*International Journal of Instruction* *October 2022 ● Vol.15, No.4*
*e-ISSN: 1308-1470 ● www.e-iji.net* *p-ISSN: 1694-609X*
*pp. 473-496*

Article submission code: 20211001180725
Received: 01/10/2021 Revision: 05/05/2022
Accepted: 26/05/2022 OnlineFirst: 30/07/2022

# Assessing the Effectiveness of Problem-Based Learning Across Two Concrete Construction Courses

**Anthony Torres**
Dr., Texas State University, USA, *ast36@txstate.edu*

**Jiong Hu**
Dr., University of Nebraska-Lincoln, USA, *jhu5@unl.edu*

**Vedaraman Sriraman**
Dr., Texas State University, USA, vs04@txstate.edu

**Araceli Martínez-Ortiz**
Dr., University of Texas at San Antonio, USA, *araceli.ortiz@utsa.edu*

**Jorge Membrillo-Hernández**
Dr., Tecnologico de Monterrey, Mexico, *jmembrillo@tec.mx*

The goal of this study is to assess the effectiveness of a Problem-Based Learning (PBL) pedagogy that was implemented in two different concrete construction courses. Both courses are a part of an industry focused four-year undergraduate concrete degree program. One of the classes focused on concrete problems, diagnosis, and repair of existing concrete, while the other class focused on handling and management methods of various concrete mixtures. In both courses, a PBL pedagogy was implemented such that students were self-learning and discovering the knowledge through an action-research case study. The action-research case study was specific to the course outcomes relevant to each course, but were assessed similarly. A total of eight different assessment methods were implemented across both courses' multiple times from 2012 – 2019. The results showed that the students are highly benefiting from the PBL pedagogy, which was indicated across all assessment methods. Each assessment technique provided a unique insight into student comprehension or benefits of the PBL pedagogy. The most beneficial assessment techniques were; pre- and post-student assessment, level of understanding and confidence, pre- and post-objective student assessment, and report assessment. These four assessment techniques provide both direct (objective) and indirect (subjective) assessment, while only requiring four total surveys.

Keywords: assessment, problem based learning, active learning, concrete, construction, engineering

**Citation:** Torres, A., Hu, J., Sriraman, V., Martínez-Ortiz, A. M., & Membrillo-Hernández, J. (2022). Assessing the effectiveness of problem-based learning across two concrete construction courses. *International Journal of Instruction*, *15*(4), 473-496. https://doi.org/10.29333/iji.2022.15426a

## INTRODUCTION

Problem Based Learning (PBL) is type of active learning pedagogy that is student-centered, in which the students learn through their own experiences solving a problem. Typically, the problem is an open-ended problem with a specific goal, which stems from the specific class or discipline. This process does not typically emphasis problem solving, with a specific solution, however, it promotes growth and development of specific skills and attributes. The primary goal of implementing PBL in a classroom is knowledge acquisition, enhanced group collaboration, and effective communication. PBL was originally introduced and developed in the School of Medicine at McMaster University in 1969. The overall goal of this original implementation was to move away from the standard lecture in which students can get bored easily and not retain the specific knowledge trying to be transmitted. The goal of this original study was to establish a system where students became more active in their own learning and self-discovery, in which students were more involved in the learning process (Lee and Kwan, 1997). The success of this pedagogy began to extend to other newly founded medical schools such as Maastricht in the Netherlands and Newcastle in Australia, in which their curriculum was now based on PBL (Barrows, 1996). Since these original implementations, many educators and researchers began implementing PBL in many other classes across many different disciplines as this process is not medicine specific (Choden, 2020, Mustafa, 2020, Palupi, 2021, Sriraman, 2017, and Torres, 2021). The PBL process allows for any learner to develop their skills within any area. These skills can then be used for future practice in other classes as well as in their future careers. PBL is known to enhance students' understanding, comprehensions, and literature retrieval, which overall, encourages ongoing learning.

Typically, the PBL process involves structuring the curriculum such that students work together in small groups and confront problems together. Each student is assigned (or individually takes on) a role within the group, such that an individual student is responsible for smaller portions of the knowledge gathering. These rolls are not typically permanent as they often informally rotate depending on one's understanding and comfort level with a specific problem or issue. The Maastricht seven-jump process involves clarifying terms, defining problems(s), brainstorming, structuring and hypothesis, learning objectives, independent study and synthesis (Wood, 2003 and Sriraman, 2017).

At Texas State University, a four-year undergraduate degree program is offered in Concrete Industry Management (CIM). The CIM program is an industry focused, hands-on program, in which students become technical managers within the concrete industry. Due to the nature of the program, active learning pedagogy such as PBL, Project Based Learning, and Challenge Based Learning are an ideal fit for most classes in the curriculum. Therefore, a PBL teaching method was incorporated into two different classes within the program, in which eight different assessment methods were implemented across both classes that incorporate multiple objective and subjective assessment methods. The first course is titled *Concrete Problems, Diagnosis and Repair (CIM 4340)* and the PBL method was incorporated from 2012 - 2014. The second

course is titled *Concrete Construction Methods (CIM 3330)* and the PBL method was incorporated from 2014 – 2019. The PBL method did not continue in CIM 4340 due to a change in the original instructor. It was no longer included in CIM 3330 due to the instructor taking a sabbatical leave, but will continue upon the instructor's return. Both courses expose upper division undergraduate students to various kinds of concrete topics included: placing, handling, curing, mixture types, product failure, the mechanisms that underlie such failure, and the repair or restorative processes that would correct these problems. Both of these courses require background in science, engineering, and technology principles. In a general offering of these principles, they come across to students as dull, or boring, even though they are within their specific discipline. This then leads to lower active participation in the learning process. As many authors have pointed out (Usmani, 2011; Zotou, 2020; Moayyedian, 2020; Elizondo-Montemayor, 2004, Choden, 2020, Mustafa, 2020, Palupi, 2021, Sriraman, 2017, and Torres, 2021) problem solving is best learned by engaging students in real-world problem-solving exercises. Most real-world problem solving is characterized by problems that are often structured such that they require the problem solver to think critically, work in teams, reflect on one's learning, and acquire knowledge as they solve the problem. Therefore, a real-world PBL pedagogy was an ideal fit for both CIM 3330 and CIM 4340.

The rationale for adopting a PBL pedagogy in these courses was similar to that which originally motivated medical schools in the 70s. In the case of medical schools, the academic community felt that medical knowledge was growing at an explosive rate. This implied that professional education should prepare medical students to learn throughout their professional lives rather than to simply master current information and techniques. This demands that the pedagogical model includes active, independent, self-directed learning. Thus, students need to be able to not only solve problems, but also be able to identify and formulate them, develop deep understanding of basic concepts and have the ability to obtain and analyze data critically. PBL addresses these requirements directly. Since the introduction of PBL in both courses, each year the PBL implementation was refined based on the assessment of student learning and instructor reflections from the previous year. A previously publication, discusses the initial implementation of the PBL in the CIM 4340 course (Hu, 2014), however, the focus of this study is on the assessment of PBL and particularly in concrete construction courses.

**Background on Educational Assessment**

The value of any educational intervention can be judged by measuring what and how well students learn and by measuring if a specific intervention is more efficacious than its rivals in facilitating learning. The word assessment is used to determine how well the students have met the overall learning objectives for a course and the word evaluation is used in connection with determining how well the intervention is working (Waters and McCracken, 1997). This study focuses on the assessment of student learning by means of the PBL pedagogy. Research suggests that classroom assessments, which have the potential to enhance instruction and learning, are not being used to their fullest potential. Advances in the cognitive and measurement sciences make this an opportune time to

rethink the fundamental scientific principles and philosophical assumptions serving as the foundations for current approaches to assessment (Pellegrino, 2012 and Choden, 2021). Some findings from the Committee on the Foundations of Assessment from the Center for Education at the National Research Council (Pellegrino, 2012) serve as an important background for this study and include the following. Every assessment, regardless of its purpose, rests on three pillars: a model of how students represent knowledge and develop competence in the subject domain, tasks or situations that allow one to observe students' performance, and an interpretation method for drawing inferences from the performance evidence thus obtained. These three elements – cognition, observation, and interpretation – must be explicitly connected and designed as a coordinated whole. A model of cognition and learning should serve as the cornerstone of the assessment design process. The model of learning can serve as a unifying element – a nucleus that brings cohesion to curriculum, instruction, and assessment. This cohesive function is a crucial one because educational assessment does not exist in isolation, but must be aligned with curriculum and instruction, if it is to support learning (Pellegrino, 2012).

Advances in educational research suggests that one should move away from testing students on regurgitation of factual information and "bookish" problem solving and instead move toward assessing their deep understanding of the subject material and their ability to apply this knowledge to new situations. Cognitive scientists also suggest that human brains have short-term memory and a long-term memory. It is the ability to efficiently store, retrieve and apply information from this long-term memory that distinguishes expert problem solvers from novice problem solvers. Understanding the contents of long-term memory is especially critical for determining what people know; how they know it; and how they are able to use that knowledge to answer questions, solve problems, and engage in additional learning. While the contents include both general and specific knowledge, much of what one knows is domain- and task-specific and organized into structures known as schemas. Assessments should evaluate what schemas an individual has and under what circumstances he or she regards the information as relevant. This evaluation should include how a person organizes acquired information, encompassing both strategies for problem solving and ways of compartmentalizing relevant information into manageable units (Pellegrino, 2012). Pellegrino also states that, "One of the most important aspects of cognition is metacognition—the process of reflecting on and directing one's own thinking." Metacognition is crucial to effective thinking and problem solving and is one of the hallmarks of expertise in specific areas of knowledge and skill. Experts use metacognitive strategies for monitoring understanding during problem solving and for performing self-correction. Assessment should therefore attempt to determine whether an individual has good metacognitive skills (Pellegrino, 2012).

While it is important for the instructor and researcher to collect the necessary assessment data for continuous course improvement, many students may feel overwhelmed by intense assessments throughout the class. As it can be challenging to develop direct assessment criteria with open-ended questions, additional effort is needed to develop more assessment questions that can be integrated directly into questions

during exams, as well as to provide incentives for students to take multiple self-assessments on different stages. One must not forget that evaluation is defined as a systematic and planned process of gathering information through multiple strategies, techniques and instruments, which allows making judgments and evaluating whether students have achieved the expected learning, with all the dimensions that imply: knowledge, skills, attitudes and values, and to what extent.

Historically, evaluations have consisted of the application of a written exam that certifies the acquisition of knowledge, and it seems to be objective; however, it is not the most appropriate tool when evaluating soft skills such as those pursued by PBL. Educational assessment is a multi-faceted and multi-dimensional process of assessing student learning. It is not only a question of whether the students assimilated the contents of the course, it is a question of whether the students acquired and developed knowledge and skills, adopted new attitudes, and assumed new values.

**Assessment Challenges in PBL**

Successful PBL implementation requires that several challenges from the standpoint of curriculum, instruction and assessment be resolved and that the three activities be aligned holistically (Biggs, 2003). A poor assessment strategy can render the positive gains associated with sound curriculum and instruction design to be of little or no consequence to the learning process. Major and Palmer (2001), echoing this caution, state that PBL presents some unique challenges for assessment. Macdonald and Savin-Baden (2004) suggest that assessment in PBL requires no less thought and care than it does under other approaches to learning. Biggs (2003) stresses the need to align curriculum objectives, teaching, and learning activities and assessment tasks, particularly where the intention is to encourage deep, rather than surface approaches to learning. Assessment techniques that are commonplace in traditional pedagogy such as multiple-choice and true false examination do little to truly assess a student's understanding and transfer of PBL learning experience (Waters and McCracken, 1997). Thus, if instruction is problem-based, assessment should be similarly structured (Nowak and Plucker, 1999). By way of illustration, these authors present a situation where the students design and build a model of a better solar home. If the ensuing assessment is based solely on a true and false, multiple-choice test, this would undermine the creative process and send mixed messages to students about the importance of the PBL activity (Nowak and Plucker, 1999).

Moursund (2003) argues that as the curriculum content in PBL is authentic and resembles the real-world setting, assessment must also be authentic in that it should measure the students' performance and learning of authentic content (i.e., not mere retrieval of factual information, but the application and deep understanding of discipline knowledge). Authentic assessment utilizes performance samples or learning activities that encourage students to use higher-order thinking skills (Alkhasawneh, 2007).

More recent PBL studies (Choden, 2020, Mustafa, 2020, Palupi, 2021, Sriraman, 2017, and Torres, 2021) have demonstrated PBL interventions with good results, however, the

vast majority of these studies are lacking sufficient assessment procedures of their PBL techniques.

In the design of such assessment procedures for PBL, Macdonald (2005) suggests that the following be considered when assessing a PBL pedagogy:

- Why are you assessing the students?
- What are you assessing?
- When are you going to assess?
- Who is going to carry out the assessment (students, peers, tutors, etc.)?
- How are you going to assess?
- Where will the assessment take place?
- How are you going to grade assignments?
- What feedback will students receive?

**Types of Assessment in PBL**

Consistent with the requirements for authentic assessment in PBL, Macdonald and Savin-Baden (2004) provide the following list of types of assessment that have been successfully used in this context and that move away from traditional assessment methods. These include:

- Group presentations
- Individual presentations
- Tripartite assessment
- Case-based individual essay
- Case-based care plan in clinical practice/client-led project
- Portfolio
- Triple jump
- Peer assessment
- Viva voce examinations
- Reflective (online) journals
- Facilitator/tutor assessment
- Reports
- Patchwork text

Based on these recommendations, the following methodology was developed to assess the two courses in this study.

**METHOD**

The purpose of this research is to assess the PBL methodology implemented in the CIM 4340 and CIM 3330 courses. The research questions that were explored are listed below:

1) Is the use of a PBL pedagogy promoting the students understanding of the course outcomes?
2) Which delivery method did the students prefer from each course?
3) Which assessment method has provided the most beneficial results?

## Demographics and Details of Assessment Methods

### Demographics

The participants of this study include the authors and the students enrolled in the 2012 - 2014 semesters of CIM 4340 and the 2014 – 2019 semesters of CIM 3330. Both courses were only offered one semester per year. CIM 3330 was only offered in the Fall semesters, whereas, the CIM 4340 moved semesters, initially this study to accommodate the course flow plan, as needed, therefore it was original taught in the summer semester but has since been taught in the Spring semesters. A total of 94 students were taught between all offerings of these courses with an average age of 21 years old. Of the 94 students, only 6 were female, which is typical for the CIM program. All of the students enrolled in both courses were required to have the same pre-requisites in order to enroll in either course. All students were full time students taking a minimum of 12 credit hours at the university. Two different instructors taught the respective courses, but were the same throughout the study.

### Assessment Methodology

In order to develop a proper assessment methodology, the pre-established course outcomes were first identified in order to better align the assessment techniques. As Maastricht pointed out, a student within a PBL framework needs to first identify what they already know, what they need to know, and how and where to access new information that can lead to solving the problem. Therefore, the pre-established course outcomes already consider this framework, such that they are already written considering what the student already knows and what their endpoint would be. All that needs to be established is the PBL roadmap that would lead the students towards solving the problem. An ideal assessment, not only assess the students' grades at the end of the semester, but assesses how well was the PBL roadmap established and benefited the students.

The six outcomes for CIM 4340 course are as follows:

1. Students will develop an understanding of the role of concrete maintenance, concrete problem prevention and repairing in sustainable practices in the concrete construction industry.
2. Students will demonstrate a strong understanding of the root causes of concrete problems.
3. Students will develop basic technical knowledge related to common methods for analyzing concrete problems.
4. Students will demonstrate a basic understanding of concrete related problem prevention and resolution methods.
5. Students will develop basic technical knowledge related to concrete repairing and protection.
6. Develop problem-solving skills and self-learning abilities.

The specifics and requirements of the project utilized in CIM 4340 can be seen in the citation by Hu *et al.* (2014).

The outcomes for the CIM 3330 course are as follows:

1. Students will process a basic understanding of concrete construction methods in paving, site cast concrete, prestress and precast concrete.

2. Students will process a strong understanding in the various steps in the proper transporting, formwork, placing, consolidation, finishing, jointing and curing of concrete under a variety of environmental conditions.

3. Student will develop a basic technical knowledge related to concrete construction in sustainable concrete construction and special concrete technologies.

The specific project utilized in CIM 3330, in which implements the PBL methodology, covers all three of the course outcomes. The project covers sustainable concrete construction, which is assigned at the beginning of the semester. The project objectives/questions are as follows:

- What are the challenges/issues in the concrete industry from a sustainability perspective?
- What are some ways the concrete industry is currently being sustainable?
- Choose an existing sustainable concrete method and briefly describe it, or develop a new, unique, method that can improve the sustainability of the concrete industry.
- 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 one can see, the objectives of the project cover all of the course outcomes for the course. The project requires students to process a basic understanding of concrete construction methods, the specific steps required in the full processing of the material, and the technical knowledge related to sustainable construction practices. As previously stated, this project was assigned to the students at the beginning of the semester. The project was assigned to groups of students (on average 3 students per group). Throughout the semester, the course content provided more and more detail to allow the students to develop the knowledge to help meet their specific problem goals. Throughout the semester, the students were required to provide updates to their project a total of five times. Then the students were required to complete a 15-minute presentation to the rest of the class, the instructor, and guest judges invited from the local concrete industry. Along with their presentation the students also had to submit a written report also covering the project objectives.

In order to evaluate the outcomes from both courses, various forms of assessment methods were implemented, as shown below in Table 1.

Table 1
Comprehensive list of assessment methods used

| | CIM 4340 | | | CIM 3330 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 2012 | 2013 | 2014 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Self-assessment | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Pre- and Post- assessment | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Teaching methods ranking | Yes | Yes | Yes | No | No | No | No | No | No |
| Comprehensive five-session survey | No | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Level of Understanding and Confidence Survey | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Group Presentations | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Report | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Peer-assessment | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes |

As seen in Table 1 a total of eight different assessment methods were implement in the two concrete construction courses. Not all were implemented across both courses, which was done to best suit the specific nature and outcomes of the course.

**Assessment Results**

The self-assessment was administered at the end of the semester of both courses, in which the students were asked to self-assess their knowledge gained in regards to the specific course objectives. Figure 1 and 2 shows the results of the self-assessment for both courses with respect to their course outcomes.

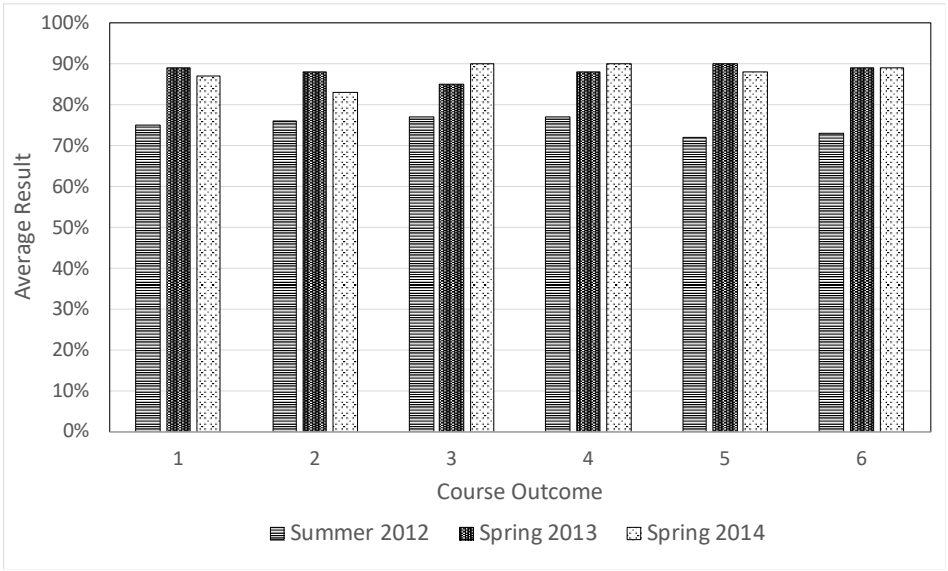


Figure 1
Self-assessment results for the CIM 4340 course

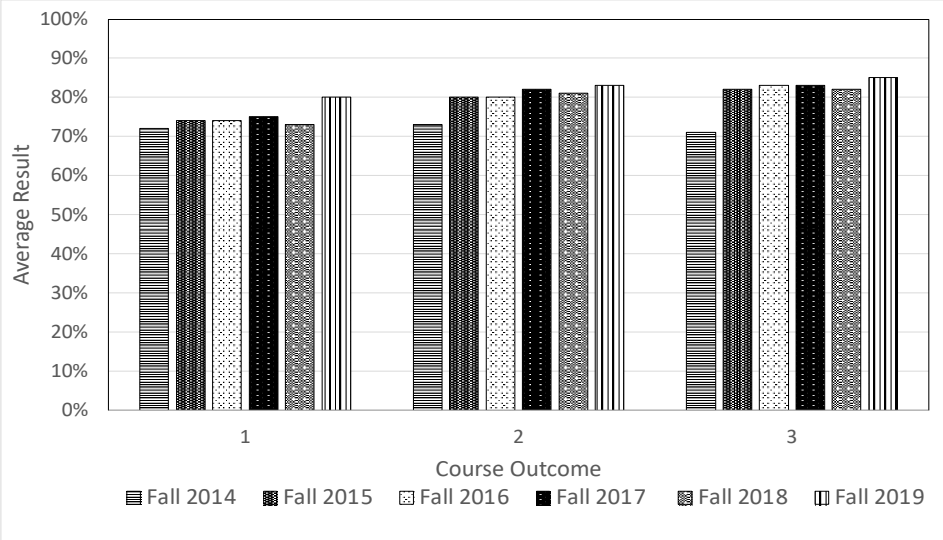


Figure 2
Self-assessment results for the CIM 3330 course

For both of the self-assessment results presented in Figures 1 and 2, the students evaluated each outcome using a 5-point Likert scale, with a score of 1 indicating very strong disagreement and a score of 5 indicating very strong agreement in regard to the accomplishment of the particular outcome. While the highest possible summary score of 100% indicates all students chose "very strongly agree" on that specific outcome, the lowest possible score of 12.5% indicates all students chose "very strongly disagree". As shown in Figure 1 (CIM 4340), all outcomes received higher scores in Spring 2013 and Fall 2014 in comparison to 2012. This is likely due to it being the first time the author taught the course and therefore learned from prior experiences to approve upon on the initial implementation. Outcome 6 (develop problem-solving skills and self-learning abilities) received significantly higher student endorsement in comparison to results from Summer 2012. This substantial improvement in outcome 6 is due to the fact that students were provided explanations about the nature of PBL pedagogy at the commencement of the semester. This allowed the students to experience a more systematic PBL implementation, and a better understanding of what was being asked of them in regards to the learning pedagogy. This is a similar process and results to work completed by Sriraman *et al.* (2017) and Torres, *et al.* (2021).

Based off the lessons learned from the CIM 4340 implementation, the PBL pedagogy was explained to the students upon the initial implementation of the course. As seen in Figure 2, the results of the self-assessment in CIM 3330 were all positive and above a score of 70%. This is of course a positive result, but does allow room for improvement. As noticed in Figure 2, the lowest results were observed in the first implementation of

the PBL pedagogy in the course (Fall 2014). Across the years, the students showed improved understanding of each course outcome, however, Outcome 1 (understanding the concrete construction methods) showed marginal improvement across the years aside from the Fall 2019 implementation. This is likely due to the broad nature of the topic, as this outcome encompasses the entire course which contains many different aspects of concrete construction methods in regards to site casting and pre casting concrete. In contrast to this result, Outcome 2 and 3, demonstrated a larger improvement beginning in Fall 2015 with the highest year still being Fall 2019. The results showed an overall average self-assessed understanding of 84% for the CIM 4340 course and 79% for the CIM 3330 course. Mustofa *et al.* (2020) showed that improvements in self-assessment are commonly attributed to the intervention of PBL techniques, as students are more engaged in the instructional programming.

In order to better assess the improvement of students' knowledge through the course, a pre- and post-student assessment were applied on the same six outcomes. A Likert scale of 0-4 was used and coded as follows: 0-no understanding, 1- minimal understanding, 2- moderate understanding, 3- proficient understanding, and 4- expert understanding. The analysis was completed to evaluate the understanding of concrete concepts from the beginning (pre-) and the end (post-) course student self-assessment. As seen in Table 1, the pre- and post-student evaluations were only completed in Fall 2013 and 2014 for the CIM 4340 course, and all offerings of the CIM 3330 course. The results of the pre- and post-student assessment for CIM 4340 and CIM 3330 can be seen in Figures 3 and 4 respectively.

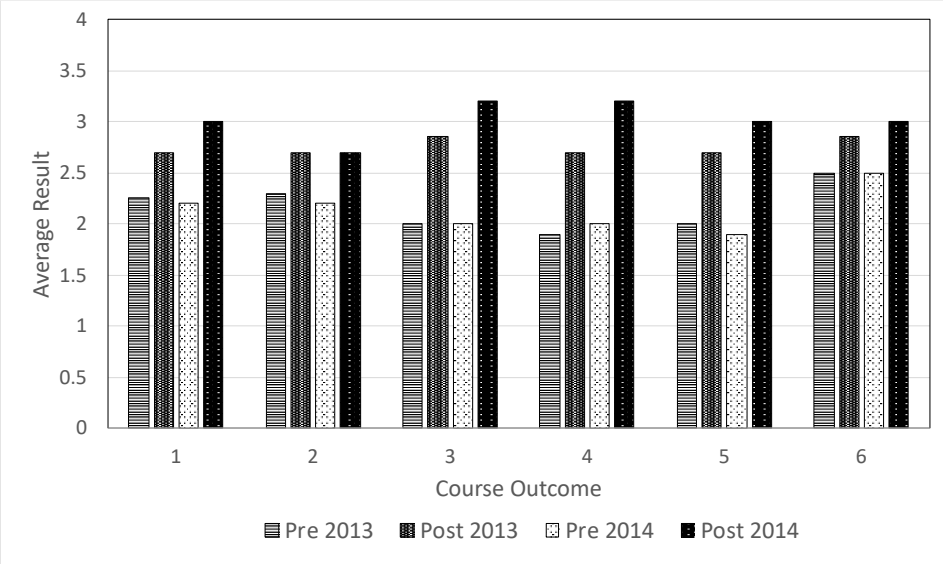


Figure 3
Pre- and post-student assessment results for the CIM 4340 course

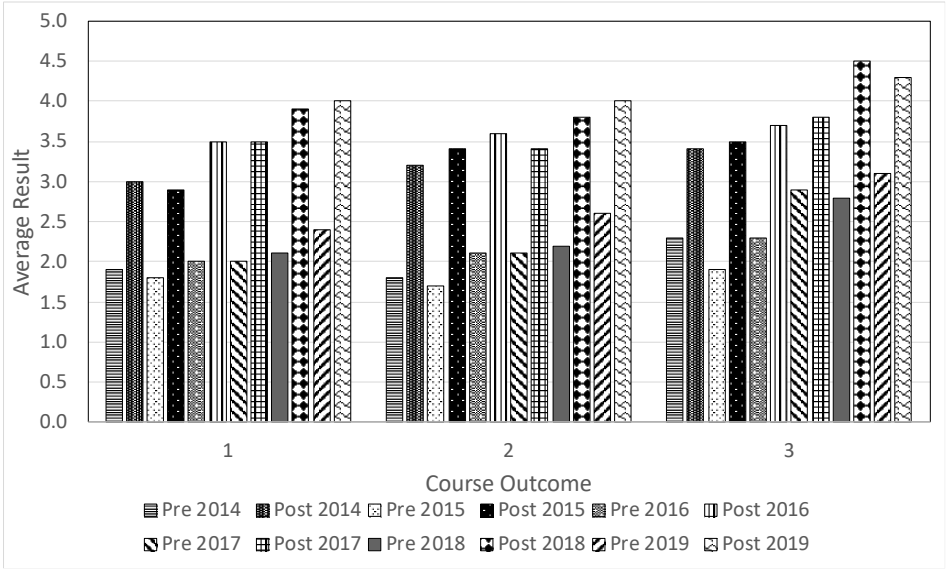


Figure 4
Pre- and post-student assessment results for the CIM 3330 course

As shown in Figure 3, the CIM 4340 students from the 2013 and 2014 class rated themselves at a level ranging between 1.83 (moderate understanding) to 2.44 before the course on each of the six outcomes. Students then rated themselves at a level ranging between 2.71 to 3.22 (approaching proficient understanding) after the course. There was a clear improvement in students' assessment of their improved understanding of course specific content after the course intervention. A similar result was observed for the CIM 3330 course, in which the students rated themselves higher in the respective outcomes after the course. Upon initial self-assessment, the students in the CIM 3330 course rated themselves between 1.71 – 3.12 (approaching proficient understanding). After the course the students rated themselves between 2.90 – 4.51 (expert understanding). It is important to note that in general, the post-assessment result increased with each semester. There was no change to the project during this time, however, and improvement was generally observed. It is also noticed that Outcome 3 produced the highest self-assessed understanding in both the pre- and post-student assessment. It is believed that the pre-assessment is high is due to sustainability being a topic discussed often in other classes, in the news, and online. Therefore, students have a pre-understanding of what sustainability is and how things can affect the environment. Secondly, the post-assessment revealed a large increase, which is likely due to the nature of the project, specifically focusing on sustainability. Whereas Outcomes 1 and 2 are more on general concrete placing and finishing methods. This is a similar result also observed in the Self-assessment shown in Figure 2. In order to assess the effectiveness of this assessment method, a "normalized gain" (also known as N-gain) analysis was completed, which rough measure of the effectiveness of a course in promoting

conceptual understanding, specifically for pre and post-analysis. The average N-gain for CIM 4340 in 2013, and in 2014 was 31.4% and 46.3% improvement respectively, across each course outcome. For the CIM 3330 course the N-gain results were 39.9%, 45.8%, 51.2%, 45.9%, 65.5%, and 61% for each year investigated beginning with 2014. This analysis further confirms that efficacy of this assessment method as well as showing the continued improvement for the CIM 3330 course.

The next assessment method investigated was teaching method ranking. This involved administering a survey at the end of the semester in which the students were asked to evaluate the effectiveness and rank the different delivery methods used in the class. Therefore, the students ranked both how effective they found each delivery method to be as well as their preference to each delivery method, with 1 being the highest and 14 the lowest. It is important to ask the students to do both, as they may not necessarily agree with each other. One student may prefer one method over the other, but they may find another to be more effective and transmitting the knowledge. Therefore, the assessment not only elucidates their preferred method, but also the one they found the most effective. This was only completed in the CIM 4340 course. The results were collected and averaged for each semester and shown in Table 2.

Table 2
Effectiveness and preference ranking of different teaching methods used in CIM 4340

| | Effectiveness Rank | | | Preference Rank | | |
|---|---|---|---|---|---|---|
| Delivery Method | 2012 | 2013 | 2014 | 2012 | 2013 | 2014 |
| Lecturers (Instructor) | **1** | 4 | **2** | **1** | **3** | 4 |
| Lecturers (Guests) | 6 | 9 | **3** | 5 | 8 | 9 |
| In Class Discussion | **2** | **2** | **1** | **2** | **1** | **3** |
| Term Project (Concrete Problems and Repair Case Studies) | 5 | 3 | 4 | 3 | 7 | **2** |
| Field Hunting (Concrete Distresses and Deteriorations) | **3** | 6 | 5 | 4 | **1** | 7 |
| Labs | **3** | 5 | 9 | 7 | 10 | 5 |
| Working in Teams | 8 | 13 | 6 | 14 | 14 | 10 |
| Weekly Updates | 11 | 11 | 9 | 11 | 7 | 7 |
| Weekly Meeting with the Instructor | 10 | 7 | 10 | 13 | 11 | 9 |
| Peer Review | 13 | 13 | 12 | 12 | 13 | 12 |
| Self-Evaluation and Assessment | 12 | 14 | 11 | 9 | 13 | 11 |
| Homework and Reading Assignments | 9 | 10 | 13 | 10 | 9 | 14 |
| Exams | 14 | 8 | 14 | 6 | 5 | 13 |
| One-on-One Consultation with the Instructor | 7 | **1** | 7 | 8 | 3 | **1** |

As shown in Table 2, while "Lecturers (Instructor)" was ranked first in both effectiveness and preference in 2012, the rank dropped to second, then to fourth in 2013 and 2014. The most improved delivery method was found to be "in class discussion" as it began as second most effective in both 2012 and 2013, then moved to first in 2014. In "class discussion" was also consistently in the top three delivery method preferences. Contrary to this, the worst ranked delivery methods in regards to effectiveness were Exams, peer-review, and self-evaluation and assessment. However, the students ranked working in teams as their worst preference in 2012 and 2013. The 2014 semester had homework and reading assignments as the lowest ranked preference. These results are as expected as, often, students prefer to work alone or there could be a teammate that is not performing to one's expectations. Homework and reading assignments are also not a

preference amongst many students. Beyond the traditional lecture and class discussions performing high, were the PBL-based activities – one-on-one consultation with the instructor, term project, field hunting, and labs. These delivery methods were more aligned with the PBL pedagogy and were ranked high in effectiveness and/or preference among the students. These results indicate that students highly valued the PBL approach implemented in this course. As Palupi *et al.* (2020) demonstrated, it is important to align the objectives and approach of the PBL to the course outcomes.

The next assessment technique implemented was a comprehensive five-session question and knowledge of student competencies. This was first implemented in the CIM 4340 class in 2013 and in 2014 for the CIM 3330 class. The purpose of the sessions was to ascertain varied information from demographics, to comprehension, and college career readiness standards. The first of the five sessions included a short section with four questions on student demographic information, which is where the demographic information was acquired for this study, and previously discussed. The second section included six questions regarding student motivation general and study preferences. The third section included six questions asking students to rate their current understanding of the concrete course learning objectives as well as included six problem solving questions, related to the course. The fifth section included six questions regarding college and career readiness standards. The format for the responses of most sections utilized a 5-point Likert scale and some open-ended responses. While the intent was to collect more comprehensive knowledge of students' knowledge of the course objectives, the initial iteration of the sessions and surveys was found not to be successful because of the time required and interfered with the course. Additionally, some students left sections blank, which makes these sections invalid. Therefore, no results are presented from the CIM 4340 course. Due to this, this assessment was not continued in CIM 4340. However, lessons learned from the CIM 4340 were carried over such that the comprehensive session survey was better integrated into the CIM 3330 course. For example, the sessions were more interspersed throughout the semester, whenever it was an ideal time in regards to the course content. Some of the problem-solving questions were worked in as in-class quizzes or homework assignments that were due as a completion grade not a performance grade. Additionally, the sessions were not necessarily administered in the order previously described for the CIM 4340 course and were combined with some of the other surveys, such that the students were not overwhelmed with surveys. Lastly, the fifth session covering student college readiness was dropped, as these courses are Junior level courses, and the students are already established college students. Therefore, the new comprehensive five-session question and knowledge of student competencies, became a four-session assessment with the following sections: Demographics, Motivation and Learning Preference, Pre- and post-student self-assessment (subjective assessment), and pre- and post-objective assessment.

The demographics survey along with the pre-and post-student self-assessment (Figures 1 and 2) have already been discussed in this study. The new results, not previously discussed, are the motivation and learning preference questions and the pre- and post-objective assessment. The results of the motivation and learning preference assessment can be seen in Table 3.

Table 3
Motivation and Learning Preference Survey Results from the CIM 3330 Course

| Motivations and Preferences | Fall 2014 | Fall 2015 | Fall 2016 | Fall 2017 | Fall 2018 | Fall 2019 |
|---|---|---|---|---|---|---|
| How motivated are you? | 3.5 | 3.8 | 4.1 | 3.8 | 3.9 | 4.2 |
| Going to class motivates me? | 3.9 | 4.1 | 3.2 | 2.9 | 2.8 | 3.9 |
| Doing homework motivates me? | 2.2 | 2.1 | 2.9 | 2.8 | 3.1 | 2.9 |
| I prefer to learn from the professor? | 3.9 | 3.9 | 4.1 | 3.7 | 4.7 | 4.3 |
| I prefer to study in groups. | 3.1 | 2.9 | 2.8 | 2.7 | 3.3 | 2.9 |
| I prefer to study alone. | 3.9 | 3.7 | 3.7 | 3.1 | 3.9 | 3.2 |

The results from the motivation and preference survey showed additional information regarding the students in the class. Recall that the survey was administered on a 5-point Likert scale in which 5 was the high (strongly prefer). The first question gauged how motived the students are in general, which showed results all above 3 (neutral) and in the low 4s (agree), which shows that the students are general motivated to highly motivated. This result makes sense as the students are in college, which requires general motivation to earn a degree to then earn a job within the industry. Therefore, a typical student is at least motivated to learn or motivated to get through college to begin working. The next two questions ascertain what motivates the students more, going to class or doing homework, and the results indicate that the students are more motivated by the classroom than they are by homework. Learning via the classroom had an average answer of 3.6 whereas learning via homework had an average answer of 2.6. This shows a stronger preference to the classroom. The next three questions probed the students' learning preferences and the results clearly indicate that learning from the professor is preferred over both group learning and learning by themselves. In fact, group learning was ranked the lowest. This result agrees with the results from delivery method ranking, discussed in Table 2. Learning from the professor had an average result of 4.1, followed by self-learning with an average answer of 3.6, then group learning with an average answer of 2.9.

The next survey assessment was a pre- and post- objective assessment of the students' comprehension of specific course topics. This was included as it provides a direct (objective) measurement as opposed to the students' perceived comprehension (subjective assessment). Three different multiple-choice questions were asked to the students at the beginning of the semester and at the end of the semester in order to ascertain how well the students performed before and after taking the course. Six questions were asked in the initial attempt in the CIM 4340 course, to align with the course objectives. However, only three questions were asked in the CIM 3330 course to align with the three course objectives. This also reduced the time of the survey, so to not interfere with the class. Each question pertained directly to the course objective, and had one single answer. The three questions are seen below:

1. Which of the following type of prestressing steel is currently the most widely used?
   A. Seven-wire steel strand B. Steel wire C. High-strength steel bars
   D. High-strength steel chain E. Deformed wire fabrics

2. Which of the following is a reasonable amount of cement used in one cubic yard of normal concrete?
   A. 72.5lb B. 125lb C. 250lb D. 500lb E. 1,000lb
3. In a conventional concrete mixture, which constituent typically produces the most greenhouse gas?
   A. Water B. Cement C. Sand D. Rock E. Superplasticizer

The average grades from each question across all semesters can be seen in Figure 5.

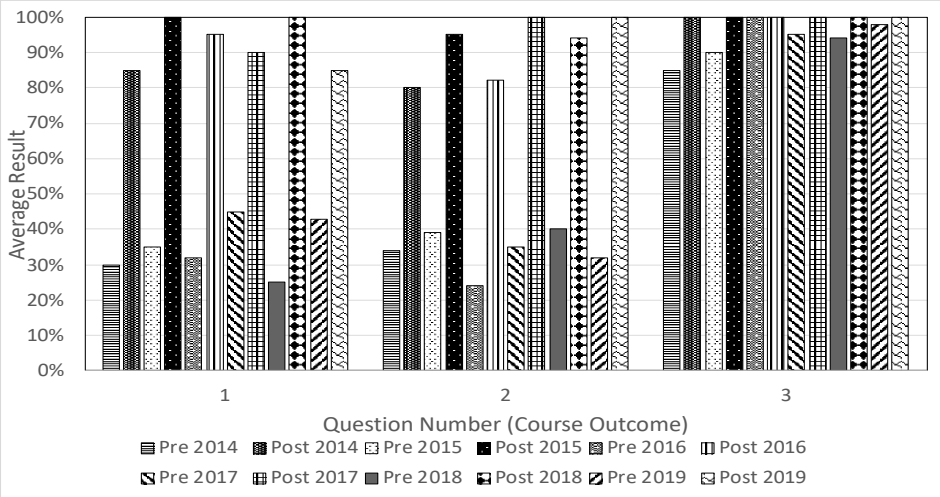


Figure 5
Pre- and post-student objective survey assessment for the CIM 3330 course

As seen in Figure 5, the results show that the students drastically improved their comprehension when asked the same questions after learning the course content (in the post assessment). It can be seen that the average scores were very low for both Questions 1 and 2 at the beginning of the semester, with an average of 35% for Question 1 and 34% for Question 2. These questions improved to 93% and 93% respectively at the end of the semester. This also shows that students did not have much understanding of these topics from previous courses or by any other means, and the intervention of the class (and PBL pedagogy) improved the understanding in regards to these questions. Question 3 also showed improvement, however, it was marginal. The pre-assessment average of Question 3 was 94%, indicating that the students had previously knowledge of this topic, either from other classes or by other means. However, it is observed that the post assessment of Question 3, revealed an average result of 100%, indicating that not a single student got the question wrong after taking the course. This result makes sense as the course and the PBL pedagogy heavily discusses that cement is the primary constituent, contributing to greenhouse gas in the concrete construction industry. As with the pre and post student assessment an N-gain assessment was completed on this method.

The N-gain results showed 82.8%, 92.3%, 84.5%, 93.9%, 96.6% and 91.3% increase across each year beginning with 2014. As with the previous N-gain analysis, this analysis confirms the improvements made following the intervention of the specific PBL technique.

The next assessment method, was the level of understanding and confidence survey. This was first implemented in the CIM 4340 course in Spring 2014. This was done to assess the students' level of understanding of general topics within each course. This survey was completed at the end of the semester after the intervention of the PBL pedagogy. The survey scale used were was a 5-point scale with the following information assigned to each point: 5 – Fully understand, 4- Understand, 3 – Have an idea, 2 – Recognize the topic, and 1 – I don't understand this topic at all. The results for both classes can be seen in Table 4.

Table 4
Results of level of understanding and confidence survey

| CIM 4340 | Spring 2014 | -- | -- | -- | -- | -- |
|---|---|---|---|---|---|---|
| Typical Concrete Problems and Disintegration Mechanisms | 4.4 | -- | -- | -- | -- | -- |
| Diagnosis and Evaluation of Existing Damage | 4.1 | -- | -- | -- | -- | -- |
| Concrete Repair | 4.1 | -- | -- | -- | -- | -- |
| **CIM 3330** | **Fall 2014** | **Fall 2015** | **Fall 2016** | **Fall 2017** | **Fall 2018** | **Fall 2019** |
| Site Cast, Pre-Cast, Cast in Place, and Concrete Paving | 3.8 | 3.7 | 4.1 | 3.7 | 4.2 | 3.5 |
| Mixing, Transporting, Forming, Placing, Finish, and Curing | 4.1 | 3.8 | 4.3 | 3.2 | 4.4 | 3.7 |
| Sustainable Concrete and Practices | 4.1 | 4.2 | 4.4 | 3.9 | 4.1 | 3.5 |

As seen in Table 4, the level of understanding and confidence survey results demonstrate a high level of understanding and confidence after the PBL intervention in both courses. Although the CIM 4340 course only had one iteration, the results still indicated a perceived high level of understanding and confidence of the three broad topics. All results were in the "understand" category. The results of the CIM 3330 course showed a slightly broader range from 3.2 – 4.4 across all semesters. Although a broader range was observed the answers, at minimum, showed a "I have an idea" level of understanding and confidence. This is likely due to their being a lot of topics included in the three broad categories probed in this class. For example, the first category has four different topics, and one student may feel comfortable in one (or more) but not another, therefore they may score their confidence lower, due to the broad nature of the category. This is the case for all three categories used in this assessment with this course. The average across semesters for the first question was 3.8, 3.9 for the second question, and 4.0 for the last question. The average results show a level of confidence of "Have an idea" or "Understand", but the first two questions are very close to "Understand".

The next assessment method utilized, was a group presentation assessment, in which the students had to present their PBL project findings to the rest of the class at the end of the semester. This assessment method only took place in the CIM 3330 course and was

completed in all semesters. The assessment was completed by the instructor of the course and three professionals from the industry. The three professionals were from the local cement and concrete industry and were present at all presentations for all semesters. Prior to the start of each group presentations, a grading rubric was handed to each judge (included the instructor) and the assessment took place during or at the end of the presentation. The rubric included 5 assessment categories. Introduction, Sustainability in the Industry, Definition of Specific Topic, Discussion of "Case Study", Questions and Answers. Each category was assessed on a 10-point scale, 10 points being the highest. The results of each judge's assessment (including the instructor) were averaged and are presented in Table 5.

Table 5
Results of group presentation in CIM 3330

| CIM 3330 | Fall 2014 | Fall 2015 | Fall 2016 | Fall 2017 | Fall 2018 | Fall 2019 |
|---|---|---|---|---|---|---|
| Introduction | 8.3 | 8.5 | 10 | 9.3 | 9 | 10 |
| Sustainability in the Industry | 9 | 9 | 9.3 | 10 | 8.5 | 9.4 |
| Definition of Specific Topic | 8.4 | 8.9 | 9.3 | 9.4 | 10 | 8.4 |
| Discussion of Case Study | 7.3 | 8.2 | 8 | 9.3 | 8.4 | 8.3 |
| Question and Answers | 7.5 | 7.3 | 7.9 | 8.2 | 7.4 | 7 |

As seen in Table 5, the group presentation results were all relatively high, with results ranging from 7 – 10 across all semesters in all categories. The highest performing category was the "Sustainability in the Industry" category, with an average score across all semesters of 9.2. The judges seemed to agree that all groups across all semesters were providing sufficient information regarding typical sustainable measures in the industry. Closely behind this category was, "introduction" with an average score of 9.1. This result is not as expected, as it appears to be the easier of the five categories, however, students scored lower than expected as groups in the early semesters failed to introduce themselves in addition to their topic. The students merely began discussing their topic without introducing themselves to the judges, who before the presentations, they have not met. Following the first iterations, the instructor of the course reminded the students to introduce themselves in addition to their topic, which helped bring the scores up. The next highest performing category was the "Definition of Specific Topic" category with an overall average of 9.0. This is as expected as this section is relatively short, with on average 2-3 slides, simply introducing the topic, topic name, and brief information about the topic. The judges were not looking for in-depth discussion from this category, as that was left for the "Discussion of Case Study" category, in which the students were required to find a real-world project using their specific topic or find a published journal article to discuss. This category, was actually the fourth highest performing category, with an average of 8.3. This result is as expected as more often than not, the selected real-world project or journal article contained a great deal of technical information that the students did not fully understand. However, the scores are slightly lower, there are still high, given the slightly higher degree of difficulty that could be encountered in this category. The lowest performing category was the "Question and Answer" category with an average result of 7.6. This was expected as the judges tried to ask each student a question, and certain students did not have a grasp of their topic, and often stumbled

with their answers. Similar to the previous category scores, the average result is still a 7.6/10, which would still be a passing grade in most university courses. Overall, this assessment provided quality results and feedback that contribute to the overall assessment through an additional objective assessment (non-opinion based).

The next assessment method was the grading of the final written report for the students' PBL project. In addition to the presentation the students were asked to submit and write a report summarizing all that they learned about their project. It was categorized very similar to the presentation with minor modification. The report categories were as follows: Introduction, Sustainability in the Industry, Definition of Specific Topic, Discussion of "Case Study", Conclusions and Lessons Learned. As with the presentation, the "Introduction" category had no emphasis on introducing the students themselves, but was focused on introducing the general topic/issue as a whole. The report had few formatting requirements and no page length requirements. The students were asked to present everything in a professional manner, and long enough to sufficiently convey all the necessary information. The reports were graded by the instructor of the class, who graded all reports across all semesters. As with the presentations the reports were also graded on a 10-point scale, with 10 being the highest. The grades were averaged and reported across all semesters in Table 6.

Table 6
Results of student reports in CIM 3330

| CIM 3330 | Fall 2014 | Fall 2015 | Fall 2016 | Fall 2017 | Fall 2018 | Fall 2019 |
|---|---|---|---|---|---|---|
| Introduction | 9.3 | 9.2 | 8.9 | 8.3 | 9.2 | 9.1 |
| Sustainability in the Industry | 8.2 | 8.4 | 8.3 | 8.9 | 9.2 | 8.4 |
| Definition of Specific Topic | 9.4 | 9.1 | 8.2 | 9.2 | 9.1 | 8.9 |
| Discussion of Case Study | 7.9 | 8.2 | 7.7 | 7.4 | 8.9 | 8.2 |
| Conclusions and Lessons Learned | 9.2 | 9.1 | 8.8 | 7.2 | 7.1 | 8.6 |

As observed in Table 6, the results of the student reports are also favorable across each category and each semester. The results ranged from 7.1 – 9.3, which are overall passing grades for each category. The highest performing category in this assessment was the "Introduction" category with an average result of 9.0. This result make sense, as it intuitively is the easier of the five categories as the students merely need to introduce the sustainability topic. Shortly behind this category, was the "Definition of Specific Topic" category with an overall average of 8.9. This also makes sense as this section is relatively short, and does not require much depth. The students, in this category, needed to simply describe their specific topic and how it is sustainable. Shortly behind this category, was the "Sustainability in the Industry" category with an overall average of 8.5. This category also had a high performing result, likely due to previous classes and discussions throughout the semester in regards to sustainable efforts in the industry. Shortly behind that category was the "Conclusions and Lessons Learned" category with an average result of 8.3, followed by the "Discussion of Case Study" category with an average result of 8.0. Again, both of these categories performed at an overall high average, indicating a comprehension of the specific topic. These categories performed the lowest amongst the five categories, likely due to their higher complexity. The students were required to discuss their particular "case study" in depth and with specific

information as it pertains to sustainability. The conclusions also required a comprehensive summary of the project as well as lessons learned from the PBL project. Although the students still performed high, the students still seemed to have minor difficulty articulating their lessons learned, which cost them a point, when being assessed. Overall, this assessment method produced quality, objective, results, which demonstrates that the PBL pedagogy is working.

The last assessment technique utilized in this study was that of a peer-assessment. As with the last two assessments, this was only used in the CIM 3330 course. This was completed at the end of the semester after the PBL project intervention and after their presentation and final report was submitted. The students were asked to grade their group partners, as if they were an instructor, assessing the quality of their work and contribution to the PBL project. They were asked to assess the presentation and the report individually, as a whole, on a 100% scale, in which 100% was a perfect score. The results of the peer-assessment can be seen in Figure 6.

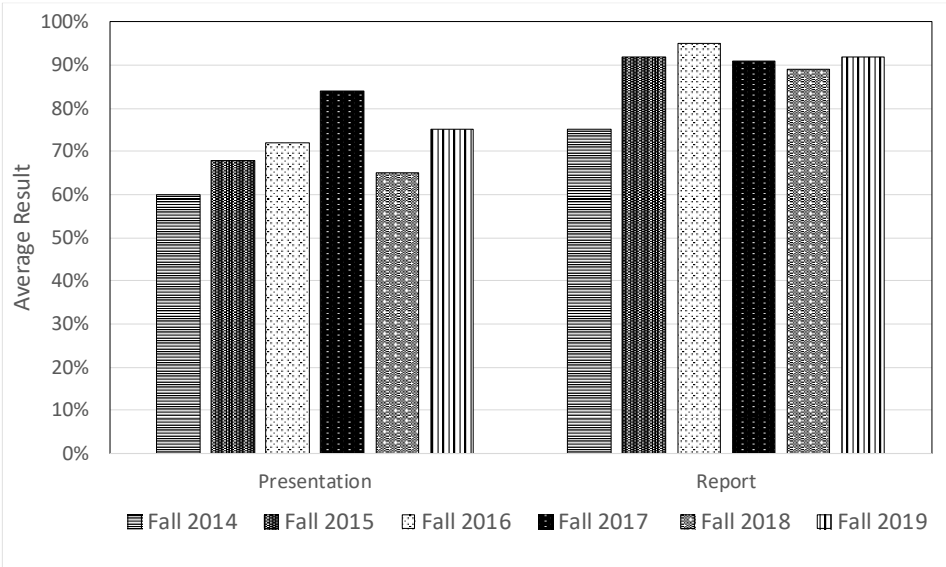


Figure 6
Peer-assessment results for the CIM 3330 course.

As observed in Figure 6, the results of the peer-assessment also provide quality results. The range of values offered from the presentation peer-assessment ranged from 60% - 84%, with an average result of 71%. The report values ranged from 75% - 95% with an average result of 89%. These results are favorable, as the students did not assess their peers extremely low, which would indicate certain students did not contribute at all. With a minimum score of 71%, this indicates that students felt as though their peers were contributing to the group in both categories. It can also be seen that the peer-assessment results indicated an overall lower score for the presentation than for the report. This

result makes sense, as the majority of the students do not feel comfortable presenting in front of people (and was observed in their presentations), therefore certain students had better presenting skills than others. Thus, their peers may have rated them lower than others due to their perceived performance during the presentation. Overall, this assessment provides further objective insight as to the performance of the students in the course.

## CONCLUSIONS

The results of this study indicate the effectiveness of a PBL pedagogy implemented in two different concrete construction courses across multiple years. A total of eight different assessment techniques were used, some of which had multiple parts, and all contained varied degree of subjective and objective assessment techniques. As discussed by Wood *et al.* (2003) as well as Mustofo (2020), an ideal PBL assessment contains multiple assessment methods. Therefore, this study incorporated many techniques in which multiple aspects of the PBL were assessed, and they were assessed by varied personnel involved in the pedagogy, including the students themselves. This investigation posed three research questions, which can be answered as follows:

1) Is the use of a PBL pedagogy promoting the students understanding of the course outcomes?

Yes, the PBL pedagogy is improving students understanding of the course outcomes. This can clearly be seen in the following assessment results: Self-assessment, Pre- and Post-assessment, Comprehensive five-session survey, Level of Understanding and Confidence Survey, Group Presentations, Peer Assessment, and Report. All of these assessment techniques provide quality and reliable results that demonstrate the effectiveness of the PBL intervention across both classes in all of the semesters investigated.

2) Which delivery method did the students prefer from each course?

The results indicate that in-class lectures, one-on-one with the instructor, and in class discussion were the most effective delivery methods used in this study. However, the students were also asked what their preferred delivery method was outside of what their perceived effectiveness. The results show that the students preferred in-class lectures, field hunting, and one-on-one with the instructor. The field hunting refers to a specific requirement of the project in which students left the classroom to walk around campus and the city to find and assess concrete problems that they found. Based on these two indicators, an in-class lecture and one-on-on with the instructor are the two highest rated, and most effective, delivery methods.

3) Which assessment method has provided the most beneficial results?

All of the methods used in this study are providing unique and individual results that are useful and beneficial to the study. Therefore, it depends on what the researcher is attempting to ascertain. If one desires to know which delivery method the students prefer, then the delivery method ranking provides the most beneficial results. If one desires to know how well students are performing on their reports, across the semesters,

then the report assessment is the most beneficial. However, if a researcher desired to minimize the number of surveys throughout the course, and still obtain beneficial assessment, the authors would recommend the following PBL techniques be used: Pre- and Post-student assessment, Level of Understanding and Confidence, Pre- and post-objective student assessment, and Report assessment. These four assessment techniques provide both direct (objective) and indirect (subjective) assessment, while only requiring four total surveys, which could be combined and administered at the same time, therefore only two survey sessions are used.

This study further demonstrates the effectiveness that a PBL pedagogy can have on technical engineering/construction classes. Through this investigation, it was shown that utilizing a PBL pedagogy is not only ideal for student education, but proper assessment is also required to ascertain which form of PBL delivery is the most ideal for the intended course. This study demonstrated eight different assessment methods that can be utilized by future instructors/researchers to determine the effectiveness of their PBL pedagogy.

## DISCUSSION

The authors realize that it may be difficult an instructor/researcher to incorporate all eight of these assessment techniques in one class, without compromising the course schedule. Although, the authors found all methods to be beneficial in their own manner, not all of them were easy to implement. In order to help a new instructor/researcher wishing to implement these techniques in their course, the authors have provided a summary of the "ease of application" for all of the assessment methods used. They were assessed on a 5-point scale in which 1 was very easy, and 5 was very hard to implement. The results can be seen in Table 7.

Table 7
Authors' perception of ease of application of the assessment methods

| | Ease of application |
|---|---|
| Self-assessment | 2 |
| Pre- and Post- self-assessment | 2 |
| Teaching methods ranking | 2 |
| Comprehensive Five-Session Survey | 5 |
| Level of Understanding and Confidence Survey | 2 |
| Group Presentation | 2 |
| Report | 1 |
| Peer-Assessment | 2 |

As seen in Table 7, the report assessment was the easiest assessment, as a final report is typically required for most courses, and only required the instructor to assess it upon submission. Contrary to this, the most difficult assessment method to implement was the comprehensive five-session survey. Other researchers (Choden, 2020 and Torres, 2021) do a much higher number of sessions, upwards to eight, however, the authors felt as though the five-sessions were too invasive to the course structure. This was one of the main reasons why it was dropped from the CIM 4340 course, as the students became overwhelmed and complained about all of the surveys. Therefore, in general it is

recommended to minimize the number of surveys asked of the students. This is why this assessment method was blended into other surveys or other tasks asked of the students in the CIM 3330. This method could be completed with future researchers, however, it may be easier to simply eliminate it, and extract 1-2 topics that they may want to keep. All other methods were given a rank of 2 as they were fairly easy to implement, however, since they are all surveys (or a student presentation) the students tended to not prefer these methods over other methods. Too many surveys could lead to students not providing meaningful feedback or leaving sections blank, since they are not required for a grade or credit.

**REFERENCES**

Alkhasawneh, Esra & Mrayyan, Majd & Docherty, Charles & Alashram, Safaa & Yousef, Hamzeh. (2008). Problem-based learning (PBL): Assessing students' learning preferences using VARK. *Nurse education today. 28*, 572-9. 10.1016/j.nedt.2007.09.012.

Barrows, H.S. (1996), Problem-based learning in medicine and beyond: A brief overview. New Directions for Teaching and Learning, 1996: 3-12. https://doi.org/10.1002/tl.37219966804

Biggs, John. (2003). Aligning teaching and assessing to course objectives. International Conference on Teaching and Learning in Higher Education: New trend and innovations. 2.

Choden, T., & Kijkuakul, S. (2020). Blending Problem Based Learning with Scientific Argumentation to Enhance Students' Understanding of Basic Genetics. *International Journal of Instruction, 13*(1), 445-462. https://doi.org/10.29333/iji.2020.13129a

Elizondo-Montemayor, Leticia. (2004). Formative and Summative Assessment of the Problem Based Learning Tutorial Session Using a Criterion Referenced System. JIAMSE. 14.

Hu, J., Ortiz, A., and Sriraman, V., "Implementing PBL in a Concrete Construction Course", ASEE Annual Convention, Indianapolis, IN, June 2014.

Lee, R., & Kwan, C. (1997). "The Use of Problem-Based Learning in Medical Education." Medicine, DOI:10.6145/JME.199706_*1*(2).0003Corpus ID: 74717272

Macdonald, R. (2005), "Assessment strategies for enquiry and problem-based learning", in Barrett, T., Mac Labhrainn, I. and Fallon, H. (Eds), Handbook of Enquiry & Problem Based Learning, CELT, Galway, pp. 85-93.

Macdonald, R. and Savin-Baden, M.A. (2004), A Briefing on Assessment in Problem-Based Learning, LTSN Generic Centre, Series No. 13, Heslington York.

Major, C., and B. Palmer, (2001).''Assessing the Effectiveness of Problem-Based Learning in Higher Education: Lessons from the Literature,'' *Academic Exchange Quarterly, 5*(1).

Moayyedian, Mehdi & Alateeqi, Ameenah & Alzuabi, Dalal & Burhama, Reem & Alathari, Shouq. (2020). Solar Car Chassis Design and Optimization Using PBL and Design of Experiment. 10.5278/ojs.jpblhe.v0i0.5805.

Moursund, David. (2003). "Project-based learning using information technology." International Society for Technology in Education, ISBN 1-56484-145-6

Mustofa, R. F., & Hidayah, Y. R. (2020). The Effect of Problem-Based Learning on Lateral Thinking Skills. *International Journal of Instruction, 13*(1), 463-474. https://doi.org/10.29333/iji.2020.13130a

Palupi, B. S., Subiyantoro, S., Rukayah, & Triyanto. (2020). The Effectiveness of Guided Inquiry Learning (GIL) and Problem-Based Learning (PBL) for Explanatory Writing Skill. *International Journal of Instruction, 13*(1), 713-730. https://doi.org/10.29333/iji.2020.13146a

Plucker, J., & Nowak, J. (1999). How to use problem-based learning in the classroom. Roeper Review, *Journal of Turkish Science Education, 22*(1), 69-70.

Sriraman, V.*, Ortiz, A., Torres, A., "Teaching Sustainable Engineering and Industrial Ecology using a Hybrid Problem-Project Based Learning Approach", *Journal of Engineering Technology, 4*(2), Fall 2017, pp. 8-15

Torres, A., Sriraman, V., & Ortiz, A. (2021). Comprehensive assessment of a project based learning application in a project management course. *International Journal of Instruction, 14*(3), 463-480. https://doi.org/10.29333/iji.2021.14327a

Usmani, Ambreen & Sultan, Syed & Ali, Sobia & Fatima, Nazish & Babar, Shazia. (2011). Comparison of students and facilitators' perception of implementing problem based learning. JPMA. *The Journal of the Pakistan Medical Association, 61*, 332-5.

Waters, R., & McCracken, M. (1997). Assessment and evaluation in problem-based learning. Proceedings Frontiers in Education 1997 27th Annual Conference. *Teaching and Learning in an Era of Change, 2*, 689-693 vol.2.

Pellegrino, J. W., & Hilton, M. L. (2012). Developing transferable knowledge and skills in the 21st century. Washington, DC: National Research Council.

Wood, D. F. (2003). "ABC of learning and teaching in medicine: Problem based learning". *BMJ. 326*(7384), 328–330. doi:10.1136/bmj.326.7384.328. PMC 1125189. PMID 12574050.

Zotou, Maria & Tambouris, Efthimios & Tarabanis, Konstantinos. (2020). Data-driven problem based learning: enhancing problem based learning with learning analytics. *Educational Technology Research and Development, 68*. 10.1007/s11423-020-09828-8.