Small Group, Self-Directed Problem Based Learning Development In A Traditional Engineering Program

Kevin C. Bower¹, Timothy W. Mays², and Christopher M. Miller³,

Abstract - Criterion 3 of ABET 2003-2004 Criteria for Accrediting Engineering Programs [1] requires that all engineering programs demonstrate that their graduates possess the ability and desire to become lifelong learners as well as an ability to formulate and solve engineering problems. Self-directed problem based learning is a pedagogical approach that can help students learn and retain material while developing skills for lifelong learning. The question this paper seeks to answer is “can this approach be applied effectively by a single professor in a program where students are accustomed to traditional teaching techniques?” The justification and description of the pedagogical approach used and preliminary results are presented which show a shift in students’ learning preferences and motivation toward lifelong learning. In addition, the impact this pedagogy has on students’ performances and results from teaching evaluations are compared to data gathered from semesters where the class was taught using traditional lecture based instruction.

Index Terms - ABET, active classroom pedagogy, lifelong learning, and open ended problems.

INTRODUCTION/BACKGROUND

Problem based learning (PBL) is a teaching/learning strategy that Norman and Schmidt [11] define as a collection of carefully constructed problems that are presented to small groups of students who discuss the issues, identify what is known from prior knowledge and what is not, and seek out information to solve the problem. The strategy was first developed in the mid-1960s at McMaster University in Canada to help medical students prepare to be practitioners of medicine [11]. Since its inception, PBL has taken on many different forms and has been presented under different environments [16]. For purposes of this paper, the term PBL refers to a process consisting of problem guided self-directed small-group instruction followed by self-assessment. The problems are typically ill-structured or purposely slightly ambiguous resulting in many paths to the solution, and are designed by the instructor to include the use of prior knowledge as well as require learning of the particular course content [12]. The original goals of PBL are provided below [7]:

- Foster clinical-reasoning skills, problem-solving skills, or both
- Enhance acquisition, retention, and use of knowledge
- Improve students’ self-directed learning skills
- Develop students’ intrinsic interest in the subject matter and, subsequently, their motivation to learn
- Develop students’ capacity to see problems from multi-disciplinary viewpoints, integrating information from many different sources
- Facilitate the development of collaborative learning practices
- Emphasize, for students, the importance of learning for understanding rather than learning for recall
- Improve flexible thought and the capacity to change

The most obvious correlation between the PBL strategy and engineering is related to practicing engineers. Upon graduation, engineering students will be hired to solve ill-structured problems using their engineering knowledge and in most real-world situations the problem itself is not identified. The engineer is forced to identify the problem, determine the required time to solve the problem either alone or in groups, stay on task as to not over charge a job or client, and present their findings to a multi-disciplined group of peers and supervisors. If PBL can transfer the required knowledge base while preparing students to solve ill-structured problems similar to real-world situations, PBL and engineering seem like a perfect match.

The research from a cognitive point of view provides much more solid support for selecting PBL as a teaching/learning strategy. Evensen and Hmelo [5] identify that the PBL strategy is successful in activating prior knowledge and uses the activation of prior knowledge to positively affect processing of new information. In addition, they identify group work helps students to process new information and to stay actively involved in learning while aiding in the long-term retention of knowledge. While this does not represent the entire body of research on the cognitive benefits of PBL, the research presented is encouraging.

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One possible long-term benefit of PBL instruction is early facilitation of knowledge encapsulation and expertise development [8]. The concept of knowledge encapsulation was first presented by Boshuizen and Schmidt [3]. While replicating a study on the relationship between biomedical knowledge and clinical reasoning among experts, intermediates, and novices, they found that experts did not draw on their previously obtained biomedical theoretical knowledge when solving clinical problems but rather simply recent practical clinical experience. They hypothesize that the expert does not need to use as much mental resources to activate base knowledge because the process is automated, and they refer to this as knowledge encapsulation; that is the mental placing of base knowledge within the schema of practical and procedural knowledge. Johnstone and Biggs [8] suggest that the PBL environment may facilitate this process. The implications here to engineering curriculum are that faculty members may be able to positively affect our students’ expertise development making them more beneficial in the workplace. While identification of the benefits of the PBL process and why these authors has selected it is beneficial to this discussion, the use of PBL may be positively improved by applying it in a classroom atmosphere that fosters cognitive and motivational development in other ways.

As previously mentioned, PBL can take on many different forms and be applied to many different environments [16]. Jones [9] discusses cognitive instruction and defines it as any effort an instructor makes to encourage students to think about information processing and become lifelong learners. As part of this, he emphasizes the importance of how tests and objectives are used. As engineering faculty, we will almost always be force to do most of our assessment by testing. However Woods [15] suggests if students, upon the completion of the problem, are asked to write learning objectives associated with the solving of a given problem these objectives can be compiled by the instructor and provide the basis for test question preparation. To some degree, the students are responsible for what they will be tested upon. In addition, testing can occur more frequently and result in a smaller percentage of the students’ final grade. By reducing the significance of the test scores, the students can be rewarded for their cognitive efforts associated with the problem solving resulting in a more learning rather than performance oriented class.

Motivation for learning can also be improved by encouraging goal driven approaches to problem solving and reinforcement of positive attribution responses. The way a student attributes success and failure can significantly affect their motivation to learn. Alderman [2] discusses the significance of attributional beliefs to motivation. She cites research that supports the idea that an effort driven attributional response is the most positive and easiest to affect for future success. The final grade in the class can be based on effort driven tasks rather than performance, such as tests. In addition, the concept of attributional theory can be presented to the students and they can be encouraged along those lines. Positive feedback is almost absent in most engineering environments. Therefore, if it is applied throughout the class in the context of positive attributional responses, it is reasonable to assume the students may respond positively. In addition, the nature of PBL is to divide the problems into subtasks. During this process, the importance of the concept of goal setting can be conveyed. Ultimately, the environment of PBL in conjunction with additional cognitive and motivational aspects could result in the development of a more prepared metacognitive learner.

The question this paper seeks to answer is whether this approach can be applied effectively by a single professor in a program that students are accustomed to, and in some instances expect, traditional teaching techniques. For the purpose of this paper, a traditional teaching technique refers to lecture based direct instruction. This paper discusses the following:

- Specific pedagogical approaches used in the classroom for small group self-directed problem based learning for a senior level technical elective.
- Preliminary results are presented which show a shift in students’ learning preferences and motivation toward lifelong learning.
- The impact PBL has on students’ performances and results from teaching evaluations are compared to data gathered from semesters where the class was taught using traditional lecture based instruction.

**METHODS**

With significant guidance from Woods [14,15], Sage and Torp [12], Johnstone and Biggs [8], and Stepien and Pyke [13], the following strategy for PBL implementation has been developed by Dr. Christopher M. Miller and Dr. Kevin C. Bower (graduate student at the time) on a combination senior-level and graduate-level course, Water Quality Modeling and Management, at the University of Akron starting the fall semester 1999 and continuing today. The class meets twice a week for approximately 1 hour and 15 minutes each day for 15 weeks and covered a variety of topics relating to water quality modeling and management, which can be found in Table 1. The class operates under the small group format with four groups (3 to 4 students per group). The groups change once during the semester.

**TABLE 1**

<table>
<thead>
<tr>
<th>Specific Topics</th>
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<tbody>
<tr>
<td>Water Quality Topics Covered in PBL Format</td>
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<tr>
<td>Chemical Kinetics</td>
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<tr>
<td>CSTR - Completely Mixed Systems</td>
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<td>PFR - Plug Flow Reactor</td>
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<tr>
<td>River BOD and Oxygen Modeling</td>
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<td>Nitrogen and Bacteria Modeling</td>
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<tr>
<td>River BOD and Oxygen Modeling Using Qual2E</td>
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<tr>
<td>Chlorine Decay in a Water Distribution System Using EPAnet</td>
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</table>

The first two periods of the semester were devoted to presenting and adjusting the students to the change that they were about to face by the implementation of the PBL format for the course. During this time, information on how to adjust to the change and learning the specifics about the process of
PBL were given to the students using material from Woods [14]. Non-engineering problems given to the students during these first few periods helped to introduce them to the PBL process in a non-technical capacity to ease the transition and familiarize them with their group. Starting the second week of the semester, the first of the nine actual problems were given to the students. Each problem generally had a two-week solution procedure process (or 4 class periods). The problem was distributed to the groups on the first day. The first goal of the day was to read and evaluate the problem and have the group identify the core of the problem. The next step was to determine what information was necessary to solve the problem and determine which of the information was already known and what needed to be learned. Assignments were then given to each member as their topic for the teach meeting.

Teach meetings were given on the second day and conducted only within each group. The purpose of the teach meetings was to give an opportunity for each individual of the group to present the information collected on their assigned topic. To help the other students follow along with the lecture and understand the essential information presented in a reference tool, handouts were also required. Each individual student’s teach meeting lecture was about 15 minutes in length. Evaluations were performed by the students on each group member immediately after their presentation on the basis of the quality of knowledge obtained, the quality of instruction, and the amount of follow-up information required by the other students and was worth 8% of the students’ final grade. With 3 to 4 students in each group, the teach meeting lectures generally took the entire class period.

The students were instructed to base the information gathered for teach meetings on the learning objectives that were defined for the particular problem, because those were the measurable outcomes that could be assessed. As a stepping-stone for the first 3 problems, the students were given learning objectives that were prepared by the instructor. This alleviated pressure on the students allowing them to focus on the task of adjusting to this new teaching format as well as learning through example, how learning objectives were formulated. The ultimate goal was to eventually have the students determine the learning objectives for the problem. When this occurs, the students are truly teaching themselves.

On the third day a new problem was distributed, with a whole process beginning again, overlapping the existing problem and on the fourth day, the first problem solution was due. Students presented their solutions to the group and they were evaluated by both students and professor. It should be mentioned, however, although not directly required, groups frequently met between class sessions to work on the solution.

Each problem, a group member rotated to the position of chairperson. This chairperson was responsible for coordinating meeting times, assigning teach meeting topics, and the completion and submittal of the problem. For every problem, the chairperson was also responsible for writing a brief paragraph describing the interaction between the members of the group and the PBL experience. In addition, every group member was required to submit, directly to the professor, a short paragraph describing their individual feedback on the PBL format and reflect upon their experiences with it on a weekly basis.

Figure 1 illustrates the impact the PBL pedagogy had on students Perry Learning Preferences [15]. Perry Learning Preferences are a measure of a student’s interest in having the professor guide their learning (scores lower on the 0-5 scale) or the interest students have in directing their own learning (scores higher on the 0-5 scale). The implication of the test is that students scoring higher will be more likely to embrace self-paced lifelong learning once outside the structured

% of Students in Each Range

FIGURE 1

PERRY LEARNING PREFERENCES SCORE BEFORE AND AFTER PBL EXPERIENCE

One slight alteration to the teaching format was made to this general plan. At the beginning, it was initially the students responsibility to determine what they did not know and to assign someone to teach it at the teach meeting. However, it became more apparent that the students were having problems in this initial stage. The material was so new to them that they were unable to see everything they needed to eventually learn and sometimes went too far. A compromise was then made to help alleviate these effects. The instructor would answer simple, fundamental questions that the groups decided they needed answered before they progressed. This allowed the groups enough background information to search in the right direction, without giving away the problem itself and therefore reduce the effectiveness of the method. This not only reduced the amount of time wasted by the students on those “blind alleys”, but it also made the students more optimistic about the method and less resistant to it.

Throughout the process students’ motivational and attributional responses were monitored and appropriate levels of encouragement were supplied. One tool used to encourage students to work together was a weighted grading scale on all tests. A portion of the students’ grade was based on their own score on the test and a smaller portion was based on the average score of the group.

RESULTS

Figure 1 illustrates the impact the PBL pedagogy had on students Perry Learning Preferences [15]. Perry Learning Preferences are a measure of a student’s interest in having the professor guide their learning (scores lower on the 0-5 scale) or the interest students have in directing their own learning (scores higher on the 0-5 scale). The implication of the test is that students scoring higher will be more likely to embrace self-paced lifelong learning once outside the structured
academic environment and may be an indirect indication of their ability to be lifelong learners. It should be pointed out that one drawback of the test is that, while the purpose of the test was never revealed to the students; the questions are not structured in a manner to effectively conceal the general intent of the test. Prior to the PBL experience, seniors and graduate students rated in the middle scoring brackets with nearly 65% of the students scoring in the 2.0 – 3.0 range. At the conclusion of the semester students’ preference shifted with 75% of the students in or above the 3.1 – 3.5 range with over 10% of the students scoring in the highest bracket (4.1- 5.0). While not enough data points have been gathered to make a statistical comparison, the trend for this course is clear that the PBL experience positively affects the students’ learning preferences.

Another indicator used to evaluate the effectiveness of a given pedagogy is the amount of time students spend studying the subject outside of class. Figure 2 illustrates this for the traditional lecture pedagogy (2 years of data) compared to the PBL approach (3 years of data). Nearly 80% of the students in the traditional lecture class spent less than 6 hours studying outside of class per week. On the other hand, 100% of the students in the PBL class spent 6 hours or more studying each week with nearly 40% of the students studying 12 or more hours per week. This attributed to the students’ responsibility in PBL to acquire all necessary knowledge on their own and each individual is solely responsible for conveying that information back to the group. Recall that the students’ test scores not only depend on how well they perform on the test but also how well their group performs on average on the test. This motivation becomes more significant as the semester proceeds and students realize the importance of helping their fellow group members learn the material in hope that they perform well on the test.

Even with the individual and group grades, students in the PBL class slightly outperform students from the traditional pedagogy. Figure 3 illustrates the average course grades of the class as a whole as well as the undergraduate and graduate students’ average scores from the traditional lecture class compared to the PBL class. In all cases, the students in the PBL class had higher scores on tests than the traditional class by as much as 9%. Previous years test were returned to the students and therefore modifications in test given were required. The tests utilized to assess the students were therefore not identical but were designed to be of the same difficulty and covered the same material. The higher scores are consistent with the material presented in the literature review. Recall that Evensen and Hmelo [5] identify that the PBL strategy was successful in activating prior knowledge and then uses the activation of prior knowledge to positively affect processing of new information. In conjunction with the peer generated motivation to not let other members of the group down, the resulting higher scores from the PBL class are not a surprise.

<table>
<thead>
<tr>
<th>Number</th>
<th>Question</th>
<th>Topic</th>
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<tbody>
<tr>
<td>1</td>
<td>Rate the instructor's overall teaching effectiveness:</td>
<td></td>
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<tr>
<td>2</td>
<td>General course organization:</td>
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<tr>
<td>3</td>
<td>Conceptual clarity:</td>
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<tr>
<td>4</td>
<td>Course objectives:</td>
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<tr>
<td>5</td>
<td>Ability to answer questions:</td>
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<tr>
<td>6</td>
<td>Ability to explain difficult material:</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Concern for student's development and learning:</td>
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The addition of the motivational element of the weighted grading was not added to the course without significant consideration. The University of Akron is primarily a commuter school. After the first semester of teaching the class in the PBL approach, it became apparent that for group work to be effective the students needed to be motivated to care about the learning of their fellow student. As a result of
this, the weighted grading was instituted. Students were concerned about this element of the class and it was met with some resistance. However, after the first test the benefit was apparent. In one group of three, students’ scores consisted of 92, 85, and 76. As a result, the student who scored 92 received a grade of B on the test and the student who scored 76 received a grade of B. When the tests were returned, the student who scored in the 76 told the rest of the group that they would never let that happen again and the student who scored in the 92 said that he would make an increased effort to clearly convey teaching meeting materials. While just a single example of the motivation of weighed group and individual scoring, it was determined that this element of the class was important and needed to remain for further investigation.

FIGURE 4
COMPARISON OF STUDENT EVALUATIONS SCORES FOR TRADITIONAL CLASS AND PBL CLASS (QUESTION NUMBERS CORRESPOND TO TABLE 2)

The final portion of data gathered as part of this study pertains to the scores on the students’ evaluation of the professor. One of the concerns when introducing a PBL strategy into a traditional lecture based program was that evaluation scores may suffer as a result. Figure 4 compares the teaching evaluation scores from the traditional lecture classes with the PBL pedagogy classes. Table 2 outlines the specific question topics and the corresponding question number. In all cases, student evaluation scores either stayed the same between traditional and PBL or increased as a result of the PBL environment. One interesting observation is made between question one, rating the overall effectiveness of the instructor, with questions five, six and seven, rating the instructors teaching ability. The overall teaching effectiveness rating did not change significantly between PBL and traditional classes, however, questions specifically related to the instructors ability to teach (questions five, six, and seven) all increased significantly with the use of the PBL pedagogy. A possible explanation for this observation stems from the students’ initial stress of the PBL teaching approach. No matter how much explanation is placed at the beginning of the class as to the importance and significance of the teaching method to the students’ development, a segment of the students seem to think that if it is the students’ responsibility to teach and learn then the professor is not effectively doing their job and as a result rate the overall effectiveness of the professor appropriately. As far as the observed increase in the ability to answer questions, the students in the PBL class typically have spent more time struggling with the solution and when answers to questions are provided, the professor can meet the students at the specific point of their problem. This results in the student feeling that the professor has a better ability to explain difficult ideas and cares more about the student. In traditional classes, every student is not at the same point and answers to group questions are only timely to a portion of the students.

CONCLUSIONS
The original question this paper seeks to answer is can a PBL approach be applied effectively by a single professor in a program that students are accustomed to, and in some instances expect, traditional teaching techniques with a positive outcome. On the basis of the results from the study of this question, the following conclusions were made:

- A brief literature review on PBL reveals potential for positive impact on students’ development and may be of particular benefit to engineering students
- Preliminary data from Perry learning preferences evaluation shows that student interest and desire in self-paced independent instruction increases after the PBL experience. This has significant impact to ABET accreditation which requires programs to produce graduates who have an ability to be lifelong learners
- Students in the PBL pedagogy spend more time per week studying the material
- Students in the PBL pedagogy performed better on tests than students under the traditional pedagogy. While a statistically significant difference was not observed, the data revealed a clear trend
- Student evaluations of the professor in all instances rated the professor similarly or higher during the PBL pedagogy than the traditional pedagogy
- Based on the data collected, PBL can effectively be applied in a traditional lecture based civil engineering program resulting in improved student performance, improved professor evaluations scores, and most importantly it can positively affect students learning and development.

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REFERENCES


