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Implementing PBL in a Concrete Construction Course

Dr. Jiong Hu, Texas State University, San Marcos

Dr. Jiong Hu an Assistant Professor in the Concrete Industry Management (CIM) program at Texas State University, United States. Dr. Hu received his BS and MS in 1996 and 1999 from Southeast University, China, respectively, and his PhD from Iowa State University in 2005. He is teaching construction and concrete related courses including Construction Materials and Processes, Concrete Construction Methods, Management of Concrete Products and Concrete Problems: Diagnosis, Prevention, and Dispute Resolution. His research interests include concrete materials and construction, engineering and technology education and problem-based learning.

Dr. Araceli Martinez Ortiz, Texas State University, San Marcos

Araceli Martinez Ortiz, Ph.D, is Assistant Professor of Engineering Education in the College of Education at Texas State University. She teachers graduate courses in the Department of Curriculum and Instruction and collaborates on various state and national STEM teacher professional development programs and pre-engineering student outreach programs.

Araceli holds a B.S. in Industrial Engineering from the University of Michigan in Ann Arbor and a M.S. degree in Manufacturing Management from Kettering University. After a career in engineering working with companies such as General Motors, Ford Motor Company and Microsoft, she pursued a Master's degree in Education from Michigan State University. Later, Araceli completed a PhD in Engineering Education from Tufts University. She is also experienced in education policy and prior to joining the Professoriate, she was Director of Educator Preparation - focusing on STEM education projects at the Texas Higher Education Coordinating Board.

In 2013, she was named Director of the Texas State University LBJ Institute for STEM Education and Research. Her research interests include studying the role of engineering as a curricular context and problem-based learning as an instructional strategy to facilitate students' mathematics and science learning. She works with teachers and students from traditionally under-served populations and seeks to understand challenges and solutions to support student academic readiness for college and career success.

Contact: amo56@txstate.edu

Dr. Vedaraman Sriraman, Texas State University, San Marcos

Dr. Vedaraman Sriraman is a University Distinguished Professor of Engineering Technology at Texas State University. Dr. Sriraman's degrees are in Mechanical and Industrial Engineering. He is a faculty associate of the LBJ Institute for STEM Education and Research at Texas State University. His research interests are in engineering education, sustainability and applied statistics. In the past, he has implemented several grants from the NSF and SME-EF. He has also received several teaching awards at Texas State.

Implementing PBL in a Concrete Construction Course

Abstract

An action-research case study is presented detailing the evolutionary changes in the implementation of the problem-based learning (PBL) method in an undergraduate concrete construction course. The case study incorporates the perspective of the course instructor as action-researcher and reviews the quantitative and qualitative student impact data. PBL was first implemented in this course in 2011 as a student centered active learning pedagogy. The first implementation adopted a minimalist approach owing to the issues typically associated with PBL adoption such as increased instructor effort and student resistance to a new learning paradigm. Through 2012 and 2013, the action researcher continued to adopt and increase the scope of the PBL application. In 2013, the course moved from a summer offering to a spring offering. This change proved to be very positive for both instructor and students alike. Most significantly, the change in schedule permitted a longer time span in which the PBL activities were more effectively implemented compared to the short, fast paced summer offering. The evolution in the adaptation of PBL pedagogy and the key components for success in the implementation of PBL in the engineering and engineering technology classroom will be presented. In addition, a discussion of the assessment methods that also underwent an evolution in scope and detail will be presented. The paper concludes with recommendations for further research.

Introduction to PBL

Problem Based Learning (PBL) was introduced in the then newly founded School of Medicine at McMaster University in 1969. The impetus for the educators at McMaster's was to "stay away from the standard building - block structure, where a lot of content is shoved down the throats of students, which they do not retain anyway, and adopt a system where students are actively involved in the learning process" [1]. This new system was PBL. In the wake of this early success in implementing PBL at McMaster, several other newly founded medical schools such as those in Maastricht in the Netherlands and Newcastle in Australia developed curricula based on PBL in the early 1970s [2].

PBL has enormous popularity all over the world today [3]. It has been applied in many disciplines besides medicine. In particular, in Science, Technology, Engineering and Math (STEM), this pedagogical approach has been applied in nearly all disciplines. Bowe [4] and Kelly and Finlayson [5] describe the application of PBL in first year Physics and Chemistry courses respectively. Nuutila et al. [6] describe the application of PBL in computer programming. Allen and Tanner [7] describe the use of PBL in teaching Cell Biology and Cazolla [8] describes the use of PBL in teaching Mathematics. In the world of Engineering and Technology PBL enjoys considerable popularity. The following provide some examples of application and the impacted areas: Engineering Design [9], Chemical Engineering [10], Biomedical Engineering [11], Civil Engineering [12], Circuit Analysis [13], Construction [14] and Microelectronics [15].

What does the PBL instructional approach entail? To answer this question it would be worthwhile to examine why medical educators gravitated to this approach. Findings suggest that teaching content in anatomy, psychology, and pharmacology in a separate teacher driven classroom did little to improve the practical application or diagnosis skills required by medical doctors [16]. Accordingly, Savery [16] defines "PBL as an instructional learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem. Critical to the success of the approach is the selection of ill-structured problems (often interdisciplinary) and a tutor who guides the learning process and conducts a through debriefing at the conclusion of the learning experience".

Evolution of the course

At Texas State University, a course in *Concrete Problems, Diagnosis and Repair* has been taught since 2011. This course exposes upper division undergraduate engineering technology students to various kinds of concrete structure and product failure, the mechanisms that underlie such failure, and the repair or restorative processes that would "fix" these problems. Such ill structured problems require diagnostic skills based on theoretical knowledge, similar to the medical students' education challenges that gave rise to the PBL approach in the first place. Thus, in addition to mastering theoretical technical content knowledge, it is important for students to develop problem solving skills. The importance of problem solving skills for future engineers and technologists (engineers hereafter) can hardly be overstated. Solving open-ended problems is arguably the corner stone of the engineering endeavor and employers look for engineers who are effective at solving open-ended problems faced in real workplaces [17]. However, the practice of teaching students technical content while providing opportunities for the learning of field specific problem solving is challenging. In addition, an effort to strategically improve engineering education and university teaching practice in a scholarly manner requires thoughtfulness and use of carefully selected methodology. Case and Light [18] argue for this very need and present various emerging methodologies in engineering education research.

In the first offering, the course material was delivered nearly completely through the medium of traditional classroom based lecture. The instructor included PBL only within one project wherein students were required to "hunt" for concrete problems in and around the campus, identify the failure mechanism and finally recommend the subsequent corrective procedures. This first PBL implementation adopted a minimalist approach that included problem solving in a team based-environment

In the second offering of the course in 2012, the application of PBL pedagogy was cautiously increased so as not to overburden the instructor with significant course redesign and the fact that the course was being offered in a fast paced 4.5 weeks long summer session. The key reason for adopting PBL was the same as that which motivated medical schools. 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 include 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 squarely.

In the third offering of the course, the instructor was able to expansively apply PBL. In addition, action based research (to be described below) was included. This occurred in Spring 2013. The course had moved from a summer session offering to a long semester. Thus, both students and instructor had the luxury of 3.5 months as opposed to little over a month. Additionally, as the use of PBL had been increased in 2012, the continued expansion of PBL use in 2013 was not contrived and seemed natural. The details of the expanded version of PBL are presented in the next section.

Details of Current Implementation

Due to its unique nature (i.e. including significant theoretical technical content and problem solving aspects), the *Concrete Problems, Diagnosis and Repair* course was taught with a combination of lecture-based and PBL approaches. Most of the theoretical content was delivered through traditional lecture-based approach in order to provide students with sufficient basic technical knowledge. The PBL activities including the *Field Hunting of Concrete Distresses* project and *Concrete Distresses and Repair Case Studies* term project were used to reinforce content knowledge and develop critical thinking and problem-solving skills.

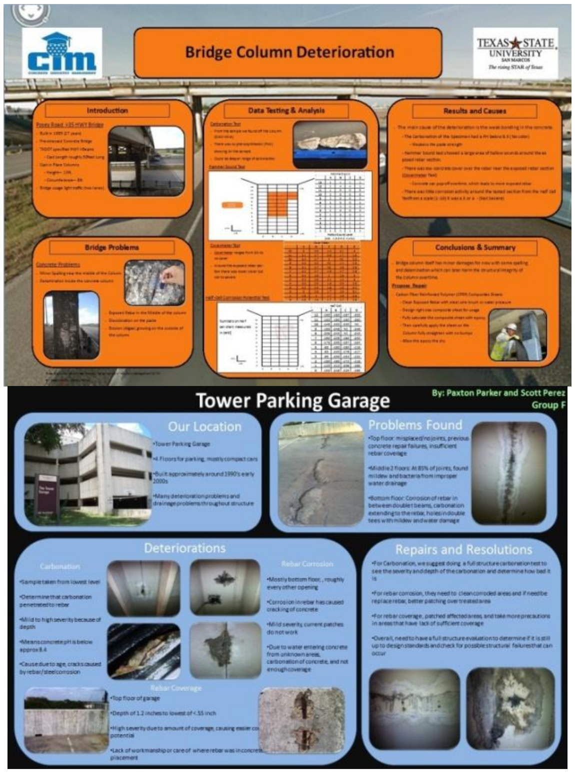
In order to better organize the multitude of topics covered in this course, the class material was thematically arranged into three major segments, which included a) typical concrete problem and deterioration mechanisms; b) diagnosis and evaluation of concrete problems; and c) concrete protection and distress prevention. This special arrangement of course content helped students to distinguish the roles of the different components covered in the course and the logical progression in which problems are resolved. Due to the uniqueness and complex nature of concrete distresses that result from variation in concrete mixtures, and differences in environmental and physical exposure, there is no ”standard” procedure to identify, evaluate or repair concrete distresses. This class therefore used the PBL approach in addition to lectures so as to enable students to confront open-ended workplace problems, develop deep understanding of conceptual knowledge, and become adept in self-learning.

In order to help students gain a fundamental understanding of PBL and appreciation for the new pedagogical approach, a lecture on PBL entitled “*How to be Successful as an Engineering Student By Developing Content Knowledge & Cross-Cutting Knowledge and Skills*” was given at the beginning of the semester in the Spring 2013 offering. The PBL approach was then used throughout the class with case-based examples, in class discussions, as well as in the form of special class projects. Following the section on the mechanism of concrete problems and deteriorations, an activity called “*Field Hunting of Concrete Distresses*” was assigned to the class. The words “concrete distress” here means instances of concrete structures that were damaged or had their integrity compromised. Students were broken into groups and required to perform a “field hunt”, the object of which was to identify instances of concrete problems within and outside of the campus.

Figure 1 illustrates examples of concrete problems students identified during this activity. The photos on the left and on the right are associated with deteriorations from an underwater structure and a recreation facility respectively. All results, including digital pictures of the concrete problems and extent of concrete distresses (through onsite measurements of, for example, patterns, lengths, width of cracks) were to be documented. Based upon results obtained from the field hunting activity, students were to present their work in front of judges (served by the instructor and faculty members), and their peers. During the presentation, students not only presented their findings of different kinds of concrete distresses, but also provided their analysis of potential causes of these distresses. Thus, the "problem" to be solved was open-ended and defined by the student. While students' analyses of potential causes of these distresses were not necessarily accurate, the process of brainstorming the causes for failure and the determination of appropriate relief measures exercises problem solving and critical thinking skills because unlike academic problems, no one "correct" solution may be found by reading a textbook on the topic. During the field hunting, students encountered a variety of concrete problems, including delamination, cracking, plastic shrinkage, honeycomb, efflorescence, spalling, corrosion and poor repairing. The activity was intentionally designed to be conducted in the early part of the semester, while students still lacked specific technical background on related topics. While the approach was challenging for students, the presentations led to good discussions and cultivated their interest in a gamut of technical topics. This in turn promoted students' enthusiasm in the remaining topics of the course that followed this activity.

Figure 1. Examples of photos students took during field hunting

As there were a significant number of special concrete problems to be covered in the course, it was not practically possible to cover all of these in depth due to limited availability of time. In order to provide students with the opportunity for a comprehensive study of particular concrete distress, from mechanism, identification, to potential methods for repairing, another PBL activity entitled "*Concrete Distresses and Repair Case Studies*" was included toward the end of the semester. Students in the class were asked to choose specific concrete problems and perform a comprehensive study based on fundamental knowledge obtained through the class, together with literature review, and case studies. The project was announced mid-semester, which allowed students to have approximately six weeks to complete the assignment. Besides regular updates from students, the instructor also provided one-on-one consultation weekly either in class or during office hours. These consultations facilitated the PBL pedagogy by enabling the instructor to provide knowledge on demand. Students were required to prepare a poster based on the topic they selected and provide information including mechanism of concrete distresses, measures to identify and evaluate the distresses, possible causes of the distresses, measurements and measures to minimize/mitigate the distresses. During this project, students were encouraged to use advanced equipment to examine actual structures and use the information thus gained to provide better evaluation of structural integrity and rational analysis of potential causes of distresses. In contrast to the conventional lecture and laboratory environment, in which students were told to use specific equipment or tools for specific specimens, student in this exercise were asked to identify the equipment or tools that they might require and then consult with the instructor on the procedural details of equipment usage. Specifically, students were required to include a case study in each of their posters. Students were to present their poster in front of the judge panel composed of industrial experts and faculty members from related programs within the department. Two examples of student posters may be found in Figure 2. All posters were set up in a room with enough space for judges to walk past individual posters and ask questions related to those posters. The setup allowed students to have a one-on-one opportunity to present their poster to individual judges.



Bridge Column Deterioration

TEXAS STATE UNIVERSITY SAN MARCOS
The rising STAR of Texas

Introduction

Data Testing & Analysis

Results and Causes

Bridge Problems

Conclusions & Summary

Tower Parking Garage

By: Paxton Parker and Scott Perez
Group F

Our Location

•Tower Parking Garage

•4 Floors for parking, mostly compact cars

•Built approximately around 1990's early 2000s

•Many deterioration problems and drainage problems throughout structure

Problems Found

•Top floor: misplaced/no joints, previous concrete repair failures, insufficient rebar coverage

•Middle 2 floors: At 85% of joints, found mildew and bacteria from improper water drainage

•Bottom floor: Corrosion of rebar in between double t beams, carbonation extending to the rebar, holes in double tees with mildew and water damage

Deteriorations

Carbonation

•Sample taken from lowest level

•Determine that carbonation penetrated to rebar

•Mild to high severity because of depth

•Means concrete pH is below approx 8.4

•Cause due to age, cracks caused by rebar/steel corrosion

Rebar Corrosion

•Mostly bottom floor, , roughly every other opening

•Corrosion in rebar has caused cracking of concrete

•Mild severity, current patches do not work

•Due to water entering concrete from unknown areas, carbonation of concrete, and not enough coverage

Rebar Coverage

•Top floor of garage

•Depth of 1.2 inches to lowest of <.55 inch

•High severity due to amount of coverage, causing easier co potential

•Lack of workmanship or care of where rebar was in concrete placement

Repairs and Resolutions

•For Carbonation, we suggest doing a full structure carbonation test to see the severity and depth of the carbonation and determine how bad it is

•For rebar corrosion, they need to clean corroded areas and if need be replace rebar, better patching over treated area

•For rebar coverage, patched affected areas, and take more precautions in areas that have lack of sufficient coverage

•Overall, need to have a full structure evaluation to determine if it is still up to design standards and check for possible structural failures that can occur

Figure 2. Examples of posters presented in the poster competition

One other noteworthy change in the spring 2013 offering was the evaluation method, i.e., the format of exam questions. As the class is highly PBL orientated, in order to evaluate the effectiveness of PBL, instead of employing regular types of exam questions, such as multiple choices, fill-in-the-blank, and short answers, specific PBL related questions were included in all three exams. The questions were constructed in the manner of a case study. Thus, the exam was also cast in the model of real world problem solving, requiring the application of knowledge rather than simply regurgitating facts and data. The final exam was completely PBL-based and included three specific cases. The exam comprised a written section and an oral section, which accounted for 70% and 30% of the grade respectively. Information provided in the cases included an explanation of the structure (location, age, environmental condition, etc.) and a description of the visual appearance of concrete distresses. This information was provided to the students one week before the final exam, which allowed them to have enough time to review related documents and search for potential solutions. During the written portion of the exam, the students were required to propose in-situ test methods and procedures to evaluate structural integrity and explain the reason for their selection. As multiple methods can be used for similar purposes and as dynamic adjustments of test methods and procedures are often called for during the course of testing, answers to these questions were generally open-ended. Since problem solving approaches and thought processes that underlie them are often difficult to describe or capture in a written exam, the oral portion mentioned earlier was incorporated. The oral portion facilitated a dialogue between the instructor and the individual student on a one-on-one basis. The dialogue also included follow up questions to students based on their responses to the written portion of the exam. The oral evaluations were therefore focused more so on the students' problem solving approaches, rather than on technical content.

The method outlined in this paper regarding PBL implementation may be applied in other courses. For instance, in a materials course, students could be presented with various failed products such as a failed reinforced concrete beam, or in a soil mechanics course, students could be presented with various foundation failures at the beginning of the semester. These would then serve as the semester long problem that students would strive to solve. The instructor would progressively provide technical instruction (on a demand basis) such as would enable students to tackle specific aspects of a larger problem. The following section describes action research methodology which was incorporated in the third offering.

Action Research Methodology

Action research is a theoretically based research methodology that shows promise in expanding the study and improvement of engineering education. In action research, as opposed to traditional research, the researcher is a part of what is being studied, most times as the instructor, examining his or her own problems or new practices. Thus, action research is carried out in the natural classroom setting (in-situ) and with a spirit of continuous improvement [19]. The four- step cycle of action research described by Kemmis & McTaggart [20] was utilized to guide implementation of the research presented in this case study: 1) [carry] out a plan of action to improve what is already happening, 2) [take] action to implement the plan, 3) observe the effects of action in the context in which it occurs, and

4) reflect on these effects as a basis for further planning, and subsequent action.

Research Questions

One of the goals of this research project was to investigate the effects of new formative and summative assessment instruments upon student learning in the PBL-infused course. These instruments were designed and incorporated in the third offering of the course. The research questions that were explored are listed below:

1) *How effective are the new assessment instruments at quantifying the impact of a PBL-enhanced curriculum upon student learning as measured by students' improvement in use of critical thinking and achievement of academic course learning objectives?*
2) *To what extent do the authentic problem-solving experiences of the PBL-enhanced curriculum impact student problem solving skill development and career motivation as measured by task-specific, criterion-referenced analytic rubrics and clinical interviews?*

Research Methods

A mixed methods research design was utilized and data was collected with pre-assessment of content knowledge inventory, a survey of expectations and perceptions of learning, and a formative problem solving assessment for 10 students during the Fall 2013 offering of the aforementioned course. A quasi-experimental methodology was used to determine whether the PBL intervention had the intended effect upon the students. Theoretically based and field-tested instruments for measuring student cognitive changes, problem solving skill development, and changes in motivation, were selected as a basis for the development of course specific assessment tools.

Project Plan

The project plan for this action research project involved course curriculum planning, development of problem based learning activities, and fine-tuning of assessment instruments. This was followed by course implementation, data collection, and data analysis.

Data Collection and Analysis

This experiment was a pre-post design and was analyzed using frequency statistics and basic descriptive statistics. Given the small sample size (n=9), no other statistical analyses were conducted with the data at this time. A student self-administered survey was designed and given to the students in the course prior to the beginning of the course and at the end of the course.

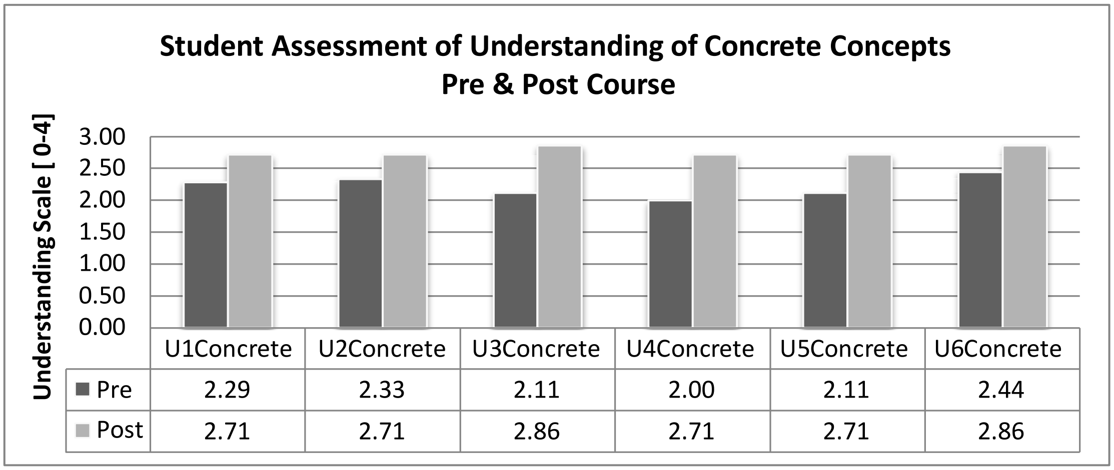
The first section of the instrument was designed to collect demographic information and student course expectations and self-reported academic preferences, while the second section was designed to collect data to evaluate students' own perceptions on the degree of accomplishment regarding various expected learning outcomes from the class. A total of six outcomes were evaluated:

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

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.

Results

As can be seen in Figure 3 below from the 2013 class of students, students rated themselves at a level ranging between 2.0 (moderate understanding) to 2.44 before the course on each of the six elements of understanding defined for the course. These are indicated as the average rating scores as shown in the pre-survey bar above. Students rated themselves at a level ranging between 2.71 to 2.86 (approaching proficient understanding) after the course on each of the six elements of understanding defined for the course. There was a clear improvement in students' assessment of their increased understanding of course specific content after the course intervention.



	U1Concrete	U2Concrete	U3Concrete	U4Concrete	U5Concrete	U6Concrete
■ Pre	2.29	2.33	2.11	2.00	2.11	2.44
■ Post	2.71	2.71	2.86	2.71	2.71	2.86

Figure 3. Course outcomes from the 2013 student self-assessment

Changes from 2012 to 2013 with two separate groups

Figure 4 below illustrates a comparison of the degree of accomplishment of learning outcomes between 2012 and 2013 as the course evolved. Students evaluated each outcome using a scale of 1 to 8, with a score of 1 indicating very strong disagreement and a score of 8 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 the figure, while all outcomes received higher scores in spring 2013 in comparison to 2012, outcome 6 (develop problem-solving skills and self-learning abilities) received significantly higher student endorsement in comparison to results from summer 2012. This significant 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 long semester, they experienced the more systematic PBL implementation and they had the benefit of the improved course structure redesign. However, data was not collected in the very limited PBL version of the course that occurred in 2011.

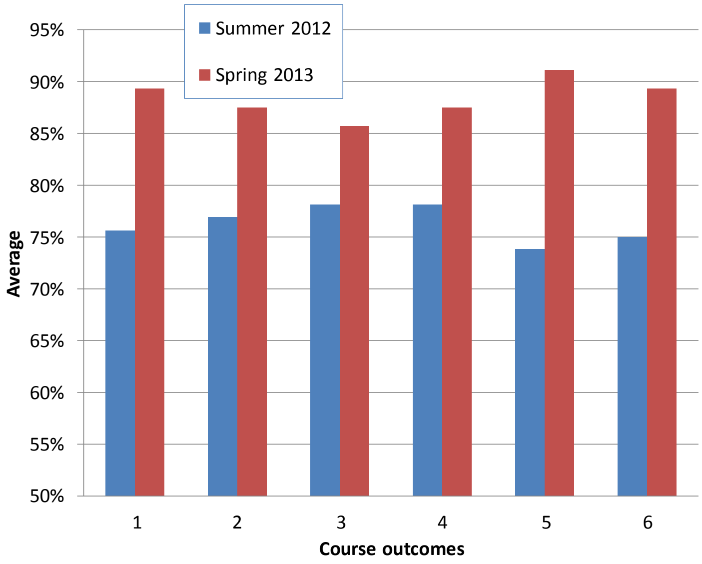


Figure 4. Course outcomes from student self-evaluation 2012 to 2013

The authors also evaluated the effectiveness and preference ranking of different delivery methods used in the class. Toward the end of the semester, students were asked to rank the delivery method they considered the most effective and the preferred method for learning (with 1 being the highest and 14 the lowest) based on their experiences in the course. Results of the analysis based on the 2012 and 2013 offerings are summarized in Table 1.

Table 1. Effectiveness and preference ranking from different teaching methods

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

As shown in Table 1, while “Lecturers (Instructor)” was ranked first in both effectiveness and preference in 2012, the rank dropped to fourth and third respectively in 2013. The most improved delivery method was found to be “One-on-One Consultation with the Instructor”, raised from the seventh and eighth to first and third respectively in effectiveness and preference ranking. Meanwhile, PBL-based activities including in-class discussion, term project, and field hunting remained very highly ranked. Results indicated that students highly valued the PBL approach.

The survey designed to collect information in 2013 was a very complete compilation of student self-perception questions and knowledge competencies. The first section included a short section with four questions on student demographic information. The second section included six questions regarding student motivation general 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. The fourth section included twelve questions from the ABET defined competencies. The fifth section included six questions regarding college and career readiness standards. The survey was effective because it was defined with the end objectives in mind using high quality questions. The format for the responses of most sections utilized a 5-point Likert scale and some open-ended responses.

Conclusions and recommendations for future work

Evolution in the adaptation of PBL pedagogy

According to survey results as well as observations from the instructor, most of the PBL-related pedagogies applied in this course were effective and improved the quality of the student learning experience. After teaching the course over three semesters, the most-desired and effective practices that fit this class were lectures, in-class (guided) discussions, field concrete distress hunting, and a final term project. While traditional lectures are still deemed necessary for imparting basic technical background, a lecture at the beginning of the semester describing the PBL approach to students is believed to be helpful to provide students a basic understanding of PBL and to promote an appreciation for the approach. These PBL approaches, especially the *field concrete distress hunting*, were found to be very helpful in promoting students’ enthusiasm about the class subjects. Other practices that were also found to be effective were the *Concrete Distresses and Repair Case Studies (Term Project),* as well as in-class discussions, and one-on-one consultation associated with the term project.

Evolution in the assessment methods

Recent internationally coordinated research efforts and publications have established engineering education research (EER) as a connected field of inquiry [21]. This has resulted in a substantial body of published research guidance involving quantitative, qualitative and mixed research methods [22,23,24]. This foundation has been used by the researchers of this study as a guide in the selection of more sophisticated assessment methods over the years. Assessment methods have evolved over the three years of this study in answer to refined research questions and supported by additional sources used to design the survey instruments and knowledge inventory. The original 2011 and 2012 assessment instruments were brief surveys that employed a forced effectiveness ranking of numbers 1-14, and only addressed students’ opinions regarding their preference for various instructional methods. In the 2013 course, the assessment instruments progressed to include metacognitive elements in the form of multi-element surveys and knowledge inventories, as students considered their own learning of specific concrete technology content understandings as well as general engineering technology skill development. These additional assessments are very rich and have the potential for answering the research questions regarding student learning. The data collected in 2013 is very useful and has definitely illuminated the opportunities for gaining insight into student learning. Nevertheless, there is room for further improvement, particularly in the manner in which the surveys were administered. Students did not appreciate the frequency of assessments, which included weekly updates, self-evaluations, and end-of-the-class self-assessment surveys. At times, understandably, students did not effectively complete the assessments. It was more successful when a survey was integrated as part of a lesson. It is a fine balance to teach and to assess, and when research surveys are administered as add-ons, it can be overwhelming for students, in particular toward the end of the semester when students have many additional assignments and projects. The survey instruments evolved from previous versions and were very effective for this course. The instruments will need to be further validated to confirm that they are measuring the variables claimed and will be tested with a larger sample size of students and a control group in order to assure reliability.

Future Recommendations

In a future offering, in order to further improve the class, the instructor plans on preparing more case studies associated with homework or in-class quizzes throughout the semester and subsequent follow up with in-class discussion. Case studies will cover all three major segments, which include typical concrete problem and deterioration mechanisms; diagnosis and evaluation of concrete problems; and concrete protection and distress prevention. In addition, efforts will be used to better organize the weekly update from students regarding the final term project. Specific questions will be developed for students to respond to week by week, which should better guide them in the problem solving. Additional assessment instruments as well as ways to encourage students to participate in assessments and surveys will be developed. In future courses, formative assessments methods will be utilized to incorporate smaller assessment “chunks” into instruction in such a way that data can be collected as part of the learning experience. In addition, some of the instruments can be designed to be more effective and promote greater interest from students in order to motivate them to complete these evaluations more thoughtfully. In the next course offering, an experimental design to include a control group will be set up in order to discern if positive changes in students’ understanding are directly attributable to the use of problem-based learning instructional approaches.

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