Journal of
Problem
Based
Learning
in Higher Education

VOL. 10, No. 1, 2022 – Page 74-87
10.5278/ojs.jpblhe.v10i1.6887

Enhancing Student's Problem-solving Skills through Project-based Learning

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ABSTRACT

The goal of the study is to overcome two main drawbacks of traditional science, technology, engineering, and math (STEM) pedagogical strategies using PBL - lack of student engagement and students who are not prepared for more complex problems. PBL teaching strategies practiced in an introductory class are assessed. Classroom observations and student surveys are used to determine at what level does the PBL affect students' problem-solving skills. For the first half of the semester of the course, traditional lectures were used, during the second half, students are divided into experimental (PBL strategy) and control groups. The results of the survey and student grades are analyzed to determine a statistically significant difference between pre/post-study results. From the students' perspective, there is a significant mean difference between their confidence level in solving problems before and after using PBL and the students earned higher grades compared to the students in the control group.

Keywords: Project-based learning; teaching strategies, construction management

INTRODUCTION

Solving problems is an essential skill for the future workforce in many science, technology, engineering, and math (STEM) careers. In the context of higher education, the development of problem solving skills includes a variety of teaching strategies to prepare students for solving new kinds of problems and provide opportunities for theoretical concepts to become more concrete (Netwong, 2018). STEM problems share many common pedagogical principles despite the obvious difference in their teaching strategies. For example, they present students with a real-world problem and ask them to propose a valid well-constructed solution (Jurdak, 2016). Hands-on and active

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participation have also been proposed in the literature to facilitate the problem solving learning process (Demirhan & Şahin, 2019). Developing such skills can be best achieved in using project-based learning (PBL) where students are engaged through a collaborative process of investigation over an extended period of time (Sahin, 2013). PBL represents a promising student-centered approach to overcome two main drawbacks of traditional STEM pedagogical strategies; firstly, lack of engagement in collaborative partnerships and, secondly, passive learning and compartmentalized curriculum (Pinho-Lopes & Macedo, 2014). By working with PBL, students, in groups, investigate the problem from the curriculum. Recent studies show that PBL curriculum has an overall positive impact on student attainment of professional attributes (Johnson & Ulseth, 2014).

It was noticed that students who falter in introductory STEM courses are more likely to develop learning gaps that grow as they tackle more difficult material (Alzen et al., 2018). The goal of this study is to close such gaps and build a solid foundation for more advanced work in upper level courses. This can be achieved by using PBL strategies in which instruction is delivered through small groups and students are encouraged to collaborate to master concepts. In working with undergraduate students over many years, the authors have experienced countless occasions where students are asked to work in groups to solve a problem, yet, they wait for the instructor or classmates to give them a hint to solve the problem for them. Perhaps, they have never been taught how to find the information required to problem solve. This issue is certainly not unique to the authors' experience; as other educators have noticed that many students are completely dependent on the help of a tutor for the majority of their class projects (Khouyibaba, 2015).

It is recommended to enhance students’ problem-solving particularly in introductory classes where students need to master the basics before moving on to an advanced course (Stanger-Hall, 2012). The format of PBL can be useful as a way of challenging students to answer/solve real problems in an authentic meaningful way. In the next section, we define characteristics of PBL in STEM education by reviewing recent studies. The foundation of this study is comprised by this question: How can PBL improve the students’ problem-solving skill in introductory STEM courses? To answer this question, we assess PBL teaching strategies practiced in an introductory STEM class.

A REVIEW OF PROJECT-BASED LEARNING IN STEM EDUCATION

PBL is a student-centered form of instruct which is based on six hallmarks: a driving question, the focus on learning goals, participation in educational activities, collaboration among students, the use of scaffolding technologies, and the creation of tangible artifacts (Krajcik & Shin, 2014). Like other student-centered pedagogies (e.g. problem-based learning), PBL requires students to work together through authentic questions and to find solutions to authentic problems within real-world practices (Al-Balushi & Al-Aamri, 2014) which lead to meaningful learning experiences (Al-Balushi & Al-Aamri, 2014).

A driving question (DQ) is an open-ended inquiry that guides the problem-solving approach and the project work. For the teachers, it helps to focus the inquiry and planning of the project. For the students, the DQ creates interest and a feeling of challenge and entices critical thinking (Miller & Krajcik, 2019). The DQ should be open-ended to allow numerous possible answers and get adequate answers to complex projects. At the same time, it should be provocative and challenging to encourage students to think creatively and raise the visibility of the key learning concepts (Bielik et al., 2018). Learning goals are simply the result of the instruction; what students will learn and/or be able to do as a result of the lesson. Therefore, it is necessary to use hands-on projects that successfully address significant learning goals. PBL helps teacher combine the project goals (the aim to achieve) and the learning goals (the knowledge learned in the course) (Michel et al., 2012).

Many studies demonstrate active participation in educational activities boosts students' level of understanding and improves the ability to process content, and the retention of knowledge (Baraldi, 2013; Nasmith & Steinert, 2001). Since students have to collaborate with their peers on how to solve a problem, most projects include opportunities for collaborative problem-solving activities by nature (Cukurova et al., 2016). Negotiating how to collectively solve a problem is also part of PBL (Bell, 2010). Once projects are undertaken as groups, two types of roles are defined with PBL: The individual role performs individual tasks, and group role which is composed of several individual roles and performs collaborative tasks (Yassine et al., 2013).

A number of scaffolding strategies have been presented in the literature. Examples of common scaffolds in PBL include but not limited to: using real-case projects grounded in the personal interests (Grant, 2009), modeling with think-aloud can be used to generate student questions during a project launch (Mou, 2019), projects can be broken into parts to better facilitate collaboration in small groups, hands-on activities can be used to link theory to practice (Joyce et al., 2013), and graphic organizers can be used to visually depict an idea either through writings or charts (Chasanatun & Lestari, 2017).

Last, the creation of artifacts is a distinguishing characteristic of PBL compared to other student-centered pedagogies. Students create a set of tangible project/products that address the DQ. These artifacts are shared and present their gained knowledge (Arcidiacono et al., 2016).

RESEARCH METHODOLOGY

The class that is involved in this study is a required introductory course for BSc students in Construction Management at Sam Houston State University (SHSU). The class selected for this study is Wood Frame Construction containing 26 students with 3 females (11%) and 23 males (89%). The class is a lecture/lab course with 1-houe lecture and 3-

hour lab per week. Figure 1 shows the woodworking area that allows exposure to the machines and hands-on practices typically found in industry.

Figure 1. The woodworking lab facility for the selected class.

The section selected for this study was offered in Spring 2021 with the COVID-19 pandemic entering its second year. As a response to COVID-19, the course delivery has been modified to reduce classroom density. The class is divided into two sections; each meets once a week with half of the students enrolled in the class (13 out of 26 students).

The authors' effort has focused on applying PBL methods as an alternative to "cookbook" procedures. Traditionally, students in Wood Frame Construction were supposed to perform the exact sequence of steps specified by the instructor or the textbook. From authors' observations, it could be seen that students did not learn when and how to apply these same procedures outside of the classroom. A deeper understanding of the wood working material is needed. Most students were conditioned to wait for the instructor to give them the answer and did not take collaborative inquiry seriously.

We compiled a list of recommendations and strategies for improving engagement to fulfill educational objectives. First, we used a DQ as an entry event to give students a sense of purpose and challenge. The questions are mostly focused on solving a problem (e.g., how to frame a wall or door). Second, each project would give students opportunities to communicate, collaborate, and think critically. In addition to the PBL pedagogical benefits, there are at least three more reasons that justify the use of PBL for this introductory STEM class; First, students construct their understanding by building their wood products. Second, students are able to display their learning in a continuous process throughout a woodworking project that is consistent with real-world practices. Third, student presentations make their problem-solving skill visible to others.

The first half of the semester, traditional lectures were used to introduce all students to new topics; the instructor delivered the content over the course of a few lectures, set assignments with step-by-step procedure to measure student comprehension and moved on once it is complete. During the second half of the semester, the students enrolled in the Wood Frame Construction class are divided into experimental and control groups, with those in the experimental group being taught with PBL. Those in the control group are taught with the traditional lecture/lab method. For seven consecutive weeks, the students in the experimental group are given different wood frame projects such as framing a roof or stair, installing a door, and building a fence. As an example, the students were taught how to properly layout gable and hip roofs and introduced to rise, run, pitch, and rafter length calculations. A roof plan for a sloped gable roof was used as the DQ and the students were asked to calculate the actual length of the rafters. The DQ is presented to each team one week in advance and each team is given 5-10 minutes during the class to discuss and select which role to play or topic to study.

The student could use email, text messaging, and video communications to solve the problem. Last, students were asked to conduct real inquiry as opposed to find the information in the textbook or websites. The resources are available to use but ideas should be generated and then tested. The students were asked to actively participate in the class activities and they had to collaborate with group members to find and agree on a solution. Drawings are used as scaffolding technologies and there was a tangible artifact for each project. For example, the students were provided with a roof plan drawing and delivered a framed gable roof. In another project, the students were provided with a site plan and customer's requirements of a fence and delivered an assembled fence with a footing, two posts and pickets between the posts.

A structured problem-solving technique is used for the experiential group in the study to identify, analyze, and solve problems in an organized manner. The experimental group must agree to a solution and be able to explain the solution and the strategy used to solve the problem. Figure 2 shows students working on their woodworking projects. The learning environment for the experimental group is designed based on many elements of constructionism; the instructor acts as a facilitator and guides the students through the necessary steps to complete their project. The students are assigned tasks in which they must brainstorm, investigate, and solve problems. Other elements for the experimental group guided by constructionism include presentation of rubrics which define expectations, presentation of artifacts, collaboration between the students, and using authentic real-world projects. Constructionism (Papert, 1993) is both a theory of learning and a strategy for education asserting that knowledge is not simply transmitted from teacher to student, but actively constructed in the mind of the learner.

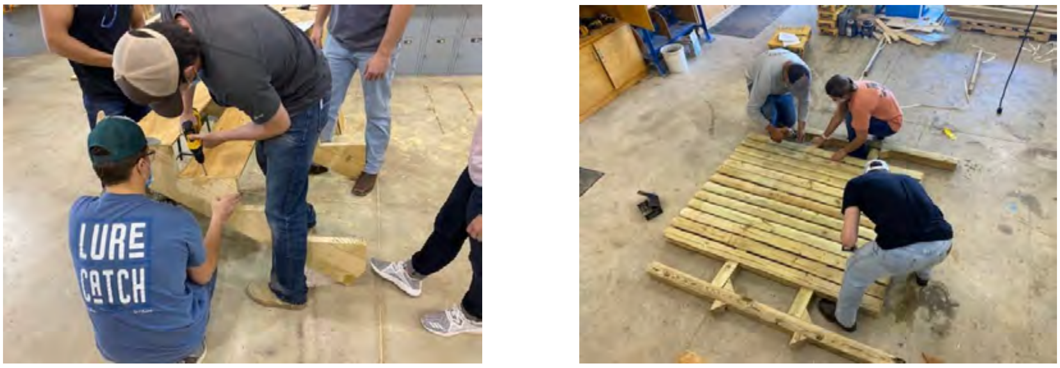

Figure 2. Examples of the woodworking projects (building stair and wood fence).

The course material has been revised to improve students' creativity and problem-solving skills through PBL techniques. Instead of providing step-by-step instruction to meet the outcome (e.g. wood planter box), the final product is identified, and students should develop creative and practical solutions (e.g. what should be used for the joints, wood glues or nail or screw connections, what are the feasible decisions based on the available tools). Once a solution is agreed upon, the team must decide how to realize that solution by building the product. Students work together in small groups and the problems are posed in a wide variety of contexts and representations.

The students were expected to present their work to the class at the end of each project. These wood products, which were representations of students' solutions resulting from the given projects, were presented as the final products to the control group. Because the projects were exactly the same for the control and experimental groups, there were opportunities for sharing ideas and getting feedback with peers. The students in both groups were given the opportunity to revise their artifact for the final project. Given the circumstances related to COVID-19, whole class presentations were not scheduled and the students did not have the opportunity to foster their intra-group communication and sharing.

DATA COLLECTION AND ANALYSIS

Data is collected for this study in two forms; through a student survey and final grades. All students in the experiential group are given a pre-survey at the beginning of the semester (when the study initially begins) which is also the same survey given at the end of the semester (conclusion of the study). The results of the survey and the students' grades are statistically analyzed to determine any statistically significant difference between pre/post-study results for the students in the experimental group. The survey used in the study is available in the appendix.

Table 1 shows the results for the pre- and post-study surveys for the experimental group. The first three questions focus on individual student's ability to solve problems. In questions 4-6, we wanted to see whether students' confidence increases while their dependence on instructors for problem solving decreases by having them present ideas and solutions. The last five questions focus on group problem-solving and the effects of various communication behaviors on the group's problem solving.

Question	**Score**	**Strongly Agree** 5	**Agree** 4	**Undecided** 3	**Disagree** 2	**Strongly Disagree** 1
1- I feel confident solving wood working problems on my own.	Pre-study	23%	46%	15%	15%	0%
	Post-study	*46%*	*38%*	*8%*	*8%*	*0%*
2- It is easy for me to find a solution to a wood working problem.	Pre-study	23%	46%	15%	15%	0%
	Post-study	*46%*	*23%*	*23%*	*8%*	*0%*
3- I use drawings or visualize the final product to find my solutions.	Pre-study	46%	38%	15%	0%	0%
	Post-study	*54%*	*46%*	*0%*	*0%*	*0%*
4- I feel comfortable explaining my solution to other group-mates.	Pre-study	31%	54%	0%	15%	0%
	Post-study	*54%*	*15%*	*23%*	*8%*	*0%*
5- Explaining my work/solution is an important part of learning about wood working	Pre-study	46%	54%	0%	0%	0%
	Post-study	*54%*	*31%*	*8%*	*8%*	*0%*
6- Problem solving is a subject that I am good at.	Pre-study	31%	54%	15%	0%	0%
	Post-study	*23%*	*69%*	*0%*	*8%*	*0%*
7- Working in groups helps me better understand woodworking.	Pre-study	85%	15%	0%	0%	0%
	Post-study	*77%*	*15%*	*8%*	*0%*	*0%*
8- I feel like I can help my group plan for a woodworking assignment.	Pre-study	46%	38%	15%	0%	0%
	Post-study	*54%*	*38%*	*8%*	*0%*	*0%*
9- If I am struggling with an assignment, it helps to have a classmate explain it to me.	Pre-study	69%	15%	15%	0%	0%
	Post-study	*54%*	*38%*	*8%*	*0%*	*0%*
10- I feel like my opinions and ideas are used in my group.	Pre-study	62%	8%	15%	15%	0%
	Post-study	*31%*	*38%*	*31%*	*0%*	*0%*
11- Working in groups could help me understand hands-on projects better.	Pre-study	69%	31%	0%	0%	0%
	Post-study	*62%*	*38%*	*0%*	*0%*	*0%*

Table 1. Survey results for the experimental group (use of PBL).

The proposed analysis is consistent with different theories, such as social constructivist theory, which emphasizes that students learn by doing especially when they work together with the teacher's guidance. The survey aims to understand whether the provided learning environments allowed students to take responsibility for their learning. Furthermore, by including mathematical statistics and data analysis the authors wanted to assess how the students (as individuals) learn differently to one another. This is also consistent with multiple intelligence theory that differentiated the intelligences of learners that are manifested in different skills and competencies.

Figure 3 demonstrates the difference between the pre- and post-study surveys. Only one data point is presented for each question. A Likert scale was used to quantify the strength/intensity of students' attitude. Each of the five responses has a numerical value to measure the attitude under investigation. The values are used to create an aggregated (or average) score for each question to measure the attitude of the experimental group. The differences in the collected Likert scale data are were considered statistically significant if the p value for a paired t-test statistic associated with the particular pair of means is smaller than 0.05. The t-test are conducted for all thirteen questions and the results are shown in Table 2.

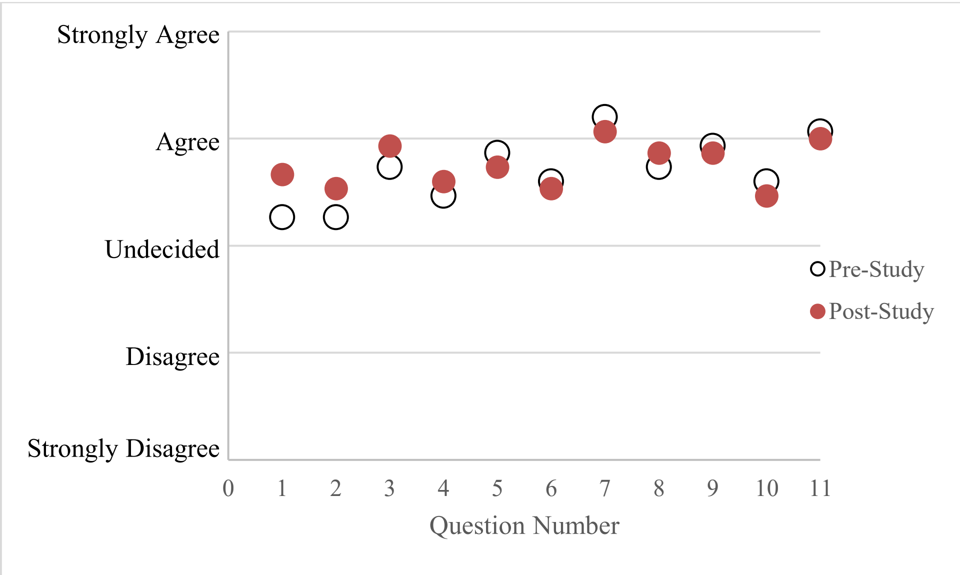

Figure 3. Survey results for the experimental group (use of PBL).

Question	Mean		Std. deviation		t	Sig. (2-tailed)
	Pre-Study	Post-Study	Pre-Study	Post-Study		
1- I feel confident solving wood working problems on my own.	3.61	4.23	1.19	0.93	-2.889	0.014*
2- It is easy for me to find a solution to a wood working problem.	3.62	4.08	1.19	1.04	-3.207	0.008*
3- I use drawings or visualize the final product to find my solutions.	4.31	4.54	0.75	0.52	-1.897	0.082**
4- I feel comfortable explaining my solution to other group-mates.	4.00	4.15	1.00	1.07	-0.805	0.436
5- Explaining my work/solution is an important part of learning about wood working	4.46	4.31	0.52	0.95	0.805	0.436
6- Problem solving is a subject that I am good at.	4.15	4.08	0.69	0.76	0.562	0.584
7- Working in groups helps me better understand woodworking.	4.85	4.69	0.38	0.63	1.477	0.165
8- I feel like I can help my group plan for a woodworking assignment.	4.31	4.46	0.75	0.66	-1.477	0.165
9- If I am struggling with an assignment, it helps to have a classmate explain it to me.	4.54	4.38	0.78	0.65	1.000	0.337
10- I feel like my opinions and ideas are used in my group.	4.15	4.08	1.21	0.86	0.433	0.673
11- Working in groups could help me understand hands-on projects better.	4.69	4.62	0.48	0.51	1.000	0.337

Table 2. Paired t-test results for the pre- and post-survey results.

* Significant at p<0.05

** Significant at p<0.1

The null hypothesis states "there is no difference in mean score of students' opinion when PBL is used". Based on the significance (2-tailed) value for the first three questions, we can conclude that there is less than 5% (or 10% for Q3) probability that there is no difference in individual student's ability to solve problems with and without using PBL. From the students' perspective, there is a significant mean difference between their confidence level in solving wood working problems when they learned through PBL compared to the traditional teaching. Furthermore, the students in the experimental group found it easier to find a solution to a wood working problem when PBL is used. Regarding the common scaffolds in PBL, the survey results show drawings and visualization of the final product are used more often to find the solutions.

Another important metric to measure the strength of PBL is the students' grades before and after using this learning method and the comparison between the grades for the students in the control and experimental groups. The control group was given similar projects but with the sequence of steps specified by the instructor or the textbook. Although students' grades are not necessarily an indicator of students' problem-solving skill, they can reflect the knowledge possessed by the students and thus show the effectiveness of PBL. We use the paired t-test to compare the students' grades before (from the beginning to the middle of the semester) and after using PBL (from the middle of the semester to the end of the semester). To exclude and understand the changes in the grades for the second half of the semester, the paired t-test is also used for the control group and the results are shown in Table 3.

Group	Mean		Std. deviation		t	Sig. (2-tailed)
	Pre-Study	Post-Study	Pre-Study	Post-Study		
Control (traditional learning)	0.752	0.749	0.113	0.244	0.085	0.933
Experimental (use of PBL)	0.797	0.816	0.113	0.158	-0.528	0.607

Table 3. Paired t-test results for the pre- and post- students' grade results.

Although the average difference in the students' grades for the experimental group before and after using PBL is not statistically significant (p=0.607>0.05), students in this group earned higher grades and could improve their grades compared to those in the control group. In addition, we use the independent samples t-test to compare the grade difference between the control and experimental group and determine whether students benefited from PBL earned grades that differ on average from those did not learn through PBL. The results for the independent samples t-test is shown in Table 4. The students who learned through the PBL performed better compared to other students in the class, but the difference was not statistically significant.

	N	Mean	Std. deviation	F	Sig. (2-tailed)
Control (traditional learning)	13	0.192	0.131	0.006	0.941
Experimental (use of PBL)	13	-0.038	0.162		

Table 4. Comparison of Students' grades for the experimental and control groups.

CONCLUSION

As a response to COVID-19, the course delivery for the selected class shall be modified to reduce classroom density. To make the most of the limited time left for face-to-face interaction, PBL was found to be an appropriate instructional approach to better engage students in the investigation of real-world problems. The purpose of the study was to understand whether PBL positively impacts students' problem-solving skills and their interests/connection to real-world problems. This quantitative study included two groups of undergraduate students. One group of students were learned through PBL for half of the semester, and the other group of students did not have the PBL learning experience. Every student in the two groups were exposed to the same curriculum throughout the duration of the study.

Data is collected for this study in two forms: through student surveys and final grades. The survey results indicate that PBL learners could benefit from this alternative learning method regarding the individual student's ability to solve problems. The survey results for the questions regarding the students' confidence, group problem-solving and the effects of various communication behaviors on the group's problem solving were not statistically significant. Regarding the students' grades, PBL learners performed better than the other group of students (2% increase compared to 0.4 decrease). Both control and experimental groups showed the same trend with respect to class participation before the beginning of the study. However, the participation rate of PBL learners in class activities was noticeably higher than that of the control group. This can be explained by the degree of active involvement of students in problem-solving as the instruction alone is not sufficient to solve the problem. The survey results and student grades were tested quantitatively in this study, but they can be further tested on more data to represent performance norms of different student-centered pedagogies.

Given that the study group may represent only a portion of the target population, it would be useful to repeat the study with a similar setting but larger student group or combining a number of introductory STEM courses in future. The investigation of communication and collaboration skills were beyond the scope of this study and the measurement of these two twenty-first-century skills can be a subject for future research. A test with open-ended questions can be used to measure students' communication skills and a peer-collaboration rubric can give students an opportunity to evaluate their team-mates.

Acknowledgement

The work described in this paper was supported by a teaching enhancement grant from Sam Houston State University – STEM Center. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the STEM Center.

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APPENDIX:
SURVEY USED IN THE STUDY

Please answer the following questions honestly. Your response to these questions will not affect your grade but will help me better understand different ways to teach you in the classroom! The survey will not be graded and your responses will be anonymous.

	5 Strongly Agree	**4 Agree**	**3 Undecided**	**2 Disagree**	**1 Strongly Disagree**
I feel confident solving wood working problems on my own.					
It is easy for me to find a solution to a wood working problem.					
I use drawings or visualize the final product to find my solutions.					
I feel comfortable explaining my solution to other group-mates.					
Explaining my work/solution is an important part of learning about wood working					
Problem solving is a subject that I am good at.					
Working in groups helps me better understand woodworking.					
I feel like I can help my group plan for a woodworking assignment.					
If I am struggling with an assignment, it helps to have a classmate explain it to me.					
I feel like my opinions and ideas are used in my group.					
Working in groups could help me understand hands-on projects better.					

Something I would like to change about group work is:
Something I like about group work is: