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Using Project Based Learning to Improve Student Comprehension of Sustainability in Concrete Technology

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The objective of this study is to develop and implement a Project Based Learning (PBL) methodology to improve student comprehension of sustainability topics relating to the concrete industry. A milestone-based PBL methodology was implemented in a concrete technology course that emphasizes the project by creating individual milestones that are due throughout the semester. This intervention took place in an undergraduate program during six semesters, not including the control semester in which a conventional end-of-semester project was used to teach the same topic. The milestone-based PBL methodology was assessed indirectly using pre- and post-questionnaires to the participants and directly using quiz, homework, exam, project, and overall grades. Additionally, the participants provided feedback regarding the methodology. The results show that the students overwhelmingly preferred the milestone-based PBL over the standard project, which is complemented with an average increase of 16, 13, 17, 28, and 14 percentage points for the quiz, homework, exam, project, and overall grades respectively. This amounted to an overall average increase from 74% to 92%. These conclusions not only demonstrate a positive impact of PBL to the students in this course, but also provide further insight and evidence regarding the effectiveness of PBL methodologies for the engineering education community.

Keywords: project-based learning, milestone, concrete technology, undergraduate, assessment, active learning

INTRODUCTION

The cement and concrete industry are undergoing a transformation due to an increase in environmental concern and more stringent regulations. Cement is the second most consumed material in the world, which places the cement industry amongst the largest CO2 emitters globally (Kanavaris, 2021). Approximately 1 ton of CO2 is emitted per ton of cement produced. In the United States alone, approximately 87 million tons of cement is produced each year. Consequently, companies and researchers are trying to develop methods and materials to help reduce the environmental impact of cement. One method is to simply use less cement in concrete production; however, the performance of concrete is typically proportional to the amount of cement used. Therefore, there are many ideas and methods that the industry is implementing or working on to facilitate

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the reduction of cement for a more sustainable industry. Due to the global importance of sustainability and the high impact that the cement and concrete industry has on carbon emissions, it is paramount that these topics be taught to civil engineering and concrete technology students. Since 2014, the author of this study has incorporated sustainability concepts into his concrete technology course, titled "Concrete Construction Methods". The 16-week course is part of a four-year undergraduate degree program in Concrete Industry Management (CIM). In 2014, the author/instructor used a conventional end-of-semester project devoted to sustainability. The project focused on general aspects of sustainability, but primarily methods and procedures currently used by the cement and concrete industry. After the completion of the 2014 semester, the author/instructor noticed a less than optimal student performance on their end-of-semester project (more than 50% of the students received a grade of 60% or lower) and felt that an instructional change was needed, especially due to the importance of the topic. The author sought a new teaching strategy that would help improve student understanding and comprehension of these important topics. Since a project was already used in the class, the author felt an active teaching and learning pedagogy, based around a project, would be an ideal fit. Therefore, the active teaching and learning pedagogy that was discovered and implemented was Project Based Learning (PBL). PBL is a pedagogical technique that is student-centered and uses a more dynamic and active classroom approach to teaching and learning a topic. It is believed that students acquire a deeper knowledge, understanding, and comprehension through active exploration of real-world topics that are both challenging and engaging. PBL is facilitated through students spending an extended period of time investigating a complex question, challenge, or problem that allows students to inquire and make beneficial gains through their own discovery process. The project is often guided by an instructor or instructional aides who help transmit the knowledge as the students develop and work on their project (Arantes (2018), Baran (2018), Choden (2020), Chu (2011), Darmuki (2023), Gunawan (2020), Indrawan (2019), Maksum (2022), Mursid (2022), Nainggolan (2020), Putra (2021, Santyassa (2020), Saputra (2019), Supena (2021), Zulfa (2022), and Sudjimat (2021)).

Torres et al. (2017) developed a milestone based PBL methodology that was used in a college level construction course. In their PBL method, they developed and implemented milestones, which are smaller, more tangible, sections of a larger project. These smaller milestones then allowed the students to build towards the project throughout the semester as opposed to working on the project in the last moments before it is due. This methodology showed meaningful improvements to students' perceptions and performance (Torres, 2017). Other authors support the importance of making the PBL project being at the center of the course (Arantes (2018), Darmuki (2023), Gunawan (2020), Sudjimat (2021))

Therefore, a PBL methodology was implemented that used milestone-based formatting as described by Torres et al. (2017). The milestone-based PBL was implemented in the next six offerings of the course and was compared to the original 2014 (control) semester. The milestone-based PBL methodology was assessed indirectly using multiple pre- and post-questionnaires to the participants and directly using quiz,

homework, exam, project, and overall grades. Additionally, the participants provided feedback regarding the methodology.

Literature Review

PBL is an instructional approach designed to give students the opportunity to develop knowledge and skills through active and engaging projects set around challenges and problems the students may face in the real world. This type of pedagogy is not merely a project that is typically assigned on the first day of the class and due at the end of the class, in which students often procrastinate until a few days before. This type of pedagogy is a project that investigates and responds to an authentic, engaging, and complex problem or challenge that facilitates the "learning by doing" approach.

A PBL pedagogy can be dated back to John Dewy (1897) when he wrote "My Pedagogical Creed". In Dewy's creed, he established his principle of "learning by doing" as well as the fact that "the teacher is not in the school to impose certain ideas or to form certain habits in the child, but is there as a member of the community to select the influences which shall affect the child and to assist him/her/them." These principles evolved into the pedagogical concept known as PBL.

In the 21st century PBL has been described by Markham (2011) as follows; "PBL integrates knowing and doing. Students learn knowledge and elements of the core curriculum, but also apply what they know to solve authentic problems and produce results that matter. PBL students take advantage of digital tools to produce high quality, collaborative products. PBL refocuses education on the student, not the curriculum—a shift mandated by the global world, which rewards intangible assets such as drive, passion, creativity, empathy, and resiliency. These cannot be taught out of a textbook, but must be activated through experience."

Worthy, et al. (2000) further elaborates that PBL is an instructional pedagogical method centered on the learner. In place of using structured lesson plans that direct a learner down a specific path, PBL allows a detailed investigation of a topic, which promotes deeper cognition (Worthy, 2000). The theories behind PBL prove that learners typically have more autonomy over what they learn, and the method helps maintain interest and motivates learners to take more responsibility for their learning. With more autonomy, learners often shape their project learning environment to fit their own interests and abilities (Arantes (2018), Baran (2018), Choden (2020), Chu (2011), Darmuki (2023), Gunawan (2020), Indrawan (2019), Maksum (2022), Mursid (2022), Nainggolan (2020), Putra (2021, Santyassa (2020), Saputra (2019), Supena (2021), Zulfa (2022), and Sudjimat (2021)). Therefore, PBL enables the expression of diversity in learners, such as interests, abilities and learning styles.

Recently, PBL has found its way into construction and civil engineering disciplines. PBL was used at Plymouth University, U.K. in a construction building course. The class was a second-year undergraduate construction course, in which students involved learned through a real world "design and build" project for a waterfront development. The researchers adopted a PBL research methodology that focused on learning construction and engineering principles, which was facilitated through the project. The

authors show that the use of real-world examples was beneficial to the students and towards the course outcomes. The research primarily focused on the learning technologies used (software, clickers, etc.) therefore the assessment of the PBL intervention mostly included interviews of students, faculty, and industry practitioners, meetings with the learning technologist, and questionnaire surveys completed by students. Thus, the publication only reported qualitative information (i.e., an indirect assessment). However, the authors report positive feedback (i.e., student preference towards the teaching methodology) from their assessment techniques, no direct quantitative data assessment was performed, which limits the assessment to only student opinions. Additionally, no statistical analysis was included (Pan & Garmston, 2012) or comparisons to a control semester.

A PBL methodology was also recently used in a construction course which predominantly focused on leadership in energy and environmental design (LEED) at Youngstown State University. This course is part of an undergraduate program in construction engineering technology, and the students were required to learn the contents of the US Green Building Council LEED Reference Guide for Green Building Design and Construction. The content was taught through lectures, case studies, and a final project (Korenic, 2014). The final project was introduced to the students at the beginning of the semester, submitted, and presented at the end of the semester. The results of this study demonstrated strong student preference for the PBL intervention. Although a project was used to help promote comprehension of the specific topics, their formatting does not seem to use the project to drive the learning. Additionally, the methodology adopted did not directly measure the effectiveness of the PBL approach as it directly relates to student performance, only as it relates to students' perceptions of performance. Instead, an indirect methodology consisting of mapping relevant Accreditation Board for Engineering and Technology (ABET) learning outcomes into case studies and exams were adopted. These outcomes include mastery of knowledge, ability to apply creativity in design, communicate effectively and engage in life-long learning. These outcomes were then assessed using a questionnaire administered at the end of the semester. Therefore, there was no direct assessment of the PBL intervention. Additionally, there was no statistical treatment of data, and no comparisons were made to a control semester in order to demonstrate the impact of the PBL methodology.

At the University of Colorado, PBL was also used in a construction management course, which consider the construction of a community building project. Both undergraduate and graduate students were involved in the study. The effort adopted the "Knowledge Landscape" approach to the solution of project scenarios with a diverse range of external and internal project variables that required the application of both technical and non-technical skills (Chinowsky, Brown, Szajnman, & Realph, 2006). A knowledge landscape is a metaphor describing the ever-changing potential knowledge peaks and valleys that surround each one of us. The authors did not describe whether the project was used throughout the course or merely submitted and presented at the end of the course. The assessment methods primarily consisted of follow up interviews with students who participated in the course and their employers. Based on the interviews, the study determined that as a consequence of the PBL experience students were more marketable, had an increased understanding of the subject matter and a deeper

understanding of their construction practices. Although the results are favorable the claims were not validated with any direct assessments. Additionally, there were no comparisons made to a class that taught the same topics without the use of the PBL intervention for comparison. Additionally, due to the nature of the subjective result, there was no statistical analysis.

At Indiana University and Purdue University, a PBL pedagogy was used in courses entitled "Mechanical Systems in Buildings", "Construction Field Operations", and "Foundation Systems". These courses were part of an undergraduate construction technology program in which student teams worked on projects designed by the instructor. The article describes early on that the research methodology included both indirect and direct assessment methods to assess the pedagogical approach. However, they do not present any qualitative direct assessment. Indirect assessment was conducted using a questionnaire and informal input from students. The indirect questionnaires showed that students preferred the PBL learning system. These studies show positive feedback from the PBL model (Sener, 1998).

PBL has also been utilized in graduate courses. At Loughborough University, UK, PBL was implemented in a design module for graduate civil and building engineering students. Students were required to simulate the multidisciplinary nature of the design of buildings by playing various roles within the areas of architecture, construction, structures, and building services. In this study, student teams worked on a fictional project assumed to be developed by the authors of the study (Demian, 2005). The assessment methodology consisted of evaluating the following elements of coursework: briefing report, design project, and reflective commentary. The results showed students preferred the PBL methodology after reporting and reflecting on the course. The study did not describe how the project was administered, so it is difficult to ascertain how the PBL was used to impart the appropriate knowledge. Additionally, there was no control group or statistical analysis to confirm if there was any recency bias.

California Polytechnic University, also enabled learning and comprehension through a PBL methodology (Barlow, 2011). The PBL methodology was adopted in a job site construction management course to teach the topics of the course. The students were seniors in this study. The project revolved around a real-world project that was currently under construction in the local area. The specific subjects of the course were as follows: estimating, controls, contracts, and temporary structures. The project utilized the actual drawing, documentation, discussions with key project personnel, and site visits to the real job site. Although it was not clearly stated in the study, it seems that the PBL methodology in this study was used to drive the learning of the course topics, plus the students benefited from a real-world problem that was actively under construction. As with the previously discussed studies, the assessment of the PBL was only completed with indirect questionnaires, and therefore, also did not contain any statistical analysis. The questionnaires, as with the previous studies discussed, seemed to favor the intervention of the PBL method used.

At California State University, Fresno a PBL pedagogy was used to teach Building Information Modeling (BIM) topics in a construction science management program.

The project dealt with sustainable living in tiny solar houses. This project reflects the recent evolution of BIM education from software training to problem-solving in the context of project execution and management (Wu & Hyatt, 2016). This study, and class, contained sophomore, junior, and senior level undergraduate students. It was mentioned that although the class is in a construction science management program, business, marketing, and mass communication students from other programs often enroll in the course as an elective, therefore, the project needed to be interdisciplinary and collaborative. The PBL intervention was assessed with student questionnaires in two parts, one focusing on the knowledge and ability to create and develop a BIM model, and the other on the students' perceived perceptions of learning BIM software through the PBL project. The results showed a perceived student knowledge and ability to create BIM models, however, without actual direct assessment and/or comparison it is difficult to ascertain if the PBL methodology actually improved students' knowledge and ability to create BIM models.

As can be seen through this literature survey, PBL has been utilized across many higher education institutions in the sciences, specifically in the construction education arena. Although, this literature survey provides a brief example of various PBL interventions, it can be surmised that although the PBL seem to be helping facilitate the knowledge, and that the students prefer the use of PBL, there still exist implementation problems. The first and primary issue is concerning the execution of the PBL pedagogy, such that it is the primary tool driving the transmission of knowledge from the instructor to the students. As previously stated PBL is not merely using a project in the course. PBL is a pedagogical technique in which the project is the course, and not ancillary to all other aspects. Additional implementation issues in the examined literature are concerning the lack of direct (objective) assessment with comparative (to a control version of the course) and statistical analysis. Executing these aspects into the study is often difficult and typically requires a complete or partial overhaul of the class, which is likely why PBL pedagogy is not seen more across all higher education courses.

Torres et al. (2017) has established a set of criteria that can be used to help implement a PBL pedagogy and are as follows:

- Identify a project that involves many (if not all) of the course outcomes. Ideally a local real-world project.
- Assign and discuss the project on the first day of the course. Administer beginning-of-semester questionnaire.
- Divide the project up into sections (referred to as "milestone" in the study). Approximately 5-10 depending on the length and topics of the course.
- Make the milestones homework assignments due throughout the semester immediately following a lecture/discussion (with examples).
- Grade and provide feedback on the milestone homework assignments. The students then get the opportunity to learn and improve from their mistakes.

- Incorporate quizzes, embedded exam questions, and other direct assessment techniques throughout the semester that are related to the project.
- Near the end of the semester, the final, overall, project is due (if possible) with a presentation. The overall project will contain all milestones, which the students had the opportunity to improve.
- Administer end-of-semester questionnaire(s).

As seen in the above suggestions, the project is driving the learning of virtually every aspect of the class, the project is a real-world project, and there is both direct and indirect assessment. Ideally, the course did not have a PBL methodology prior to the intervention which could be used as a control for comparison and analysis.

Many other current researchers (Arantes (2018), Baran (2018), Choden (2020), Chu (2011), Darmuki (2023), Gunawan (2020), Indrawan (2019), Maksum (2022), Mursid (2022), Nainggolan (2020), Putra (2021, Santyassa (2020), Saputra (2019), Supena (2021), Zulfa (2022), and Sudjimat (2021), etc.) have further established the importance and effectiveness of PBL and collaborative learning in a variety of STEM-based disciplines, including its adaptability during the COVID-19 pandemic (Maksum (2022)). Each of these researchers demonstrate the importance of assessment and validation of their techniques through a both direct and indirect assessment. Additionally, as pointed out by Arantes (2018), Darmuki (2022), Indrawan (2019) the project used in the course needs to be at the center of the instruction, such that it is directly involved in virtually every facet of the course, allowing students to learn, collaboratively, through a project.

Based off of the literature survey and the importance of the sustainability topic, a PBL methodology was developed that uses modern findings, implementation, and is at the forefront of the course delivery by incorporating milestones as suggested by multiple authors (Arantes (2018), Torres et al. (2017), Darmuki (2023)). The milestone-based PBL methodology was developed and implemented in this study to determine its effectiveness in teaching sustainability topics as it relates to the cement and concrete Industry..

Research Objectives and Hypotheses

There are two objectives of the current research study:

1) To develop and implement a milestone-based PBL in a concrete technology undergraduate course.

2) To enhance student comprehension of sustainability in general and specifically as it relates to the cement and concrete industry.

The objectives of this study will be explored by confirming/denying the following hypotheses.

1) PBL is a preferred method of learning over conventional instructor-led instruction.

2) The students perceived a deeper understanding of sustainability from PBL pedagogy versus a conventional instructor-led instruction.

3) The students' grades were higher from the PBL intervention compared to a conventional instructor-led instruction.

METHOD

The specific methodology used in this study was based on the work of Torres et al. (2017) in which they established criteria for an effective PBL intervention. Other more recent authors also describe this developmental process (Arantes (2018), Baran (2018), Darmuki (2023), and Mursid (2022)). Previously described in the literature review section but re-iterated below for consistency. The following methodology was used in developing the PBL intervention used in this study and are presented in chronological order of development:

- A real-world project was identified that involves all of the course outcomes.
- The project was assigned and discussed on the first day of the course. The beginning-of-semester pre-questionnaire was administered.
- The project was divided up into sections, which were referred to as "milestone" in the study.
- The milestones were made into homework assignments due throughout the semester immediately following a lecture/discussion (with examples).
- The milestones were graded and feedback was provided the individual milestone homework assignments. The students then had the opportunity to learn and improve from their mistakes.
- Quizzes were incorporated throughout the course alongside embedded exam questions regarding the project, into the exams.
- The final, overall, project was due at the end of the semester with a presentation, which contained all of the milestones.
- The end-of-semester questionnaire was administered following all presentations.

The project used for all interventions (including the control semester) was a group project of 3 – 4 students depending on the semester. The groups were created at random by the instructor before the first day of class and the students were informed of their groupmates during the initial discussion of the project. The project itself focuses on sustainability in general as well as specifics to the cement and concrete industry. The students were required to submit a final written report (no page length minimum, but mandatory objectives) and an accompanying verbal power point presentation on the last day of the class. There were five mandatory project objectives that the students needed to describe and discuss in their report and presentation, which are as follows.

1. Define, in your own words, sustainability in general.

2. What does sustainability mean to you personally and what are some ways you practice sustainability in your own live(s)?

3. How does the cement and concrete industry impact global warming concerns?

4. What are some ways the cement and concrete industry are currently being sustainable?

5. Find and discuss a real-world example of your chosen sustainable topic and describe it in great detail. This could be an existing, or upcoming, construction project, a published magazine, or journal article, or sourced from a combination of places.

As seen in the above project objectives, items 4-5 are the main focal point of the project beyond a basic and introductory discussion of sustainability and sustainability methods in general. Item 5 was open to the students to find a project or publication of their choosing that they felt comfortable learning about, discussing, and presenting. Although the students were allowed to choose their own topic as opposed to assigning one, they are still real-world projects that have been completed in the past, which is very similar to the literature. Also allowing the students to choose, allowed the students the freedom of selecting something they felt was important to their specific career ambitions and desires. This could also create more interest in the topic as the students feel as they have more control over the project, however, this aspect was not investigated or assessed in this study. Although the specific topics varied each semester, due to the students' choice, the five above objectives were turned into individual milestones to be submitted throughout the semester shortly after the topics were discussed in the course. The specific lectures that were discussed throughout the semester, in order, are titled as follows.

- Introduction to Global Warming and Sustainability
- Sustainability Methods, Considerations, and Procedures for Everyday Life
- Sustainability in the Cement and Concrete Industry Part 1 – Impacts of the Industry
- Sustainability in the Cement and Concrete Industry Part 2 – Current and Possible Future Practices
- Sustainability in the Cement and Concrete Industry Part 3 – Case Studies, Projects, and Other Examples

As seen in the above lecture list there were five 90-minute lectures that directly relate with the five project milestones, with active group discussions. Immediately after each lecture the milestone deliverable was assigned, and due within one week. The milestones were graded by the graders in which substantial feedback was offered for learning and improvement purposes.

To assess the effectiveness of the PBL intervention a pre- and post-questionnaire was administered to all students to assess their perceived knowledge of sustainability in general and how it relates specifically to the cement and concrete industry. This was completed each semester, for a total of six times. The pre-questionnaire was administered on the first day of class and the post-questionnaire was administered on

the last day of class, following the student presentations. All questionnaires submitted used a 5-point Likert scale in which 5 was highest. In addition to the indirect assessment, both the control version of the course and the six PBL treatment versions contained four quizzes, five milestone homework assignments (as previously discussed), 20 embedded exam questions, the final project grade, and overall course grade (only pertaining to the sustainability project) as direct student assessment. All but the final project grades were individual student assessment, whereas the final project grade was a collaborative grade of 3 – 4 students. The pre- and post-questionnaire questions for the indirect assessment can be seen in Table 1.

Table 1
Pre and post questionnaire questions

Learning
1. I prefer to figure things out on my own.
2. I prefer to learn from a traditional professor/instructor.
3. I prefer to learn from my peers.
Teamwork
4. I prefer to be a leader and give directions.
5. I expect to be able to work effectively in a team environment.
6. I prefer to be a valuable team member as opposed to a leader.
Sustainability
7. I can define sustainability.
8. I can provide examples of sustainable measures one can do every day in their own life.
9. I know how the cement and concrete industry impacts global warming.
10. I know how the cement and concrete industry are making efforts to lower their carbon emissions.
11. I can list examples of how the cement and concrete industry are being sustainable.
12. This topic is important towards the advancement of my career.
Additional Questions (only included on the post-questionnaire)
13. Please rate your experiences learning through the project.
14. Would you have rather learned from conventional instructor format?
15. Please rate the quality of your group members.
16. Please provide any additional comments on your experiences that you would like to share.

As seen in Table 1, the pre- and post-questionnaires are categorized into three sections; Learning, Teamwork, and Sustainability. This was done with the intention of establishing a baseline of how the individual student prefers to learn independently and within a team. Then there were specific baseline questions regarding the sustainability topic. Also noted are the additional questions only on the post-questionnaire probing the students' preference towards the PBL intervention as well as their group members. Additionally, there was space provided for the students to write any comments regarding the PBL methodology.

In addition to the pre- and post-questionnaires additional direct assessments were completed in this study. The direct assessment methods were administered across five different methods which were quiz, homework, exam, project, and overall grades which were all compared to a control version of the course that had the same assignments/questions. Each were administered per semester for a total of six times,

then the same assignments were compared to each other and the control semester. As previously stated, bias was removed in the grading process by having graders, with a provided grading rubric, grade all of the items used for assessment.

Regarding the quiz assessment, there were four total per individual class, that were administered at the same time regarding lecture timing. Each quiz contained only one free answer question, in which the students had 10 minutes to answer at the beginning of the class. Regarding the homework assignments, there were five total that pertained to the PBL methodology and were the five milestones as previously described. Regarding the exams, two different exams contained 10 embedded exam questions each. The questions were either True/False or Multiple Choice. Regarding the project grades, this concerns the average of the presentation and final project report for each offering of the course. Recall that the project grades are a culmination of the five milestones along with other introductory, table of contents, and conclusions sections to form a cohesive written report. The last direct assessment technique was the overall final course grades, which was an average of all assignments related to the sustainability topic.

FINDINGS

In studies related to humans, the demographics of the participants is an important factor as these factors can have an influence on the intervention outcome (Dewey, 2000. Therefore, the demographic breakdown for each implementation can be seen in Table 2.

Table 2
Demographics

	Control	Intervention					
Semester	Fall 2014	Fall 2015	Fall 2016	Fall 2017	Fall 2018	Fall 2019	Fall 2020
Number of Students in Course	15	13	16	10	12	14	12
Number of Males in Course	15	12	14	10	12	14	12
Number of Females in Course	0	1	2	0	0	0	0
Average Age of Students	21	22	22	21	22	22	22

As seen in Table 2, the PBL intervention took place a total of six times with a total of 77 students in which 74 were male and 3 were female. The average age of all students was approximately 22 years old. The six intervention semesters were compared to a control semester (Fall 2014) in which the milestone-based PBL methodology was not used, and an end-of-semester project was used. The control semester had similar demographics to the six treatment semesters. All students participating in the study had the same minimum requirements and/or pre-requisites in order to enroll in the junior level undergraduate course. The instructor/author of this study was also a participant. The instructor taught all six offerings of the course discussed in this study. The instructor is male, and was 28 years old in Fall 2014 and is qualified to teach the course. Additional participants were two different course graders used to remove bias from the instructor graded the assignments. Two different course graders were used as they were

both graduate students, in which one graduated during the duration of this study. However, all items being graded contained an assignment specific grading rubric for consistency purposes. Both graders were males; one was 25 beginning in Fall 2014, and the other was 24 beginning in Fall 2018.

As observed in this study, Objective 1 has been met. A milestone-based PBL has been developed and implemented in a concrete technology undergraduate course. Additionally, this implementation has been implemented six times not included the control semester. Objective 2, regarding improving student comprehension of sustainability (in general and specifically as it relates to the cement and concrete industry) is discussed in more detail below. Specifically, each assessment method is discussed below to further elucidate how Objective 2 was met. The discussion below also describes how the assessment techniques align with the hypotheses outlined in this study.

The data gathered from the pre and post questionnaires submitted to the PBL intervention semesters indicate a significant increase in preference of the PBL intervention. This was observed across all questions, in all semesters of this investigation. This is an excellent result, as this ultimately demonstrates that milestone-based PBL is effective as perceived by the student participants. Table 3 shows the average results of the peer-teaching group pre and post questionnaire. Recall that all questionnaires used a 5-point Likert scale in which 5 was highest and the results shown in Table 3 are an average of all students who completed the questionnaire per semester for either the pre- or post-questionnaire.

Table 3
PBL intervention semester pre and post questionnaire results.

Question Number	Fall 2015		Fall 2016		Fall 2017		Fall 2018		Fall 2019		Fall 2020	
	Pre Results	Post Results	Pre Results	Post Results	Pre Results	Post Results	Pre Results	Post Results	Pre Results	Post Results	Pre Results	Post Results
1	2.0	3.7	1.8	3.9	2.1	3.4	1.8	4.0	1.8	4.0	1.2	3.2
2	2.1	2.3	2.0	2.5	2.1	2.0	2.2	2.4	2.3	2.2	2.1	2.2
3	2.2	3.2	2.1	3.4	2.2	3.1	1.9	3.2	2.2	2.9	2.4	3.3
4	2.3	3.1	2.5	3.8	2.2	3.1	1.4	3.4	2.4	3.1	2.9	3.2
5	2.0	4.5	2.2	4.9	2.3	5.0	2.1	3.2	1.8	4.8	2	4.6
6	3.1	4.2	3.0	4.3	2.9	4.1	2.2	4.9	1.9	4.4	1.5	4.5
7	1.6	5.0	1.4	5.0	2.1	4.8	2.4	4.7	2.1	4.9	1.5	4.6
8	1.2	5.0	2.1	4.8	1.9	4.9	2.2	4.7	1.8	4.9	1.7	5
9	2.1	5.0	2.4	5.0	2.4	4.8	1.9	5.0	2.2	5.0	2.1	5
10	1.1	4.9	2.2	5.0	1.9	5.0	1.7	5.0	2.0	5.0	2.2	4.8
11	2.2	5.0	1.8	4.8	2.8	4.1	1.7	4.9	2.2	5.0	2.3	4.8
12	1.2	5.0	1.9	5.0	1.0	5.0	1.2	5.0	1.8	5.0	1.9	5
13	n/a	5.0	n/a	5.0	n/a	5.0	n/a	5.0	n/a	5.0	n/a	5.0
14	n/a	1.3	n/a	1	n/a	1.4	n/a	1.8	n/a	1.2	n/a	1.8
15	n/a	4.7	n/a	5	n/a	4.8	n/a	5	n/a	4.9	n/a	5

An in-depth analysis comparing the average pre- and post-questionnaire results of all semesters reveals the following: Question 1, which relates to the students' preference to figure things out on their own showed an average improvement of 1.9 for all treatment semesters. Therefore, after the PBL treatment students seemed to show a slight increase towards their preference of figuring things out on their own. Question 2, which relates to students' preference from learning from a conventional instruction (i.e., non-PBL based). The average pre-questionnaire result was 2.1 and the average post-questionnaire result was 2.2 showing only a 0.1 increase after the PBL intervention. This result is expected as the PBL intervention is not a conventional lecture pedagogical technique, therefore, a low score in this question is in favor of the PBL methodology. Question 3, which asks the students' if they prefer to learn from their peers showed an average increase of only 1.0. Although there was an increase, this result shows that the primary learning mechanism was the project itself, and not the students' peers within or outside of the group. Therefore, a low score on this question is in favor of the PBL intervention. The lower improvements with Questions 1-3 are likely due to an uncertainty in personal preference or an uncertainty in regard to the specific topic learned. Boud (2001) describes that the effectiveness of traditional instructor-led teaching versus PBL could depend upon the specific topic learned. Therefore, when the students were asked to answer the pre-questionnaire, they may have been uncertain of their preference at that

stage in the process. Having been taught the specific subjects through PBL, the students' perception changed slightly as they have more information.

Questions 4 – 6 probed the students' preferences towards Teamwork. Question 4, specifically, ask the students about being a team leader. As with Question 3, this question also only had an improvement of 1.0 from the pre to the post-questionnaire, indicating that the students did not have a strong preference towards being a leader. Recall that the project did not require nor assign a group leader within the group. If the students themselves chose to have a leader, that was an interpersonal decision, and the instructor was not included nor informed of this decision. The result indicates that there were likely no formal leaders assigned within the groups. Question 5 probes the students' preference towards working within a team. This question went from a 2.1 to a 4.5 indicating that before the PBL intervention, the students had some inclination towards working within a group, however, afterwards their perception increased significantly. These results provide insight into the students' preference of participating in a project as a whole and how their own personal feelings align with the project. The results of the questionnaire analysis indicate that the students in all interventions had a preference towards participating in a group project, such as the one outlined in this study.

Question 6 specifically asked the students if they would rather be a valuable group member as opposed to a team leader. Similar to Question 5, the results showed an average increase of 2.0 (2.4 to 4.4), further indicating the students' preference to working within a group, but specifically not being a leader. Overall, the results from Questions 1 – 6 supports Hypothesis 1 of this study regarding PBL being a preferred method of learning over conventional instructor-led instruction. This is as expected as there was no formal leader(s) within the groups as previously described.

Questions 7 – 12 specifically asked the students about their perceptions towards sustainability. Question 7 asks about the definition of sustainability. This result shows meaningful improvement from 1.9 to 4.8, on average. This result indicates that the PBL methodology is transmitting knowledge regarding the definition of sustainability. Question 8 asks the students if they can provide specific sustainability examples. As with Question 8 there was noteworthy improvement in the average results of this question from 1.8 to 4.9. Similarly, this result indicates that the PBL intervention is helping improve student comprehension of the sustainability topic. Question 9 probes the students' understanding of specific sustainability examples within the cement and concrete industry. This question also had high improvements from 2.2 to 5.0 and was the first question that earned a perfect 5.0 average from all intervention semesters. This is a noteworthy result as it is not only related to sustainability but also to the students' major within cement and concrete technology. Question 10 similarly asks the students about sustainability within the cement and concrete industry, but relates to specific measures the industry is taking to reduce their carbon footprint. The results of Questions 10 went from 1.9 to 5.0, further solidifying the impact of the PBL methodology on the students' perception of these topics. Question 11 gets more specific regarding sustainability within the cement and concrete industry and like the previous two questions the results are favorable. The average results of Questions 8 went from 2.2 for

the pre-questionnaire to 4.8 for the post-questionnaire. These results, as with the previous questions, provide further indirect evidence that the PBL methodology is positively impacting student perceptions. The last question specifically related to the sustainability topic. Question 12 asked the students if they felt that this topic was important to their career. Initially from the pre-questionnaire the average student answer was 1.5. After the PBL intervention, the post-questionnaire results for Question 12 earned a perfect 5.0. This result, and improvement, demonstrates that before the PBL intervention, students did not think sustainability, especially within the cement and concrete industry, was an important topic for them to learn. After the completion of the PBL methodology, the students have perceived improvements and appreciation of the sustainability topic. Overall, the results from questions 7 – 12 answer Hypothesis 2 of this research study regarding students having a deeper perceived understanding of sustainability within the cement and concrete industry.

To ascertain the validity and reliability of the pre- and post-questionnaire analysis a Confirmatory Factor Analysis (CFA) was completed on the pre and post questionnaire data. Within the CFA the latent variable is related to hypothesis 2 of this study, such that the hypothesis is that the students perceived a deeper understanding of sustainability from PBL pedagogy versus a conventional instructor-led instruction. The questionnaire does not serve as a direct assessment, and is merely opinion based, therefore the CFA can help ascertain the reliability of the students' opinions. The convergent validity was ascertained using a statistical software package and excel tools. For the questionnaires the composite reliability (CR) was 0.843, 0.908, and 0.919 for x, y, and z respectively, which are all greater than 0.7. The average variance extracted (AVE) was 0.718, 0.612, and 0.804 for x, y, and z, which is greater than 0.5, and the CR was greater than AVE, which confirms the validity of the questionnaires.

The results demonstrated that the questionnaires had a good fit to the data. The alpha coefficients also demonstrated acceptable levels. Additionally, a Mann-Whitney U-test was used to asses if the results between the pre- and post-questionnaires were statistically significant. A Mann-Whitney U-test was used as it allows a comparison between two groups of data (in the case of this study, the pre- and post-questionnaire data) that are not normally distributed and typically small (less than 20). The confidence level was set at 95%, $\alpha = 0.05$. The results of the Mann-Whitney U-test showed that the u-statistic (18) was less than the u-critical term (22), such that the null hypothesis is rejected, and indicates that the results of Questions 1 – 4 are not statistically significant and the results of Questions 5 -12 are statistically significant. The Mann-Whitney U-test was also performed using statistical software and excel tools. Recall that Questions 1 – 4 all had marginal improvement and probed students learning and teamwork preferences. Not being statistically significant for these specific questions is a positive outcome for the impact of the PBL methodology, as those questions relate to working individually and not in teams, which is a significant component in the PBL methodology. This outcome further supports Hypothesis 1 and 2.

Also included on the post-questionnaire were four additional questions. Question 13 simply asked the students' preference of learning through the PBL project on a 1 – 5 scale, 5 being the highest. The result of Question 13 was a perfect 5.0 from all

intervention semesters, indicating an overwhelming preference for the PBL methodology. Question 14 asked the opposite of Question 13, in which it asks if the students would have preferred a conventional lecture. Question 14 had an overall average result of 1.4, which indicates students preferred the PBL approach. Question 15 askes the students to rate the quality of their teammates on a scale of 1 – 5 as well. The result of Question 15 was a 4.9 on average, which indicates that there were no issues between the students' teammates. The results from the additional post-questionnaire questions are all positive and provide further insight into answering Hypothesis 1 – 2, while meeting both objectives of this study.

The post-questionnaire included one additional question that asked the students to provide any additional thought or comments related to the PBL methodology. As previously stated, there was space on the questionnaire for students to write any thoughts or opinions on the matter. A representative sampling of the students' thoughts from all semesters is shown below.

"I really enjoyed the project and the way it was formatted. I felt like a really learned better."

"The project was so unique and a lot more effective than a typical project."

"I like how we worked on the project throughout the year instead of that one late night cram session trying to remember things we were taught 5 months ago!"

"It was cool how we got multiple attempts and at parts of the project. It really helped us learn and see what are mistakes were."

"The project was a lot of fun and I really learned a lot about sustainability."

"I never knew that the world of sustainability was so vast and how I can directly impact it."

It can be seen in the above comments from the student participants, that they overall enjoyed their experiences. Although, this is the students' opinions, it still provides credible insight that supports the PBL teaching methodology developed in this study as well as supporting Hypothesis 1.

The results and analysis discussed above demonstrate that the students overall favor a PBL over a traditional instructor driven lecture. The positive increase in student perceptions for Questions 5 – 12 could be due to other factors outside of the PBL intervention such as recency bias. Looking into the questions further along with the previously discussed statistical analysis suggests that this is not the case. For example, Questions 4 – 6 probe the students' perceptions of leadership. In general, these questions ask if the students prefer being a leader or being led. These results, as discussed previously, fit into the aspect of students participating in a group project that is active and engaging such as the one outlined in this study. Further, Questions 7 – 12, assess the students' perceptions of having learned the specific sustainability topics. In the case of these questions, recall that the students are not asked to actually give the answer, but are asked how confident they are in having gained this knowledge. The issue of a recency bias for these questions actually works in favor of these questions as

the milestone-based PBL implementation used in this study is very much intertwined with the course and the information is discussed with increased frequency versus the control semester. Therefore, the fact that the results of these questions improved suggests that the PBL intervention is impacting student comprehension of the topics. Regarding Questions 13 – 16, recall that these questions were only included in the post-questionnaire and purely asked about the students' preference towards the PBL methodology. It is important to note that all students are full-time students in their undergraduate degree programs, therefore, the other classes they are taking are likely not implementing a PBL pedagogy such as the one outlined in this study. Although it is difficult and not feasible to conduct an assessment between courses, the students do have an immediate comparison of a conventional course. This is certainly a limitation of the study, that recency bias of the PBL can be impacting the students' perceptions, however, contrasting the previous questionnaire results with the students' grades discussed below suggests that the PBL intervention is impacting students' performance in a positive manner.

As previously discussed, it is of particular importance to not only assess students' perceptions via questionnaires, but also to assess the direct impact of the PBL intervention through students' performance. This is important as it excludes students' opinions of their comprehensions gains and actually quantifies their gains. It is also of particular importance to directly assess multiple facets of student performance, not just one, in order to provide further credibility as opposed to only one data point. Therefore, in this study, in addition to the pre- and post-questionnaires the students' performance was directly assessed through quiz, homework, embedded exam, project, and overall course grades. The average results, per semester, for all of the direct assessment techniques used in this study can be seen in Figure 1.

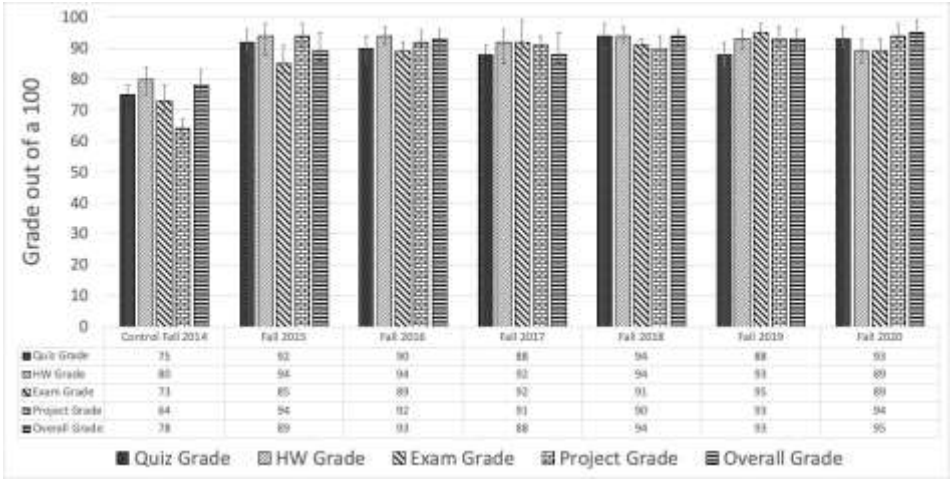

Figure 1
Average results, per semester, of all direct assessment techniques

As seen in Figure 1, there is improvement in every direct assessment technique from the control semester (Fall 2014) to that of every intervention semester (Fall 2015 – Fall 2020). Investigating the data further reveals the following. Assessing the quiz grades, shows an improvement from 75% in the control semester to an average of 90.8% from the treatment semesters. This constitutes a letter grade improvement from a "C" to an "A" on average. This result is expected as the PBL methodology put great emphasis on the project topic and the students are spending more time thinking about the specific sustainability topic. The homework assignment assessment technique shows similar results with an average grade of 80% for the control semester and an improvement to 92.7%. This constitutes a letter grade improvement from a "B" to an "A". This demonstrates that the PBL methodology is directly impacted students' comprehension of the sustainability topic. The embedded exam grades further demonstrated the impact of the PBL methodology through improved student performance. The specific embedded exam question grades went from 74% to an average of 90%, which is a letter grade of a "C" to an "A". This is a significant improvement as this assessment technique individually assesses each student, in an exam situation, in which students have to learn, study, comprehend, and recall the required information. The project grade shows similar improvement and the largest of the direct assessment techniques. The control semester for the project grade was 64% and improved to an average of 92.3%, which constitutes a 28.3 percentage point increase. This is a significant result for the PBL methodology as this assessment technique is specific to the project itself. It is important to recall that the project is a culmination of the previous milestones that were previously graded homework assignments. Therefore, the students get feedback, and have the ability to respond to the feedback and it is possible that the increase can be contributed to that process. However, it is also important to note that these milestones homework assignments do not have a specific answer as does the embedded exam grades and quizzes do, therefore, the students cannot simply memorize an answer and select the correct one on a second attempt. It is very likely that if the students heed the instructor's remarks that they will improve, but since it is an open-ended question, it is not a guarantee. Due to this concern, other direct assessment techniques were included such as the previously discussed quiz grades, and homework grades.

The last direct assessment technique was the overall student grades, which averages all assignments. As with all of the direct assessment techniques, this one also showed improvements from 78% in the control semester to 92% for the treatment semesters. This result shows direct impact of the PBL methodology on student comprehension and retention of the sustainability topic, as the students' overall grades improved from a "C" to an "A". The collective results from the five direct assessment technique demonstrates that the PBL methodology is effective at teaching PBL and superior to a conventional teaching methodology as was used in the control semester. This result supports Hypothesis 3. To determine if these values are statistically significant a Mann-Whitney U-test was performed. The confidence level was set at 95% ($\alpha = 0.05$). The results of the Mann-Whitney U-test indicated that all of the qualitative grade improvement results are statistically significant when compared to the control intervention. The results of the Mann-Whitney U-test showed that the u-statistic (15) was less than the u-critical term (20). The validity and reliability were also confirmed via a CFA statistical assessment.

Within the CFA the latent variable is related to hypothesis 3 of this study, in that the hypothesis is that the students' grades were higher from the PBL intervention compared to a conventional instructor-led instruction. The convergent validity was ascertained using a statistical software package and excel tools. For the grade assessment the composite reliability (CR) was 0.811, 0.918, and 0.817 for x, y, and z respectively, which are all greater than 0.7. The average variance extracted (AVE) was 0.722, 0.623, and 0.818 for x, y, and z, which is greater than 0.5, and the CR was greater than AVE, which confirms the validity of the questionnaires.

DISCUSSION AND LIMITATIONS

The results of this study demonstrate the efficacy of a PBL pedagogy, especially as it pertains to a concrete technology course. As Talley et al. (2016) and Torres et al. (2022) discuss, a project is a beneficial way of learning and comprehending a topic as the students learn through doing, as originally stated by John Dewey. However, if the project is not in the forefront of learning and simply forgotten until the last day of class, then the project is just another task that is often completed on the order of a day. The students still learn through doing, but the short duration, and only one setting is often not enough for the students to fully learn, understand, and retain any of the information. Therefore, the project needs to drive the learning and all (or most) aspects of the course need to build on the understanding of the project. As demonstrated and discussed in the results section, the above was implemented and utilized in this study. For instance, this study made the project the forefront of the learning and "drove" student learning through the PBL milestone intervention. There still was a final project due at the end of the semester, but the students were building toward the final project all semester long, and ideally, only had to adjust their previous milestones based on previous feedback. There was conclusive evidence supporting both student preference to the milestone based PBL used in this study as well as quantitative evidence supporting improvements in student performance (via quiz, homework, exam, project, and overall grades).

Overall, this study aimed to develop a milestone-based PBL teaching methodology to help enhance the understanding of sustainability as seen from the cement and concrete industry. Many variables existed such as the demographics of the participants, the timeframe for delivery (16-week course), the specific methodology itself and how it was delivered, and the assessment tools used (questionnaires and grade assessment). Three hypotheses were developed and investigated i) PBL is a preferred method of learning over conventional instructor-led instruction, ii) The students perceived a deeper understanding of sustainability from PBL pedagogy versus a conventional instructor-led instruction, and iii) The students' grades were higher from the PBL intervention compared to a conventional instructor-led instruction. The results show that the students overwhelming prefer the developed milestone-based PBL methodology. The results also show that the students perceived a deeper understanding of sustainability through the PBL pedagogy versus conventional instructor-led instruction. The results also show that the students' grades were higher from the PBL intervention as compared to the instructor-led instruction. Based off the results of this study it is recommended that other instructors/researchers utilize a milestone-based PBL methodology in their courses.

Some limitations exist in this study. The first being the course, instructor, and university itself. To fully solidify the effectiveness of this method, additional iterations could be completed in a similar technology course by another instructor at a different institution. The assessment techniques were compared to the instructor-led instruction, which was consistently the same instructor. Although, this helps with consistency and reliability, one could wonder if a different instructor could have a different impact. For example, if the age gap between the students was closer or wider, or if any other demographic variable changed about the instructor. A different instructor, in general, would impart their knowledge differently, which could have an impact. Additionally, it would be a rational assumption that the instructor's mastery of the material and his abilities as an instructor improved over the six years he taught the course, and this may explain some of the improvement in student achievement. In this study, it can be seen that the grades from the instructor-led instruction were all passing grades, consistently above 73%, aside from the project average of 64%, which initiated the idea of introducing a PBL technique for this course. In general, these grades are passing, but perhaps a different instructor could produce higher grades, possibly higher than the PBL intervention semesters. It should be pointed out that across the six intervention semesters the direct assessment techniques overall averaged a 91.6%. This grade is already fairly high, so the margin for improvement is low, however if control version of the course improved, the difference between the control and the PBL intervention could become marginal, which could lead to a statistically insignificant result, resulting in little-to-no difference between the two instruction methods. However, if this were the case, the questionnaire analysis indicates a strong preference to the PBL methodology, which provides justification that this instruction is worth-while, especially with the consistently high average grades.

Additionally, this study focused primarily on sustainability and how it impacts the planet we live on, so there is some emotional preference and/or connection to the topic, which could have a minor impact on the desire or lack of to learn more about this topic. This variable could also be impacted by the demographics, location, and political nature of the students. This study did not ask the students about this information, however, based on the results this does not seem to be an issue. The course investigated was an undergraduate 16-week course, therefore the results could be impacted if it were a shorter/longer course or administered in a graduate course. Another limitation to this study would be an assessment of topic retention. This is somewhat assessed throughout the semester across the five different assessment techniques, however, how are the students retaining the information long-term. Therefore, it would be interesting to assess if the students retain and/or use the knowledge over a longer period, such as 1 – 5 years, or more. This was not assessed in this study due to time constraints and the fact that the program is typically completed in two years, and students, on average, graduate within a year of taking this course. Therefore, only a short-term retention could be assessed while they were still students at the university, which was not completed.

It is also worth noting that PBL with a resubmit for regrading can be resource intensive. It would be unusual in most universities to have graders for a class that averaged about 12 students per semester. The ability to give detailed feedback is conditioned on small class sizes or teaching assistants or both.

CONCLUSIONS

This study develops and implements a milestone-based PBL methodology in a concrete technology course to teach sustainability in general and how it relates to the cement and concrete industry. The methodology was administered a total of six different times to the same class and was compared to a control semester of the course that did not use the PBL methodology. The PBL methodology was assessed through pre- and post-questionnaires and five different direct assessment techniques. Based off of the findings from this study the following conclusions can be drawn.

Both objectives of this study have been met. A milestone-based PBL was developed and implemented in a concrete technology course. Secondly, student comprehension of sustainability, in general and specifically as it relates to the cement and concrete industry, was improved.

- The quality of the milestone-based PBL was supported through pre- and post-questionnaires including student feedback.
- PBL methodology was the preferred method of teaching from the perspective of the students. This conclusion supports Hypothesis 1.
- The students perceived a deeper understanding of sustainability from the PBL instruction. This conclusion supports Hypothesis 2.
- The students' overall grades improved from 74% to 92% on average, after the PBL intervention from all six iterations. This conclusion supports Hypothesis 3.

In addition to the conclusions drawn from this study, it is also important to discuss how this study contributes to the body of knowledge within the engineering field. In general, this study is an extension of previous work regarding PBL previously published by Arantes (2018), Boud et al. (2001), Choden (2020), Demian et al. (2005), Korenic et al. (2014), Torres et al. (2017), and Torres et al. (2022) regarding PBL. These previous authors implemented real-world projects through a PBL in a variety of classes and the work published in the current study implements the lessons learned and missing information from the previous studies. For example, the current study utilizes the effectiveness of the pre and post questionnaires, the milestone formatting, and most importantly the objective assessment through a variety of means.

An additional contribution to the body of knowledge is to the specific topic itself; sustainability in the cement and concrete industry. This topic is very applicable to the following disciplines; Civil Engineering (CE), Construction Science Management (CSM), and Concrete Industry Management (CIM). All of which are typically four-year undergraduate degree programs that have courses related to cement and concrete technology. The work outlined in this study has particular emphasis to the CIM program, in that it is a unique program only at five universities, that heavily focuses on concrete materials, applications, management, and is heavily supported by the industry. Therefore, ensuring the skills gained through the intervention of this study is very impactful to such a program.

The next step and evolution of this study is to, at minimum, continue to administer the PBL methodology in the same course. If possible, it would be ideal to expand this teaching strategy to other courses, especially other CE, CSM, and CIM courses within the same university. Then extend the study to similar programs outside of the author's university. Additionally, the milestone-based PBL methodology can be used in virtually any class irrespective of the topic being taught. All that needs to change is the specifics of the project, which can be administered in the same manner as outlined in this study. Beyond, the specifics of the methodology can be changed themselves in order to view the impacts of various aspects of the PBL. For example, the only assignment assessed could be embedded exam grades to determine the impact on solely the exams (i.e., one aspect). The methodology can be more defined towards that one aspect as well.

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