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Abstract

As engineering education has moved from didactic instruction to more learner-centered methodologies, new and innovative techniques are being used to teach engineering student. One such technique is problem-based learning. Problem-based learning (PBL) has its roots in medical field, where it has been used for over a century to portray the complex and ill-structured nature of medicine and to develop complex professional reasoning in medical students. This paper describes an investigation of problem-based learning on undergraduate electrical engineering students' conceptual understanding. Fifty-five students enrolled in an electrical engineering course at a Mid-western university participated in this student. The study utilized a within-subjects A-B-A-B research design with traditional lecture as the baseline phase and problem-based learning as the experimental phase of the study. Participants completed pre-post tests surrounding the four topics covered in the study. Results suggested that participants' learning gains from problem-based learning were more than learning gains from traditional lecture.

Introduction

Recently, there has been a shift from using lecture-based teaching methods in the undergraduate courses in engineering disciplines to using a more learner-centered teaching, such as problem-based learning. This shift is fueled by the need for future engineers to demonstrate the use of higher order thinking, problem solving, and interpersonal aspects of a career, such as communication and team-work skills (NAE, 2005). Specifically, the engineering field is seeing shifts in the types of engineers needed to emerge from college ready to participate as active and effective members of a global society. This leads to the search for a new pedagogy that will allow students to have higher critical thinking skills and create problem solvers who can work in the complex and ill structured environment. However, it is not an easy task to teach students to deal with the changing nature and unpredictability of the field and the problems that will emerge. Yet students need to develop skills that will allow them to continually learn, problem-solve, and adapt. One approach, problem-based learning (PBL) has the potential to help students to cope with the demands of the complexities of the field.

Problem-based Learning (PBL)

Problem-based learning is a non-traditional, inductive, student-centered approach that centers on the introduction of a real-life problem (Ehrlich, 1998). The problem is "a complex task created by the need to design, create, build, repair, and/or improve something" (Burgess, 2004, p.42). The students seek to solve this problem through investigation such as inquiry, creating and testing hypotheses, collecting data, obtaining and utilizing resources, and independent and collaborative research. PBL was developed in the 1950s to respond to criticism that traditional lecture did not prepare medical students for problem-solving in clinical settings (Hung, Jonassen, and Liu, 2008).

Problem-based learning in engineering education. The fields of science, technology, engineering, and math (STEM) education have increasingly implemented problem-based learning during the past two decades (Eberlein et al., 2008). The basic principle of PBL in science education is that students will learn and retain information more effectively when it is presented, discussed, and applied to a real-life format.

Bizjak (2008) described the incorporation of PBL in an electrical engineering graduate program in Slovenia. The students were divided into small groups to develop a plan for an electrical power network for a small village or town. The authors found that students gained more substantial knowledge than with traditional methods, as evidenced by higher test scores. PBL also received positive feedback from a survey questionnaire taken by students and faculty. Specifically, students reported that PBL allowed them to gain confidence in their problem-solving abilities, prepared them for their future careers, and improved their inter-personal and collaborative skills by working in a group. In another electrical engineering example, De Camargo Ribiero (2008) conducted a qualitative study of student evaluation of the problem-based learning approach in a classroom at a university in Brazil. Students were observed during the PBL module and completed an open-ended questionnaire at the end. Students reported that PBL approach was more engaging and interesting as it allowed them to construct their own knowledge instead of absorbing teachers' words and seek information to solve problems. Students also reported that they developed specific work skills such as, ability to research, produce syntheses, express ideas, communicate, and effectively work in teams to develop solutions to problems. Previous research has suggested that students positively evaluate problem-based learning approach. However, majority of this research on PBL in engineering has focused on students' perceptions of this pedagogical approach. Our purpose in this study was to go beyond student perceptions and examine the impact of problem-based learning on students' learning and conceptual understanding.

Methodology

Participants

Fifty-five undergraduate students enrolled in an electrical engineering course at a large mid-western university participated in this study. Participants included forty-six males and nine females, primarily juniors (N=32), seniors (N=16), and a few sophomores (N=7). Forty-nine percent (N=27) of the participants were majoring in mechanical and aerospace engineering; about sixteen percent (N=9) in chemical engineering; about fifteen percent in electrical engineering (N=8), and remaining were majoring in other disciplines including civil engineering (N=3), biosystems engineering (N=3), industrial engineering and management, architecture (N=1), and two did not report their major.

Procedure

This study utilized pre-post test in an *A-B-A-B* research design. Specifically, this research design involved measuring the dependent variable (i.e., students' conceptual understanding) both before and after the baseline phase (i.e., first A - traditional lecture method for Ohm's and Kirchoff's Laws); introducing the treatment (i.e., first B -project-based learning for Operational Amplifiers) and measuring the dependent variable before and after the treatment phase; using a second baseline measure, returning to traditional lecture methods for a third topic (i.e., second A for inductance); and, finally re-introducing the treatment (second B for power factor). Hence, the dependent variable was measured before and after (pre-post test) each of the baseline and treatment phases. In other words, the A-B-A-B design involved two parts: (1) gathering of baseline information, the application of a treatment and measurement of the effects this treatment; and (2) measurement of a return to baseline or what happens when the treatment is removed and then again applying the treatment and measuring the change. In this project, baseline is lecture-based teaching (A) and the treatment is problem-based learning (B).

Materials

Pre-Post Test. The instructor developed separate quizzes for each of the four topics so that they covered the material covered in class. Participants completed quizzes in a pre-post test format surrounding the topics to assess their learning and conceptual understanding of the topic. Pre-test was used to account for students' prior knowledge of the topic. Hence, participants took a quiz before the topic was introduced in class via either traditional lecture or problem-based learning and then took the same quiz in a post-test after the topic was covered in the class. Specifically, each quiz consisted of a narrative problem scenario relevant to the topic an engineer might face, which was followed by two conceptual questions. The first question asked students to provide an explanation for the cause of the engineering problem, while the second question asked students to provide a solution to the problem. The assessments were developed by the course instructor and revised by other co-authors. We utilized instructor developed open-ended quizzes instead of standardized tests to gain access to students' conceptual understanding. Specifically, the questions allowed us to examine students' ability to transfer their learning from problem-based learning to novel situations.

Data Coding and Analysis

We were interested in examining participants' conceptual understanding and how they addressed the two conceptual understanding problems. Accordingly, participant responses were coded on a scale of 0 (No understanding) – 4 (Excellent understanding). Participant responses were rated as 1 (Marginal understanding) if the students exhibited some grasp of the topic, but unable to answer the question; responses were rated as 2 (Average understanding) if the students exhibited some grasp of the subject matter, but only addressed basic elements of the problem; responses were rated as 3 (Good understanding) if the students had grasp of the subject matter, is able to answer the questions but did not provide any elaboration; finally, a score of 4 (Excellent understanding) was assigned if the student showed full grasp of the subject matter by going beyond answering the question and elaboration and explanation. In the case, participant left a blank response or was completed off track, a score of 0 was assigned.

In order to establish reliability, two raters were first trained by randomly selecting 10 quizzes from each pre-post quiz for all the four topics. After the training was completed, the two raters independently coded one-third of the quizzes randomly selected from pre and post-tests for each of the four topics. Overall, the inter-rater reliability was 89.17% for Ohm's and Kirchoff's Law quizzes; 78.30% for operational amplifier quizzes; 89.17% for inductance quizzes; and 86.7% for the power factor quizzes.

As expected the scores in the first question were significantly correlated with the scores in the second question. Therefore, we formed a composite score by adding the scores from both questions. We analyzed data using paired sample t-tests for the mean difference between pre-test and post-test scores.

Results

Table 1 below presents the descriptive statistics of scores for both pre-test and post-test corresponding to each stage of the design.

Table 1. *Descriptive statistics of scores*

		pre-test	post-test
	N	Mean (Std.Dev.)	Mean (Std.Dev.)
First A	55	2.927 (1.399)	3.327 (1.139)
First B	55	2.345 (1.702)	4.600 (2.643)
Second A	55	1.473 (0.920)	2.673 (1.334)
Second B	55	1.691 (1.245)	4.000 (2.487)

For the inferential tests, social science researchers set the commonly used significance level of 0.05 for hypothesis testing. However, for multiple paired t-tests, it is prudent to adjust for inflated experiment-wise (type-I) error rate. Frequently, researchers adjust the probability level (α) depending on the number of tests planned or calculated (for example, Bonferroni adjustment). Since we used four paired t-tests, the Bonferroni adjustment resulted to alpha value of 0.0125. The gain score in first A was not significant [$t(54) = 1.822$, $p = 0.074$]. However, the gain scores were significant in First B [$t(54) = 5.571$, $p < 0.001$], Second A [$t(54) = 6.213$, $p < 0.001$], and Second B [$t(54) = 6.142$, $p < 0.001$].

Discussion

The results from this study suggest that students gained more during the problem-based learning approach as compared to traditional lecture approach. Specifically, student gains from PBL were almost twice than learning gains from traditional lecture. Given that there is limited research on the beneficial effects of PBL on student learning and majority of this research on PBL has focused on student perceptions, the results from this study are important for engineering as well as other STEM disciplines.

However, these findings have implications for researchers and faculty in STEM area. We agree with Prince (2004) that faculty adopting instructional approaches, such as PBL with expectations of seeing results similar to this study should be aware of practical limitations of educational studies. Additionally, more research needs to be conducted to replicate these results and extend the research on the impact of PBL on student learning in variety of STEM settings. In the following paragraphs, we discuss findings from this study and provide specific implications for faculty and researchers interested in problem-based learning in engineering.

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