions, as evident in this student comment, "I think there is also something, when a fellow student asks a question, you do want to like come to their aid and not let them hanging. While for professor, you are really accustomed to having them ask questions and have them beat that silence. So there is a little bit of empathy in there."

4.5 Course readings

Instructor approach

The instructor provided readings to students as a supplemental resource. These readings covered several topics related to the different projects introduced in the semester and other course content. The readings were used in group discussions that were held a week after the readings were assigned. These discussions lasted for approximately 8-10 minutes where the instructor initiated discussion by posing multiple questions to the whole class based on the assigned reading. During the activity, the instructor encouraged students to participate by asking questions multiple times to the students. In addition to discussion, the students were given a quiz in which they were assessed on their understanding of a subset of course readings. A total of three quizzes were held in the semester and each quiz lasted approximately an hour. In contrast with other course components, the students were assigned an individual grade for the quizzes.

During the semester, primarily journal articles with an exception of two white papers were assigned as course readings. The instructor reported that the reason behind the use of journal articles was to provide a broad understanding of the course content to the students. Her responses indicated her preferences for journal articles over white papers. She reported that white papers were "very superficial" and lacked depth when compared to journal articles, she expressed "I think the journal articles are a little more detailed. They talk about the research process, about how somebody conducted it, so there is more detail, so there is more content to cover".

In the interview, the instructor expressed that she found it difficult to encourage students to complete the readings task, she mentioned, "It's always a challenge to make them actually do the reading before class". In addition, she acknowledged comparatively lower levels of engagement received in reading-based discussions, she stated, "Some of them wing it before class. You can tell that they are skimming it desperately or even skimming during [discussion] on their desktops".

Student response

In comparison with other course components, course readings received lowest student interest and engagement levels. Several students reported that they did not complete the reading assignments before class. Consequently, low participation was received in majority of the discussions. The reluctance of students to participate in the discussions was also noticeable in instructor's in-class behavior. In multiple instances, the instructor asked students who have not spoken to share their opinions. In one instance, the instructor called upon a group of disengaged students and asked, "Did you guys come up with anything?" At another instance, upon noticing the lack of student response, the instructor commented, "You guys didn't get the time to get to the last paradigm in your 8 minutes?" In spite of the instructor's encouragement and intervention, resistant students did not engage in the discussion, and only a few students volunteered to share their responses.

Student responses highlighted misalignment between their preferences and instructor's approach. Specifically, while the instructor preferred journal articles over white papers as assigned readings due to superficiality of white papers, the students reported difficulty in understanding the journal articles. The students expressed concerns regarding the complexity of the readings which were mostly journal articles. For example, one student said, "Mostly, when it comes to journal papers, they are more technical and they are much lengthier. I read a couple of pages, then I stop, then I have to read again because it gets too technical." Another student mentioned, "It is not that interesting to sit down for three hours for one reading that gets too technical." Thus, instructors' approach of selecting journal articles as assigned readings did not receive positive feedback and led to lower student engagement.

In sum, overall positive student response was received for the PBL instruction and the instructor was able to promote high engagement by employing different approaches to better align instruction with students' preferences. Student responses highlighted the effectiveness of the approaches used for project design and implementation in promoting engagement. In contrast with other course components such as presentations, projects and demonstration sessions, course readings received lower student interest and engagement.

Students' survey responses were reflective of in-class and focus group response. In the survey, in response to question asking students to report their instructional preferences for their ideal course, a majority of the students indicated that they would prefer the same or more of the listed instructional components in their ideal course. However, student preference for activities requiring preview of concepts before class by reading and watching videos remained low (Table 3). For example, while more than 70% students indicated that they wanted the same or more of different project-related in-class exercises (e.g. Work in assigned groups to complete homework or other projects or Do hands-on group activities during class), 72% students indicated that they wanted less of reading-based activities.

Table 3. Students' Instructional preference in their ideal course (n = 18)

For each of the following things, please indicate how often you would like to do each in your ideal course.	Much Less	Slightly Less	About the same	Slightly More	Much More
Work in assigned groups to complete homework or other projects.	17%	11%	50%	5%	17%
Make individual presentations to the class.	5%	0%	39%	39%	17%
Discuss concepts with classmates during class.	0%	11%	50%	22%	17%
Preview concepts before class by reading, watching videos, etc.	22%	50%	17%	6%	5%
Solve problems in a group during class.	0%	17%	33%	33%	17%
Solve problems individually during class.	0%	11%	33%	39%	17%
Answer questions posed by the instructor during class.	0%	11%	44%	17%	28%
Do hands-on group activities during class.	6%	11%	22%	44%	17%

Table 4. Student Emotional and Value Response to Instruction (n = 18)

How often did you react in the following ways?	Almost never (< 10% of the time)	Seldom (~30% of the time)	Sometimes (~50% of the time)	Often (~70% of the time)	Very Often (> 90% of the time)
I felt positively towards the instructor/class.	0%	0%	6%	22%	72%
I felt the instructor had my best interests in mind.	6%	0%	6%	22%	66%
I enjoyed the activity.	0%	0%	6%	55%	39%
I felt the effort it took to do the activity was worthwhile.	0%	6%	11%	44%	39%
I saw the value in the activity.	0%	0%	0%	39%	61%
I felt the time used for the activity was beneficial.	0%	0%	11%	39%	50%

In addition, most of the students indicated that they felt positively about the instruction and saw its value (Table 4). For example, 94% students felt positively towards the instructor/class for 70% or more of the time. Similarly, 100% of the students reported that they saw the value in the activity for 70% or more of the time. Overall, the findings identified several strategies for promoting engagement in a PBL course. In the following sections, we explicate these approaches with reference to relevant literature.

5. Discussion

The use of PBL in classroom settings has been slow due to instructor concerns about preparation and administration time, students' negative perceptions, difficulty integrating supplementary material and aligning project tasks with students' workload preferences. The findings of this study identify several strategies for project design and implementation, and techniques for promoting engagement in other commonly used PBL course components. In the following sections, we discuss these strategies with reference to existing PBL literature.

Project design and implementation

Appropriately challenging activities are influential in promoting student engagement [43]. Assimilation of multiple principles in projects can lead to creating an overly complex learning environment, causing student frustration and reducing the effectiveness of the learning experience [12]. The findings of this study identify three strategies that instructors may consider when using PBL. First, in order to reduce student discomfort, instructors should optimize the complexity of the projects by adjusting the scope of the projects based on student feedback. The excessive amount of workload is a frequently noted student concern in engineering PBL courses [4, 34, 35]. Instructors have suggested to resolve these students' workload concerns by reduction in the number of projects in future offerings [4]. However, we argue that this approach would lead to a decrease in the amount of content covered in the PBL course; which may in turn aggravate student concerns regarding the lack of knowledge in PBL [14]. Instead, based on the findings of this study, we recommend that instructors should focus on monitoring the scope of the project and reduce the number of deliverables for the projects, based on simple student feedback such as time required for completion of the project and its constituent tasks.

Second, sequencing complex and time-consuming projects earlier in the semester is another strategy that instructors may use in project-based learning classrooms. Researchers have noted that activities implemented in the end of the semester receive less student interest due to limited time [44]. In PBL, students may develop their workload perceptions based on the 'peaks' experienced in the semester, leading to overestimation of overall workload [8]. Implementation of time-consuming projects earlier in the semester will assist in reducing the workload peaks that students might face at the end of semester due to other academic conflicts.

Third, to create an effective learning environment, instructors should make sure that students are trained and possess required background knowledge to complete the assigned project tasks

[1, 45]. Technology-rich PBL environments "result in cognitive overload for students before they are well acquainted with the environment" [8]. To address this, the instructor may use demonstration sessions where students follow along sample problems in class before working on their assigned projects. Providing such opportunities will not only equip students with the needed skills but also encourage further inquiry by allow students to explore software tools or other project equipment.

Student presentations

An important component of PBL is presentation of project results [8]. Student presentations serve as an instructional platform for enhancing engineering students' professional, communication and technical skills [46–49]. In engineering, presentations are often used in PBL courses as a platform for students to present their project results [e.g. 4, 15, 50, 51]. Presentation of project approaches and results also serves as a self-assessment tool for students in PBL [8]. However, when compared to other instructional methods, college students often rank classroom presentations unfavorably [4, 52, 53]. While student presentations and follow up question and answer sessions provide an avenue for student engagement with the content, student disinterest in the topic can lead to low engagement in such sessions [54]. Furthermore, students may also remain passive during the follow up sessions because they fear embarrassment [54].

Instructors should create a classroom environment in which course components such as presentations serve meaningful functions [55]. The findings of this study suggest two strategies for promoting engagement in presentation sessions. First, to create student interest in the presentations, the instructor should assign homework or projects which are common to all the students as presentation topics. Since repetitive project presentations may lead to disengagement, the instructors should assign one or two student groups to present on the different projects instead of requiring every group to give presentations on every project. This will assure that every student gets an opportunity to present during the semester and the presentations are not repetitive. This will not only allow the students to understand the presentation but also allow them to engage meaningfully in the follow-up discussions. Second, instructors should use student-initiated questions to encourage student participation. Questions posed by the presenting students to the audience may encourage students fearing embarrassment to participate in follow up discussion sessions.

Supplemental material

Assigned readings are often used in PBL approaches as a supplemental resource for students to learn the needed content [e.g. 14, 45] and are recommended in active learning classrooms to initiate discussions [56]. However, college students often do not engage in reading the assigned readings [57, 58], diminishing the effectiveness of classroom discussions [58]. Researchers have noted several factors that influence student compliance to reading assignments such as time required to complete the reading, difficulty of the reading material and relevance to subject matter [59]. In line with existing research, in this study, we found that students expressed concerns about the complexity of the assigned articles. Students reported that they had to devote a lot of time to reading and understanding the journal articles. In the context of PBL, the challenges faced in understanding the assigned readings will further aggravate students' concerns about time and workload [33]. In addition, due to insufficient understanding of the content covered in the readings, students may perceive the lack of knowledge in PBL [14]. Thus, to encourage students to read the assigned articles and engage meaningfully in classroom discussions, instructors may use white papers or other simpler articles rather than journal articles in reading based activities or provide further assistance to students in understanding the complex readings.

6. Conclusion

Project-based learning is an effective pedagogical platform to engage engineering students with course content and foster learning of professional skills such as team work and problem solving. As evidenced in existing literature, PBL has the acumen to better prepare undergraduate engineering students for future workplace needs. However, instructors often find implementation of PBL challenging and struggle with designing projects and aligning PBL instruction with student preferences. In our study, we focused on finding strategies for implementing PBL to assist instructors and consequently contribute to increasing the use of PBL in engineering classrooms. In contrast with prior anecdotal experience-based recommendations, our work identifies several evidence-based strategies for implementing PBL.

While the case study approach limits the generalizability of the findings to other scenarios, the recommendations presented in this work are not specific to particular courses and can be applied to other course settings. Instructors may use these recommendations in a manner that best suits their conditions. Future work can continue to examine PBL implementation by engineering instructors and identify strategies for overcoming challenges that hinder adoption of PBL. Replication of similar studies in other courses, departments and institutions will help in building a research-informed resource to help engineering instructors in designing and implementing PBL in their courses. Researchers may examine PBL use by triangulating instructor self-report with student in-class response and perceptions of instruction to better align PBL instruction with students' needs and preferences. In addition, since our presented work focused on PBL, researchers may investigate strategies for designing and implementing other evidence-based teaching strategies such as just-in-time teaching, peer instruction, self-directed and cooperative learning. Further research focusing on assisting instructors in implementing nontraditional teaching methods will help in promoting their use in engineering classrooms. Building evidence-based resources for instructors, teaching workshop conveners, and teaching and learning centers will assist in bridging the research to practice gap in engineering education.

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