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Comparing a Modified Problem-Based Learning Approach To a Traditional Approach to Teaching Heat Transfer

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Abstract: Experience has convinced me that traditional lectures are easy for the professor, but are not always the best educational approach for the majority of my students. Over the years I have tried to incorporate more active approaches in the classroom. I incorporated many active learning activities and added technology-driven modifications to my courses. More recently I tried adding problem-based learning (PBL) to my classes. I found that light use of a modified form of PBL along with a variety of other active learning elements have improved the level of student involvement, classroom morale, and, ultimately, the learning that occurred in my classes.

In Fall 2012, I had the opportunity to teach two sections of a junior-level heat transfer course using different pedagogies: (1) the traditional, lecture-based approach with some active-learning and (2) a modified PBL approach. My modified course alternates mini-lectures and student problems in a "leap frog" style. This class meets for 3 hours, once a week. Lectures are very brief and dispersed throughout the class meeting time. Students work problems and conduct brief experiments in class. Their results are shared and unusual results are discussed. Lecture time helps summarize these results and propel the class to the next topic. Homework reflects the material covered that day, but extends to the topics for the next class. The students come to class better-prepared than the typical classroom.

In this paper I will discuss my modifications and present data to demonstrate the effectiveness of this approach.

Introduction

Over the years I have attended conference presentations and read numerous articles touting the advantages of many active-learning or student-centered pedagogies and I have tried many of these techniques in my own classes. Many of these modifications have remained a part of my classroom style while others have been discarded. I find that I use different teaching methods for different courses and different time formats (50-minute, 75-minute, or longer sessions). Recently, I have taught ES 3073 (Heat Transfer) during the summer in ten 210-minute sessions in five weeks. For that class I rarely lecture, emphasizing active-learning methods and using many problem-based learning (PBL) techniques. Anecdotally, I had noticed that these students seemed to have a better fundamental understanding of the concepts than my students taught during a traditional lecture-based fall or spring semester course of twenty eight 75-minute sessions in 14 weeks. The quality of students in these summer courses are, arguably, lower than during the regular term, yet their performance appeared to be superior. Was this my imagination or did they have a better grasp of the material? If so, was it because the material was fresher (nothing more than 5 weeks old) or was it because the teaching method was working?

In the fall semester of 2012, I had an opportunity to compare the two techniques directly. I was assigned to teach two sections of ES 3073. This is a general engineering requirement that is required of all chemical, mechanical, and petroleum engineering students. One section was offered two days a week in 75-minute sessions. The other section was offered once a week in a single 150-minute session. I would teach the two-day-a-week course in my more traditional style. I would teach the one-day-a-week course in my modified PBL approach. At the end of the semester I would know what worked and what didn't.

Background

Problem-based learning is not new. It was first developed in medical schools in the late 1960s. Mayer and Greeno first described this method as it was used to improve the education of physicians.[1] Very briefly, PBL is intended to motivate students to self-learning by presenting them with realistic, ill-posed problems before they have been formally taught how to solve the problem. As they struggle through the solution with a group of their peers, they have the opportunity to develop critical thinking and communication skills as they evaluate and re-evaluate the problem and solution. This may be done with or without a tutor to help guide the process. The approach is appealing because it seems to relate well to the human cognitive architecture used in problem-solving processes such as used in engineering design. [2]

Many articles have been published on the topic. Twenty years after Mayer and Greeno introduced this method, Albanese and Mitchell presented a meta-analysis of more than 100 articles on the application of PBL.[3] Today, a search for articles about PBL on Google Scholar reports more than 2,250,000 results! Felder and Silverman offered my first introduction to problem-based learning and other active-learning approaches.[4] Early in my teaching career I read this article and, shortly thereafter, attended one of Dr. Felder's workshops. This convinced me to try stepping outside of the traditional methods that I had experienced and to make every effort to provide an improved learning environment for my students. Some changes have been easy to implement and resulted in students that were significantly more engaged in the course. Some changes have not worked well or did not make enough of a difference to justify the extra effort on my part. Active learning generally went well; problem-based learning did not fare as well.

I continued to read articles of PBL success stories in engineering classrooms including papers by Woods and by Perrenet, et al.[5,6] Boud and Feletti published a second edition of their book to address issues that faculty had implementing PBL such as the resources necessary to get PBL programs started.[7] One issue addressed was the mismatch that can occur when evaluation techniques do not match the learning outcomes or when grading systems do not reward the behaviors encouraged in PBL. Other articles serve as a counterpoint, arguing that PBL fails the students especially in the area of content knowledge.[8] An overall theme in all of these works was that you would only be able to cover about 80% of the course content using this technique. Dym, et al. assert that PBL works well in the correct context, such as using a "wandering tutor" in engineering design classes, and can promote the life-long learning and collaborative skills that industry so desires.[9] An article entitled "A Skeptics Look at PBL" by Lieux convinced me that PBL was worth trying again and could be a good experience for both me and my students.[10] My overall impression after reading the literature on PBL was that the method could work very well in certain situations, but it was not always the best pedagogy. I was ready to give it another try in a course that had a heavy design component, adequate time in the course to cover all topics without rushing, and that I taught frequently. My target course was ES 3073 (Heat Transfer).

Implementation

In the Fall 2012, I taught two sections of ES 3073, covering the same material in two different formats. The schedule of exams and quizzes was adapted to allow me to gather comparative data. Section 1 was taught in the time-honored lecture-based format. I continued to do the demonstrations and some active-learning activities, but most time was spent in lecture over theory or watching me do examples with input from the students that chose to participate. These sessions were 75 minutes long. A typical class might include 20 minutes of an introduction to the topic and background theory followed by a series of examples and further explanation that would extend the concept. The day would conclude with 2 – 3 minutes of summary with a brief introduction of the next topic. Problems were assigned each week from the textbook reflecting the sort of problems that an average student should be able to complete with "unlimited" time. The students completed their homework independently and were given a quiz once each week over what they had learned from homework or lectures. The class worked in groups of four to complete a design project. Two midterm exams were given as well as a comprehensive final exam.

The second section was based on my adaptation of the PBL techniques that I had read about and had tried before. I conducted several mini-lectures throughout the session, but these were interspersed between experiments and problem-solving sessions. The lectures covered theory after they had actively discovered the need for the theory. The lectures, largely, began with a discussion of what difficulties they had encountered in their last segment of work and what ideas they had for fixing them. We then, as a group, propelled the process further with any necessary theory, then split up again to continue solving the same problem or moved on to a new problem. I consider this approach to be more like a game of leap-frog than typical PBL courses. The grading would be similar to in the other section, except that their "homework" grade was based 50% on in-class problems and 50% on out-of-class problems. They also had a weekly quiz, a design project, two midterm exams, and a comprehensive final exam. Each of these was nearly identical to those given to the traditional section.

The difference between the two sections was only in my instructional technique and in the in-class and homework problems. The in-class problems used in the PBL section were similar to the examples that I did in the other class. The difference was that they did the work themselves and I had not lectured over the entire set of material before they worked the problems. The material needed for these problems had been introduced to some extent before breaking the class into groups, but in order to complete the problems the students had to develop part of the solution method on their own. Each group was assigned a variation on the same problem. While they worked on the problem, I walked around the room to answer questions, give suggestions, or ease tensions when disagreements broke out. At the end of the allotted time, they would post their final answers on the board and we discussed the solution technique and the various answers to begin seeing the effect of variables on the solution. When a group got an incorrect answer, we examined the different assumptions and decisions made in the solution process.

Homework assignments were done in groups of 1 to 4 students. The assignment would typically be three or four problems. Two or three of these reflected the material covered from the last class, but usually involved deeper analysis than the typical textbook homework problem. For instance, they might be asked to compare several insulations available at a local hardware store and make a recommendation for the most economical choice to meet a particular need. The last problem (or two) would extend the concept from the previous class to cover the concepts that would be covered in the next class. For example, after the first day's class where they had been introduced to Fourier's law, they were asked to find the temperature profile in a wall composed of two layers. (The next day's class would go over the thermal resistance approach to conduction problems.) At the beginning of class I would broadly discuss their homework and when we got to the appropriate topic in lecture that day, we could go over the solution in more detail. I would grade those answers according to how well they supported their solution technique.

Comparison

In order to compare the students in the two sections, I first had a third-party gather demographic and academic data. A summary of this information is shown in Table 1. The traditional section had a slightly lower GPA. I also looked at the percentage of students that were new to TU (and therefore had no GPA and no record of completed hours), the percentage that were international, and the percentage that were female. Since the difference between the two sections was based on the inclusion of PBL which emphasized team-learning, I also calculated the percentage of students in each section that had previous courses that emphasized team-learning.

Table 1. Comparison of Demographic and Academic Data

Category	Traditional Section	PBL Section
Grade Point Average (GPA)*	3.1 ± 0.6	3.3 ± 0.5
Hours Completed*	68 ± 14	72 ± 25
Number of Students	32	27
New to TU	15%	3.7%
International	39% (3.09 GPA)	37% (3.19 GPA)
Female	21% (3.04 GPA)	30% (3.24 GPA
Prior Team Learning Courses	33% (3.09 GPA)	33% (3.10 GPA)

*This data was not available for the students that were new to the school, so the sample size is smaller than the number of students enrolled in the section.

I then compared the results from all quizzes and exam questions where the same question was given in both sections. This data is summarized in Table 2. Generally, the PBL section performed better than the traditional section. There was one quiz where the traditional section outperformed the PBL section. The quiz scores from their class had been very poor the previous week (identified as Quiz 8 in the table). As a consequence I had spent several minutes of class discussing how to perform better and I had even told them (without details) the questions I would be asking.

Table 2: Comparison of average scores on graded items for the two sections. All scores are out of 100. Standard deviation is in parenthesis.

Graded Item	Traditional Section Grade	PBL Section Grade	Significant by t-test with α =
Quiz 1 over terminology	81 (27)	87 (26)	0.20
Quiz 4 over finned surfaces	81 (18)	89 (11)	0.02
Quiz 5 over transient conduction	81 (22)	92 (12)	0.01
Quiz 7 over forced convection	82 (13)	89 (8)	0.01
Quiz 8 over internal convection	63 (32)	96 (6)	2×10^{-6}
Quiz 9 over natural convection	89 (20)	84 (23)	0.14**
Quiz 11 over heat exchangers	86 (14)	87 (18)	0.4
Exam 1 over conduction	79 (11)	80 (11)	0.4
Exam 2 over convection	81 (11)	85 (11)	0.072
Final Exam - comprehensive	79 (14)	85 (10)	0.05

**Note that this is the one item where the traditional section scored higher than the PBL section.

I also looked at performance by a variety of demographic groupings within the classes. I compared international students, females, and those without significant teamwork experience to the same grouping from the other section. I also looked at several groupings based on GPA. Those results are summarized in Tables 3 and 4. (Note that Table 4 does not include the full class. Transfer students that did not have a University GPA were left out.) I was very concerned that this method would not be effective with the international students due to the heavy emphasis on communications. In fact, the difference in performance between the international students in the traditional section and the PBL section was not statistically significant. There is also true for the female students. The performance was significant for US students and males. The improvement of the students who had not had intensive teamwork experience was greater than for the full group (especially on exams). The improvement of students with prior significant teamwork experiences in courses was modest. The students with low and mid-range GPAs demonstrated statistically significant improvement in quiz scores, but no real improvement in exams.

Table 3. Significance level on t-test of difference in scores by student cohorts. The better score was by the PBL group unless otherwise indicated. No α-value is given if greater than 0.20.

Graded Item	Full Group	International/US Students	Male/Female	Prior Teamwork Course/None
Quiz 1	0.20	--/0.19	--/0.16	--/--
Quiz 4	0.02	--/0.02	0.03/--	--/0.02
Quiz 5	0.01	--/0.01	0.03/0.05	--/0.004
Quiz 7	0.01	0.15/0.13	0.07/--	0.11/--
Quiz 8	2×10^{-6}	3×10^{-5}/0.002	1×10^{-5}/0.06	0.03/1×10^{-5}
Quiz 9	0.14**	0.05**/--	--/0.03**	0.18/--
Quiz 11	--	--/--	--/--	--/--
Exam 1	--	0.16**/0.13	--/--	0.15**/0.01
Exam 2	0.07	0.19/0.13	0.09/--	0.20/0.02
Final	0.05	0.20/0.10	0.03/--	--/0.04

**The Traditional Section performed better than the PBL section on these items.

Table 4. Significance level on t-test of difference in scores by student GPA cohorts. The better score was by the PBL group unless otherwise indicated. No α-value is given if greater than 0.20.

Graded Item	Full Group	Only GPA Greater than 3.25	Only GPAs Between 2.75 and 3.25	Only GPA Less Than 2.75
Quiz 1	0.20	0.09	0.05	0.02
Quiz 4	0.02	--	0.02	0.13
Quiz 5	0.01	--	0.05	0.06
Quiz 7	0.01	0.01	--	0.05
Quiz 8	2×10^{-6}	0.04	0.007	0.004
Quiz 9	0.14**	0.09**	0.09**	--
Quiz 11	--	--	--	--
Exam 1	--	0.05**	--	--
Exam 2	0.07	0.12	--	--
Final	0.05	--	--	--

**The Traditional Section performed better than the PBL section on these items.

End of semester course evaluations were slightly better for the PBL section than with the traditional section. At the University of Tulsa, the course evaluations include 13 items such as “the instructor made effective use of class time” or “the instructor lectured in a clear, direct, and logical manner” that are scored on a 5-point Likert scale. The average score for the traditional section was a 4.77 while the average score for the PBL section was 4.91. There was only one item where the traditional section had a higher score (4.8 vs 4.7): “The instructor provided useful feedback on graded items.” Since in-class problems received no written feedback (only a numerical score and in class discussion), that lower score is appropriate. Comments were generally favorable from both sections. The traditional class included comments such as “she is very good at lecturing" and "very clear in conveying this subject." Their recommended improvements were to "have more examples or ones that are more in depth" and to "scatter more demonstrations throughout" the course. One student in the traditional section commented that I should "quit trying to do team work at the University level . . . it's not working". The PBL class commented that "the best thing about class was breaking up into groups and working on in-class problems" and other similar statements. They had no recommended improvements.

Conclusions

The PBL section had more academically talented students as evidenced by the higher GPA. Closer inspection of the individual GPAs indicated that three students in the traditional class were struggling to stay enrolled due to low GPA. There were no struggling students in the PBL section. The advising office had placed these into this section specifically because they believed that attending class more frequently would improve their chances of success. If these students were removed from the data set, the GPA was much closer, but it made very little difference in the overall results. They performed about as well as the other students with GPA < 2.75. Also, the traditional class had many more new-to-the-university students. These transfer students often struggle in their first semester. This may have skewed the results.

The differences in performance by the various groupings indicate that this technique was ineffective, but not detrimental, for the international students and for female students. It was most effective for US students and for male students. The short-term effect was greater for low-performing students than for high-performing students. High-performing students initially struggled with this method, but in the end performed as well as their peers in the traditional section. The greatest impact appears to be for students that had never had a course that used significant teamwork. In those cases, the performance of the PBL section was much better than the performance of the Traditional section and this improved performance was statistically significant for most of the graded items and for the exams, in particular. That this grouping would have the most dramatic difference in performance indicates that a significant part of the enhanced learning was from the collaborative skills developed in the class. Further, it seems that learning to work in teams for routine work (not just special projects) has a long-term effect on learning.

Observations

Running a course with the PBL approach requires more preparation than a traditional lecture, but as the semester progressed, it was not significantly more time. The extra time was easily balanced by the fun I was having teaching that course. My role changed to that of a coach rather than the "sage on the stage". Students from that section had better attendance (in fact, the only absences for the semester were for travel to a conference and one student illness) and were actively engaged in and out of the classroom. When I encountered these students in the hallways, it was quite common for them to make an observation about something relating to our course and ask me to confirm if they were on the right track. When I overheard conversations between students, they were along the lines of "What do you think about assuming . . ." instead of the more typical "What answer did you get on number 2?" Students from the other section were mostly coming to my office the morning that assignments were due to get hints on how to progress.

The atmosphere in the two classrooms was very contrasting also. In the traditional section, students would visit with their friends (all sitting in a cluster) before class. In the PBL section, they would put their materials down at a seat near their friends then get up and talk to the larger group at the front of the room. When I came in, they would all dash back to their seats to get started. The international students in the traditional section rarely interacted with anyone not from their home country. Design teams frequently reported difficulties in getting the international students to participate fully. On the other hand, in the PBL section, the majority of the international students visited with a variety of other students before and during class then moved to sit with their friends from their home country during lectures. The exception to this pattern was two students from China who had very poor English skills. They stayed together unless forced to interact with others in the class for in-class problems.

Summary

Based on this small sample, I would say that my modified PBL method was a success but not a resounding success. It was more effective in short-term performance of low-performing students, but was not as effective on long-term performance. However, for the overall group, the long-term retention was improved using this method. The data indicates that the improvement may be on the heavy emphasis of team exercises rather than on the problem-based approach. The modest improvements may not be worth the added time and the loss of control. Additionally, I found that the articles I had read were correct: not all material can be covered as extensively using PBL. This can be supplemented with video lectures assigned for viewing outside of class or adding reading assignments with quizzes over those materials.

Future Work

I am scheduled to teach ES 3073 again for the Spring 2013 term in two 75-minute sessions per week. The group that has pre-enrolled for the course is approximately 2/3 international students. I will be using my modified PBL approach with this class and continuing to look for ways to improve the experience for the international students. I will continue to utilize elements of the problem-based learning methodology, but I will not be adding it to all courses.

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