Project-based Learning in a Persistent COVID-19 Environment

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Project Based Learning in a COVID Environment: A New Normal in Engineering Education

Abstract

The rapid spread of COVID-19 around the world created an unforeseen challenge for both professional and academic institutions. Many institutions around the country, particularly academic institutions, are struggling to adapt to the challenges posed by the virus. In a persistent COVID-19 environment, people cannot meet in-person to collaborate as often as they once could. The environment has limited our ability to connect, work, and perform as society previously has. As such, academic institutions have recently been required to shift the means and methods of education to adapt to the virus. Historically, one of the more successful educational approaches has been project-based learning (PBL). PBL has a long track record as an alternative to traditional educational techniques. While the published benefits, as well as the drawbacks, of PBL are summarized in this article, what the authors anticipated and will demonstrate is that advantages of the PBL model relative to conventional instruction were accentuated in the COVID environment and that combined with newly minted capabilities, the model produced significant educational gains when compared to traditional instruction and earlier PBL experiences. Methodology for this research includes Likert Scale questions, CATME surveys, and open-ended survey feedback and interviews from students and instructors involved in three unique STEM-related capstone courses to obtain quantitative and qualitative feedback on project-centric learning before and during the COVID-19 pandemic. The three capstone projects investigated were the American Society of Civil Engineers (ASCE) Concrete Canoe Competition, the American Institute of Steel Construction (AISC) Student Steel Bridge Competition (SSBC), and a partnered project with the US Army Corps of Engineers (USACE) investigating sustainable solutions for lock and dam components. The study revealed that, in the midst of a pandemic, effective use of PBL will enable students to (1) capitalize on collaborative technology to efficiently and successfully solve complex engineering problems, and in doing so, improve student time management skills, (2) improve their critical thinking and engineering judgement, (3) improve their ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives, and (4) enhance their ability to acquire and apply new knowledge to real-world problems. These benefits were achieved to significantly higher degrees in our PBL capstones than in traditional coursework during the pandemic and suggest that PBL can be successfully implemented in a persistent COVID environment to achieve engineering student outcomes through a variety of mediums.

Keywords

Project-Based Learning, COVID-19, distance learning, Engineering education, ill-defined problems
Introduction

This paper presents an evidence-based study of the benefits of using Project-Based Learning (PBL) in an engineering program during the COVID-19 pandemic. The purpose of the study was to investigate how PBL in COVID-19 learning environment enables engineering students to improve their ability and preparation to enter the professional practice of engineering. PBL benefits are tied closely to four of the seven Accreditation Board for Engineering and Technology (ABET) Engineering Accreditation Committee (EAC) Criterion 3 Student Outcomes (SOs) [1]. The first PBL benefit addresses SO (1): an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. The second benefit addresses SO (6): students have an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions. The third benefit addresses SO (5): an ability to function effectively on a team whose members together provide leadership, create collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. Lastly, the fourth benefit addresses SO (7): an ability to acquire and apply new knowledge as needed, using appropriate learning strategies [1]. The scope of this paper includes discussion of PBL, implementation, and analysis of PBL in the COVID environment for a civil engineering program. The authors conducted this study with 41 seniors enrolled in a civil engineering Capstone course. The motivation for the study stems from evidence-based studies on PBL in a pre-COVID environment, which showed increased attainment of the ABET student outcomes listed above [2,3]. Due to the COVID pandemic, learning through traditional means has become a challenge for college students across the country. It was hypothesized that in a COVID environment, PBL would serve as a more effective pedagogy when compared to traditional learning in terms of student attainment of the ABET SOs.

After summarizing current literature relative to the outcomes of applying PBL, this paper provides details about implementation of the study. Data gathered for this study at the United States Military Academy (USMA) include (1) a survey disseminated to students enrolled in the civil engineering Capstone course, (2) Comprehensive Assessment of Team Member Effectiveness (CATME) surveys which focus on the effectiveness of project teams, and (3) end-of-semester course feedback. Analysis of each source is provided on students’ attitudes on their learning experience, performance, and academic outcomes. Conclusions from this analysis are described, and ideas to improve future study of PBL are attached.

Background

Project-Based Learning, in the context of this study, refers to a learning methodology in which an ambiguous problem is posed to a small team (6 members or fewer) of students who are expected to collaborate, think critically, and generate a creative solution. This investigation sought to determine how Project-Based Learning can be implemented for student benefit in a long-term COVID learning environment. The project identified three aspects of PBL that are especially beneficial to students in hybrid or remote learning environments: acquiring and applying new knowledge, improving teamwork skills, and developing critical thinking and engineering intuition. This section is subdivided to discuss each of these aspects of PBL.
The essence of PBL within the realm of engineering requires the acquisition and application of new knowledge, using appropriate learning strategies [1]. Whereas traditional learning involves students being told what they need to know, the broadly open-ended nature of real-world projects leads students to find their own relevant sources of information outside of the scope of previous courses they may have taken. When compared to more traditional and typical classroom experiences, a PBL approach has led to more motivated students who achieve higher grades than their peers. A recent quasi-experimental study provides data which supports these claims about the benefits of PBL [5]. The study showed an increase in achievement and in motivation using PBL and the Attention, Relevance, Confidence, and Satisfaction (ARCS) Model, as shown in Figure 1 below. The study consisted of students taught with traditional teaching techniques and students taught with PBL strategies. The PBL class was given projects that they had to complete before the end of the semester. Their results showed that the students in the PBL class achieved higher post-curriculum test grades and obtained higher grades on the motivational scale than the traditional classes [5].

<table>
<thead>
<tr>
<th>Group</th>
<th>N (sample size)</th>
<th>M (mean grade)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group (traditional learning)</td>
<td>33</td>
<td>13.23</td>
<td>1.54</td>
</tr>
<tr>
<td>Experimental Group (project-based learning)</td>
<td>32</td>
<td>17.85</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Figure 1: Tables of Students grades and motivation in PBL and Traditional Learning [5].

Although current knowledge suggests PBL benefits students in knowledge acquisition and application, results are less cohesive regarding knowledge acquisition and application in general online courses. A 2009 study found that students conducting online courses engaged in online activity for individual knowledge gain [6]. However, the study reports students did not engage in collaborative learning or knowledge application as frequently in the online platform. Students effectively used the online resources for individual knowledge acquisition but fell short of applying the knowledge to larger problems or sharing it with their peers [6]. This observation about online courses suggests that there is a gap to be filled in online education methods to achieve a higher degree of student engagement both with course material and other students. This “gap” in student engagement depends largely on how instructors deliver course content to students in a virtual environment, according to Lee and Recker [4]. Through a large-scale analysis of 72 basic college math courses delivered online, spanning over five years with over 2,800 instructors and 22,000 individual data points, the study found that the format in which instructors framed the course affected student performance [4]. The study showed that open-ended discussion questions, graded discussion posts in the online setting, and an emphasis on the...
engaged listening to one’s peers all led to increased student performance in the course [4]. While the study did not mention PBL, it highlights that fostering discussion and critical thought between students in an online setting improves student engagement with the course material and application of that knowledge on graded events in the course.

**Improving teamwork skills**

PBL is currently a popular approach for learning in many Science, Technology, Engineering and Math (STEM)-related fields. Its approach is distinct from traditional classroom learning, wherein students find themselves as passive recipients of information. Instead, PBL requires students to address a problem using information and knowledge they may or may not possess. The belief behind project-based learning is that students benefit more from the application of their knowledge in a group setting than from a traditional classroom model, wherein a teacher presents students with concepts and information and checks to ensure students understand [2]. A study was done at a university in Malaysia to gage the “soft skills” of engineering undergraduates. The study used questionnaires to ask students to assess their skills before and after a semester that they were enrolled into a PBL class. Figure 2 below shows the student score before and after the semester of PBL, with clear improvements demonstrated.

<table>
<thead>
<tr>
<th>Group learning</th>
<th>Pre-test mean</th>
<th>SD</th>
<th>Post-test mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaboration</td>
<td>2.68</td>
<td>0.95</td>
<td>3.54</td>
<td>0.73</td>
</tr>
<tr>
<td>Leadership</td>
<td>2.82</td>
<td>0.95</td>
<td>3.82</td>
<td>0.78</td>
</tr>
<tr>
<td>Information gathering</td>
<td>2.98</td>
<td>0.83</td>
<td>3.77</td>
<td>0.71</td>
</tr>
<tr>
<td>Multitasking skills</td>
<td>3.13</td>
<td>0.86</td>
<td>3.61</td>
<td>0.66</td>
</tr>
<tr>
<td>Meeting/discussion</td>
<td>2.82</td>
<td>0.89</td>
<td>3.89</td>
<td>0.72</td>
</tr>
<tr>
<td>Negotiation</td>
<td>2.74</td>
<td>0.95</td>
<td>3.77</td>
<td>0.73</td>
</tr>
<tr>
<td>Teamwork</td>
<td>3.12</td>
<td>0.97</td>
<td>4.14</td>
<td>0.79</td>
</tr>
<tr>
<td>Total</td>
<td>2.89</td>
<td>0.93</td>
<td>2.8</td>
<td>0.73</td>
</tr>
</tbody>
</table>

**Table IV. Group learning**

Figure 2: A table showing student group learning [2].

A study was done at the University of Washington to see how PBL affects teamwork and collaboration skills in a learning environment. “The initial three to four class periods are structured so that the teams must work together to complete specific tasks. As the quarter progressed, direction from the instructor was gradually reduced to the point that the team did all planning for upcoming events [7].” Evaluation forms were submitted by students which asked about how the team was functioning. At the end of the semester, the results showed that switching from traditional classroom style to the Project-based learning moves the students away from a focus on content to a clearly defined focus on communication, leadership, teamwork, and other skills needed for lifelong success [7].

**Developing critical thinking/engineering intuition/engineering judgement and ability to solve complex problems**

PBL can be used to challenge students with ill-defined problems, requiring students to develop and execute solutions. That results in “a significant improvement in student skills that can be attributed to the use of PBL,” as shown by Quevedo et. al. [8]. They note that PBL is a powerful
tool that “balances and complements an engineering curriculum that strives to develop the generic skills of engineering students.” According to the “new normal” COVID-19 imposes, individuals are habitually more “wary, prudent, deliberate, composed, [and] adventurous” [9]. These are all attributes that enhance critical thinking and build engineering intuition.

<table>
<thead>
<tr>
<th>Research skills</th>
<th>Pre-test mean</th>
<th>SD</th>
<th>Post-test mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving</td>
<td>2.77</td>
<td>0.85</td>
<td>3.68</td>
<td>0.69</td>
</tr>
<tr>
<td>Information gathering</td>
<td>2.98</td>
<td>0.83</td>
<td>3.77</td>
<td>0.71</td>
</tr>
<tr>
<td>Research</td>
<td>2.74</td>
<td>0.99</td>
<td>3.72</td>
<td>0.7</td>
</tr>
<tr>
<td>Analytical thinking</td>
<td>2.6</td>
<td>0.82</td>
<td>3.54</td>
<td>0.73</td>
</tr>
<tr>
<td>Critical thinking skills</td>
<td>2.84</td>
<td>0.86</td>
<td>3.63</td>
<td>0.64</td>
</tr>
<tr>
<td>Level of inquisitiveness / curiosity</td>
<td>3.28</td>
<td>1.06</td>
<td>3.95</td>
<td>0.77</td>
</tr>
<tr>
<td>Total</td>
<td>2.87</td>
<td>0.9</td>
<td>3.72</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Figure 3: A table showing student research skill [2].

Figure 3 above shows results from a study done on engineering study at a Malayan university. The study was done to evaluate how PBL learning would improve the soft skills of engineering students. The students were enrolled into a PBL class. At the beginning and at the end of the semester, students were given a survey to give an assessment of their skills [2]. As seen in Figure 3, students’ critical problem solving, analytical thinking and critical thinking improved after the PBL course ended. These problem solving and analytical thinking skills are essential to critical thinking and analysis [2]. Therefore, if they can improve these areas, then they can improve their critical thinking. Thus, the study shows that PBL can serve as a conduit to improve student critical thinking skills.

These results are backed by the 2012 Griffith University study [3]. In that study, student feedback was largely positive regarding the course’s focus on project work and the relevance of coursework to that of the professional industry [3]. These problems and topics of study give students the opportunity to exercise their critical thinking skills and practice engineering judgement by generating and sharing solutions. Together, the studies listed above provide strong support for PBL’s value in developing critical thinking and engineering judgement in students.

**Experimental Methodology**

In order to gather information on the effectiveness of teamwork skills, new knowledge, critical thinking, and engineering intuition in a COVID environment, a survey asking stimulating questions needed to be administered to students. In addition to this survey, CATME surveys and course end feedback surveys from PBL courses were used to gather data on PBL in a COVID environment.

**Author Survey**

The survey created by the authors was made in a Google Form and consisted of three sections: PBL-Focused Questions, COVID-Specific Questions, and Open Response Questions. Each question in the PBL-focused questions and the COVID-specific questions were multiple choice
style questions and allowed students one of the five responses using a Likert scale: strongly agree, somewhat agree, neutral, somewhat disagree, and strongly disagree. The PBL section of the survey consisted of eight total questions that gage experience with projects completed in the past such as Engineering Design Problems, Independent Studies, and Capstones. The second section of the survey asked nine COVID-specific questions, which focused on learning experiences in a COVID environment with remote or hybrid classes. The last section sought student feedback on what tools or practices would be helpful to carry into the post-pandemic learning environment. The last section was an open response section with four questions aimed at getting opinions on PBL as a method of education, its advantages and disadvantages over traditional classroom learning, and how PBL could be implemented in a persistent COVID environment. This section was not intended to gather data but to afford students an opportunity to express their thoughts about these topics.

Survey Questions

Section 1: Project-Based Learning Questions
1. Project-Based Learning has increased my group communication/collaboration skills.
2. Project-Based Learning has increased my professional communication/presentation skills.
3. Project-Based Learning has improved my ability to cooperate outside of traditional classrooms.
4. Project-Based Learning has increased my ability to think critically about a problem.
5. Project-Based Learning has increased my resourcefulness in finding useful information to solve engineering problems.
6. Project-Based Learning has increased my desire to seek out new knowledge on my own that is relevant to my studies.
7. Project-Based Learning has increased my motivation to learn about new subjects or topics.
8. Project-Based Learning has increased the amount of trust I have in my own ideas, assumptions, and/or solutions.

Section 2: COVID-Specific Questions
1. The COVID environment has NEGATIVELY impacted my ability to collaborate with teammates and instructors through traditional means (i.e. regular face-to-face meetings).
2. Learning in the COVID environment has given me more skills/tools to use to collaborate effectively in groups.
3. Learning in the COVID environment has improved/broadened my professional communication and presentation skills.
4. Learning in a COVID environment improved my ability to cooperate and collaborate outside a traditional classroom setting.
5. Learning in a COVID environment has increased my ability to think critically on my own about problems.
6. I have become more resourceful in seeking out information/instruction to solve problems while learning in a COVID environment.
7. Learning in a COVID environment increased my desire to seek out new knowledge and learn about new subjects.
8. In the COVID learning environment, I have become more likely to make reasonable assumptions when solving complex problems (rather than seek out specific guidance from an instructor).
9. Project-Based Learning is an appropriate and feasible method of learning in a COVID environment.

Section 3: Open Response PBL/COVID Feedback
- Do you feel that Project-Based Learning has any ADVANTAGES over traditional classroom learning?
- Do you feel that Project-Based Learning has any DISADVANTAGES compared to traditional classroom learning?
- How did COVID-19 change the way you participated in group projects?
- What practices or tools from the COVID learning environment would you like to see carried on into future projects, even after the COVID pandemic ends?

This survey was administered to 41 USMA Civil Engineering students. All the students in this survey were undergraduate seniors that had previously completed classes that were project based focused. Students completed the survey at the conclusion of their fall semester, which was conducted entirely through the COVID environment.

CATME Surveys

The authors also used CATME surveys to assess student ability to function effectively on a team. CATME, or Comprehensive Assessment of Team Member Effectiveness, surveys were issued by the USMA Civil Engineering department to assess team member dynamics in five specific aspects of collaboration. These areas included contributing to the team’s work, interacting with teammates, keeping the team on track, expecting quality, and having relevant knowledge. The same group of 41 seniors completed these surveys at the midterm and the end of the 2020 fall semester. The questions in the CATME survey asked about teamwork and collaborative manners. For instance, the survey asks how everyone contributes to team’s work, interacts with teammates, keeps the team on track, and has provided skills. Capstone courses are designed to be a PBL class. During the late spring of 2020, and throughout the subsequent fall semester, the course was conducted during a pandemic. Thus, the data from the 2020 fall semester CATME surveys are appropriate to be used in this study. The questions provided to each capstone project for the CATME survey are provided below.

T1) How much conflict of ideas is there in your work group?
T2) How frequently do you have disagreements within your work group about the task of the project you are working on?
T3) How often do people in your work group have conflicting opinions about the project you are working on?
R1) How much relationship tension is there in your work group?
R2) How often do people get angry while working in your group?
R3) How much emotional conflict is there in your work group?
P1) How often are there disagreements about who should do what in your work group?
P2) How much conflict is there in your group about task responsibilities?
P3) How often do you disagree about resource allocation in your work group?

Course End Feedback

Another set of data came from USMA Capstone and senior elective course end feedback. Questions on the feedback surveys come from a variety of sources and range in specificity. The courses of particular interest to the authors were those that utilized PBL throughout a COVID environment. Most appropriate among the courses were the senior-level capstone courses and a senior-level advanced soil mechanics course, which were both project-oriented for the duration of the semester. Questions from these course end feedback surveys that pertain to this study are listed below:

1. I took more responsibility for my own learning in this course as a result of switching to a remote learning environment.
2. In this course, my ability to think creatively and take intellectual risks increased.
3. In this course, my critical thinking ability increased.
4. My fellow students contributed to my learning in this course.
5. My motivation to learn and to continue learning has increased because of this course.
6. This instructor encouraged students to be responsible for their own learning.

As with the author-created survey, a Likert scale with possible responses of strongly agree, agree, neutral, disagree, and strongly disagree gaged students’ opinions on the above topics.

Results

Author Survey

The USMA student survey created by the authors received 42 responses from senior level Civil Engineering students. The results of the Project-Based Learning section of the survey are shown below in Figure 4. Each question number on the vertical axis represents the corresponding question number from the PBL-focused questions in the methodology section of this report.

While students surveyed appear to be relatively in agreeance on the value of Project-Based Learning, the survey results on learning in a COVID-persistent environment were somewhat less cohesive. Results from the COVID-focused section of the survey are presented in Figure 5 below. As with the Project-Based Learning portion of the survey, the numbers along the vertical axis of the graph reflect the corresponding question number as listed in the methodology section of this report.
Figure 4: Student Responses to Project-Based Learning Survey.

Figure 5: Student Responses to COVID Learning Environment Survey.
1. Do you feel that Project-Based Learning has any ADVANTAGES over traditional classroom learning?
   - “Project based learning provides an opportunity to work as a team to accomplish a big objective. It allows opportunity for design review and the freedom to get to an objective at any means possible.”
   - “Directly puts the learning of material in the hands of students and gives them experience solving a real-world engineering problem which helps from their engineering judgment.”
   - “It is a forcing function to learn material. You can't complete a project without knowing the basics and details. Another advantage is that it mimics how real-world projects are completed in industries and other organizations.”
   - “Yes, project-based learning improves critical thinking, engineering judgements, ability to apply knowledge to real-world problems.”
   - “Project-based learning provides for a more applied way of learning. It allows us to think through and solve real world problems. It also highlights collaborative work instead of independent learning.”
   - “It incorporates all one has learned which is better than learning one skill in a traditional classroom learning.”

2. Do you feel that Project-Based Learning has any DISADVANTAGES compared to traditional classroom learning?
   - “Sometimes advisors can let students hang too much and work becomes too unguided and unproductive. Some guidance and oversight from teachers is necessary.”
   - “The time aspect. Project Based Learning involves more time to learn material. It is also difficult at times to predict how long it will take to do a task, making time management difficult at times.”
   - “It takes more time to achieve knowledge gaining.”
   - “The advantages gained from project-based learning are entirely dependent on the students effort level. Should the student be active and pursue knowledge, the system works well; however, if this is not the case, the system is worse off.”

3. How did COVID-19 change the way you participated in group projects?
   - “It required more time on the front end to get adjusted to the new settings and pushed some aspects of work to the virtual environment.”
   - “Utilized different communication applications such as Microsoft Teams more frequently. Realized you don't need to meet in-person to accomplish work.”
   - “Many of our meetings were virtual on Teams instead of meeting in person. I think we would have been more productive if we had to meet in person for each class hour. It was easy to do work for other classes or do other things during our capstone hour when you are in your room without any of your teammates.”
• “No more in-person meetings, but Microsoft Teams is an effective tool. It provides more freedom for when groups can meet however in person meetings provide better communication with immediate assistance.”

4. What practices or tools from the COVID learning environment would you like to see carried on into future projects, even after the COVID pandemic ends?
   • “Virtual class, instructor videos.”
   • “I would like to take a few things. The ability to meet virtually and save time from meeting in person was awesome. Also, we met more because it was easier to do it over the virtual platform. I would like to continue this in future projects.”
   • “Use of Microsoft Teams and synchronized file sharing.”
   • “Continuing the use of remote communication for group projects to take away a lot of the time it takes up to meet with a group in person.”
   • “Microsoft Teams and the whole integrated Microsoft Suite are very useful tools that enhance the environment of the classroom.”
   • “Technology usage of being able to work simultaneously on projects, store things, and meet instantly whenever/wherever if in person is unable.”
   • “The ability to meet anywhere with a group virtually and set up collaborative spaces online will no doubt be extremely useful.”
   • “The use of remote meetings means that working with students from other schools is much more feasible.”

CATME Surveys

The CATME surveys were provided twice during a single semester to 11 various capstone projects within the USMA Civil Engineering Department, which returned 41 responses. Responses were recorded on a Likert scale of 1 to 5, with each increasing number corresponding to a greater frequency of disagreements or conflicts within the group. The horizontal axis of Figure 6 represents the number of responses received for the questions and the vertical axis represents the various questions as labeled previously. The chart indicates an overall low level of conflict, with the most disagreement stemming from questions related to the task of the project such as the responsibilities within the team and the allocation of resources. There were zero instances of any value recorded above 4, which would have indicated a common level of conflict within group. The mean value for all responses was 1.367, indicating an extremely low level of conflict and disagreement among the various capstones.
Course End Feedback

The Capstone course end feedback surveys received various numbers of responses; however, trends are still observable among the responses received. Responses to the six questions of interest in this study are presented below in Figure 7. The vertical axis in Figure 7 corresponds to the question number as listed in the methodology section of this report, and the horizontal axis corresponds to the number of responses received on each question.

General trends suggest cohesion among student opinions about their critical thinking, creativity, responsibility, and collaboration skills in Capstone courses. Responses from the advanced soil mechanics course showed similar trends, as seen below in Figure 8. Axis labels on Figure 8 are the same as those on Figure 7.
Figure 7: Student Responses to Capstone Course End Feedback Surveys.

Figure 8: Student Responses to Senior PBL Elective Course End Feedback Surveys.
Analysis and Discussion

Critical thinking and engineering judgement

Results of the COVID section of the author survey suggest that critical thinking skills, which are crucial for practicing engineers as discussed in ABET Student Outcomes 1 and 6, are often not sufficiently developed in the COVID-persistent learning environment. However, results from the PBL section of the survey indicate that PBL-oriented courses did not suffer the same stagnation in student critical thinking development. This trend suggests that the implementation of PBL could improve students’ educational experience and maximize learning in this COVID-persistent environment.

The author-written survey responses showed a consensus that Project-Based Learning stimulates students’ critical thinking skills. From the survey responses, over 97% of students agreed that PBL increased their ability to think critically about problems. Over 85% of students surveyed agreed that through PBL, the level of trust in their own ideas, assumptions, and solutions had increased. These responses highlight the benefits of complex problem solving at the student level. The more students practice receiving, understanding, and addressing a complex and sometimes ambiguous problem, the better prepared they will be to complete similar projects in their future careers.

According to the open-feedback questions, students agree that PBL is a better environment than the traditional-classroom learning to enhance critical thinking and engineering judgement. However, the tradeoff is that new knowledge may not be attained and applied as quickly. It is because of limited guidance and the nature of ill-defined problems that exposes the students to use more critical thinking and engineering judgement.

Data points from course end feedback surveys showed similar trends. Every member surveyed in both populations agreed that in these project-oriented courses, their critical thinking skills were stimulated and developed. Students improved their ability to take intellectual risks when addressing problems and generate creative solutions. It is worth noting again that these courses were conducted throughout an ongoing COVID environment. Despite the challenges of learning in a COVID environment, students in these PBL-oriented courses thrived and developed critical thinking skills in accordance with ABET SOs 1 and 6.

The survey results also trend with the studies in the Background section. A study in Malayan University and Griffith University mention that students’ critical problem solving, analytical thinking and critical thinking improved after the PBL course ended [2] [3]. In the COVID environment where students cannot maximize a traditional classroom experience, PBL is a tool to maximize their critical thinking skills.

Improving teamwork skills

Regarding the COVID-persistent learning environment, 57% of students surveyed by the authors agreed that new limitations negatively impacted their ability to collaborate with teammates and instructors through traditional, face-to-face means, which raises concerns for students to meet
ABET Student Outcome 5. However, over 60% of those interviewed agreed that learning in the COVID environment has given them new skills and tools to use to collaborate effectively. Over 75% of interviewees agreed that their ability to collaborate and cooperate outside a traditional classroom setting improved. This is likely due to the widespread use of collaborative technology such as Microsoft Teams, Zoom, or Webex. These technologies were widely referenced in the open-ended section of the survey as a useful tool for collaboration, whereas before the COVID pandemic, these technologies were not as widely used.

Open feedback from the author survey suggests that the online tools listed above played a crucial role in enabling project groups to succeed in a COVID-persistent environment. While some students mentioned that virtual team meetings left individuals more prone to being distracted from their work, others noted the increased flexibility in group meeting times and locations. Consensus from the qualitative student feedback showed that while virtual meetings were not favored over in-person meetings, using collaborative software offered a convenient alternative when meeting in person was not possible. This proved to be especially valuable for connecting with remote industry advisors and experts.

The author survey received generally positive feedback in each of the PBL-focused questions relating to teamwork skills. This both confirmed the Deep study and further defined the broad “soft skills” term used in that study [2]. Students were asked if PBL improved their group communication and collaboration skills, to which the overwhelming response (95% of those surveyed) was positive, while every student surveyed agreed that PBL had improved their ability to cooperate with teammates outside a traditional classroom environment. Most students (95%) agreed that PBL increased their professional communication and presentation skills, again confirming the results of the Deep and University of Washington Studies [2, 7].

Students agreed in course end feedback surveys that they benefited from their peers in learning course material in PBL classes. 100% of students agreed that their fellow students contributed to their learning in these courses. Over 90% of students in these courses felt that the instructor encouraged them to take responsibility for their own learning and education. The increased reliance on peers observed here parallels the improvements in collaboration observed in the Malaysian university study [2]. PBL forces students to take more responsibility for one’s own learning, which makes them more likely to reach out to their peers and ask for help when needed.

The results of the CATME survey reinforce these findings. The survey shows that in a PBL environment there is relatively little conflict, especially in areas pertaining to relationships amongst team members and the scope of the project. In Figure 6, we see that about 83% of students responded that there was a low level of conflict when delegating tasks to each group member during a PBL class. This shows that many of the students sampled are motivated to identify and complete the parts of the project assignment they have been assigned. Here, as with the Malaysian university study, PBL necessitates strong communication skills during group meetings to identify member responsibilities and complete portions of a project [2].

These results show the positive effect of PBL on skills necessary for the professional workspace: communication, collaboration, and presentation. Students agree that PBL allows them to learn to work effectively with peers. In doing so, they learn valuable skills, such as time management,
distribution of tasks, and conflict resolution. In addition to communicating more effectively with peers, students also acknowledge that PBL improves their ability to communicate results and recommendations in project presentations. These skills, just as with group collaboration, reflect underlying development associated with PBL that students can refine and carry into their professional careers.

*Acquiring and applying new knowledge*

The most troublesome results from the COVID section of the survey are perhaps those regarding student motivation for learning. Almost 70 percent of students were neutral towards or in disagreement with an increase in their general desire to continue learning about new subjects in the COVID environment. Understandably, learning has been made more difficult by the pandemic; however, the author survey also indicates that PBL may offer a way to improve student motivation during the pandemic.

Over 90% of students who responded to the author survey felt that PBL has increased their motivation to learn about new subjects and topics. Additionally, the same number of students reported their ability to find useful information increased when solving engineering problems through PBL methods. These trends suggest that in addition to providing students a way to apply learned knowledge to a project, PBL increases students’ motivation to continue learning. This self-motivated learning style empowers students to take responsibility for their education.

Similar trends were apparent in course end feedback for Capstone and senior level PBL elective courses. Students largely reported an increase in responsibility for their own learning, particularly in the remote learning environment of the 2020 fall semester. Students overwhelmingly reported an increase in motivation to continue learning after completing these PBL-oriented courses. In a profession where even the forefront experts must continue learning new concepts and applications, it is crucial that undergraduate students be motivated to continue their education, even if it is on their own. This hunger for knowledge, spurred by PBL and in clear support of ABET Student Outcome 7, establishes a crucial aspect of professional development in young students that will serve them well as they progress through their careers [1].

Student feedback from open-ended questions in the author survey agree that PBL improves students’ ability to apply new knowledge to real-world problems. Students use all of their knowledge, integrate them, in order to solve the problems. The COVID-19 also creates an environment that engineering students have to be more initiative to solve problems on their own. A remote learning education requires students to acquire new capabilities in, for example, technology, information collecting, etc. Thus, students are more familiar and prepared than ever to use knowledge to apply in real-world problems.

The results from the author survey support similar results in the background section about students’ motivation to and acquire new knowledge. The result showed that student motivation to acquire new knowledge increased after they participated in a PBL course. In addition to their high motivation for new knowledge, these students were able to retain more information related to the course to the course and obtained a higher score post-curriculum [5]. This corresponds
with the authors’ result that PBL increase motivation to acquire and apply new knowledge as well as retain the knowledge learned.

The survey results suggest that students have learned valuable new collaboration skills the COVID pandemic. However, students have also lost out on opportunities to think critically about engineering problems and have also communicated a lack of motivation to learn about new topics in a COVID environment. To capitalize on the wide spread use and fluency with collaborative technology, and to utilize the strengths of the learning method to account for the challenges of critical thinking opportunities and motivation to learn that have occurred during the pandemic, recommended to emphasize PBL over more traditional coursework to an even higher degree during the ongoing pandemic.

Conclusion and Further Research

The COVID-19 pandemic has presented several challenges for universities and students as they transition to a hybrid or fully online education model to mitigate the risk of viral transmission. Online learning gives students easier access to information and course material. Despite this advantage and the significant advances that have been made in collaborative technology in recent years, the COVID-persistent environment has left educators in search of a way to implement virtual learning while maximizing student engagement, learning, and still achieving ABET Student Outcomes. According to survey results, peer feedback, and course feedback from 41 senior-level undergraduate students, the implementation of PBL in a hybrid or fully online environment promoted student development in accordance with SOs 1, 5, 6, and 7 [1]. Particularly evident in course end feedback, PBL enhanced students’ ability to acquire knowledge from a variety of sources and apply it to a problem, using appropriate learning strategies in accordance with SO 7. Importantly, PBL also helped fulfill SOs 1, 5, and 6, which have previously been a shortcoming of education in an online environment. Students also recognized the value of collaborating in project teams and reported that they gained collaboration, cooperation, and presentation skills because of these project-oriented courses, fulfilling SO 5. Additionally, PBL-oriented courses gave students the opportunity to exercise critical thinking and engineering judgement in a realistic and complex problem-solving process, which fulfilled ABET SOs 1 and 6 [1]. While this study provides strong support that PBL improves student experience and outcomes in a hybrid or virtual environment resulting from COVID, it does not assess actual student performance. Further research can still be done to assess student performance in the hybrid or virtual environment that has resulted from the COVID pandemic, particularly comparing performance of students in traditional-style online courses and PBL-oriented courses using exam or course grades.
References


