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Effectiveness of Problem-Based Learning Prior to Lectures on Learning and Retention

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Abstract

In the mandatory tutorial sections of an introductory probability and statistics course of just over 70 students in the Arts and Science undergraduate program, students were randomly assigned to small groups to work on accessible problems from upcoming material without any prior instruction on how to solve them. Solutions were ungraded, and marks were assigned for participation only. A multiyear study was conducted to test students for their level of retention one year later, comparing them to a previous control group. The test question concerned Bayes' Theorem. Results suggest that the strategy improves student reasoning and retention of concepts while, as expected, a formula is long forgotten. However, low participation rates in the survey post-test produced a p-value of 20%, precluding a claim of statistical significance. Nonetheless, qualitative student feedback on surveys during the course showed a very strong positive response to the approach. Students reported the approach helped their thinking and reasoning, and assisted in their learning. They appreciated the informal, low-pressure environment of the problem-based learning (PBL) sessions, and reported that the sessions were beneficial for developing their own understanding of the concepts before going to lecture. Notwithstanding their positive feedback on PBL activities, students still expressed a preference for traditional instructional approaches where the teaching assistant leads them through solution procedures.

Keywords: problem-based learning, statistics instruction, probability, retention

Introduction

Problem-based learning (PBL) is a "learner centered" pedagogical method which can trace some of its origins to McMaster University's School of Medicine, and which has taken many forms since its inception (Savery, 2006). Versions of PBL have been used in many subject areas and at all levels of education. In general, PBL consists of students working in small groups to solve problems; they divide the workload, research independently, and share the fruit of their research, with the intent being for students to develop a stronger understanding of the concepts, to foster deep learning, and to develop their problem solving and analytical skills. Proponents of PBL argue that it engages students as active learners, supports higher order thinking, and promotes retention of material (Dods, 1997; Duch, Groh, & Allen, 2001).

A meta-analysis by Walker and Leary (2009) provides evidence of PBL's effectiveness. The authors compiled results from 82 studies ranging from eight to 2469 participants per study in science and engineering. The studies they analyzed compared PBL lectures or tutorials with traditional lectures or tutorials. The results showed that, generally, students favoured PBL. In addition, the analysis found that the students in PBL courses exhibited higher performance on teacher-designed problems, diagnosis problems, and strategic-performance problems. The story problems did not appear to enhance grades compared to traditional lectures.

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In addition to the meta-analysis, specific papers on PBL in a statistics or mathematics course provide further insights. A study by Karpiak (2011) focused on the effects of PBL on retention and rating in an undergraduate research methods statistics course. The results showed that PBL produced scores that were significantly higher on the exams, and produced deeper understanding.

Olson, Cooper, and Lougheed (2011) studied the effect of class size and teaching approaches on students in a first year university pre-calculus course. The approaches were evaluated using scores on common midterms and the final exam. The results showed a statistically significant positive effect on results for students in the PBL section of the course. However, the researchers found that students from the PBL section were no more likely than those in other groups to succeed in calculus in subsequent years.

Metz (2008) conducted a study looking at the effects of introducing statistical concepts using PBL to a first year university-level biology course. PBL activities were found to have increased statistical knowledge for all students, and improved retention of statistical knowledge.

Background

A version of PBL methods was introduced into a one-semester introductory probability and statistics course for students in McMaster's Arts and Science program in the spring of 2012. The Arts and Science program is a selective program at McMaster University, where entry requirements that include supplemental applications tend to produce a student cohort that is fairly actively engaged in learning. At the time of the study, the program and course enrollment was about 70 students per year. Students worked on PBL activities in the mandatory weekly tutorial sections in order to discover concepts in probability and statistics prior to any reading or lecturing on the topic. The rationale for introducing PBL is that many of the concepts underlying probability and statistics can be intuitive, but students often forego such understanding in favor of memorizing a formula. It was hoped that PBL would promote conceptual understanding, leading to improved retention of course material. For that reason, this version of PBL differs from the classic form in that the students were not to research for solutions externally, but rather research possible solutions through their own reasoning and experimentation as a group.

Prior to the introduction of PBL to this course, the tutorial sections were operated as traditional tutorials where a teaching assistant (TA) would field questions from the students. It was recognized that students in the year prior to PBL introduction would make a suitable control group to investigate the effects of PBL on retention, inasmuch as they were similar in number, academic achievement, and background. Students from both the PBL and control sections were given a follow-up question one year after completing the course to see if there was any change in the retention of course material for the cohorts that had the PBL experience.

The PBL sessions were done weekly during the first half of the students' mandatory tutorial. Each week, students were randomly assigned to a group of about four students, with one student identified as the group leader. Students were given a problem to solve that brought out a key concept that had not yet been lectured to. Similarly, they were asked not to use the textbook or any online resources, but instead were to figure out the problem on their own. Some scaffolding of the problem was required in order to lead the students to the intended concept, particularly early in the term, but efforts were made to keep the scaffolding to a minimum, particularly as the term went on. The intent was that the students would discover a concept in an intuitive fashion, in order to understand the concept prior to its formalization in the lecture.

Each group's PBL solution was to be written up and submitted prior to taking it up together in the tutorial. However, the solutions were not graded. Instead, all that was required was that the submission demonstrated that the group put thought and effort into pursing a solution, whether or not they succeeded in finding it. This took some adjusting to for the high-achieving students in the class who seemed to be conditioned to be more comfortable with getting explicitly graded feedback on the accuracy or inaccuracy of the end result, rather than receiving recognition for trying stuff, even if that stuff didn't work. But in the end, students identified this approach as providing a good low-pressure environment in which they could explore ideas, be creative, and learn.

Retention Study

In order to gauge the effect of PBL on the retention of the course material, students were asked to attempt a retention question one year after completing the course. The question was a rephrasing of a question given on their final exam one year earlier, so that results on the two questions could be compared. Students were also asked for feedback with the questions "Do you remember learning how to do a question like this in <the course>?" "To what extent do you feel that you were able to use concepts learned in <the course> to answer the question?," and "Please provide any additional comments that you feel may be of use in interpreting answers, including the nature of any additional courses you took this last year that you feel have influenced your solution."

The question used to assess retention tested understanding of Bayes' Theorem for computing conditional probabilities. The theorem is an important and highly relevant, for instance, when considering the probability of a positive result in a medical test being a false positive. The theorem seemed an appropriate topic as it is typically stated using a formula that is difficult to memorize and use without an understanding of its meaning. However, an understanding of the concept it embodies leads quite readily to the correct calculation without relying on any memorized formula. Moreover, the PBL activity for Bayes' Theorem developed the notion that the result could be computed more intuitively and reliably using a headcount of different members of a population of, say, 100,000 subjects being observed. To try to control for other effects that would impact the results, conscious efforts were made to ensure the in-class lectures on the topic were repeated in the exact same manner each year.

Students were not told the topic in advance and were asked to do no preparation for answering the question. The students were assured that it would take no more than 5 or 10 minutes to complete, and that, for participating, they would be entered into a draw for $50 at the campus bookstore. Participation in the retention question was voluntary and was conducted with anonymity in keeping with McMaster's research ethics requirements. The researchers were provided with student results identified by a random two-character code only. For each student that participated, office staff photocopied their corresponding solution from the final exam and marked that with the same anonymous code.

This process was carried out for the control group, as well as two successive years for students who had the PBL experience. Nonetheless, the number of responses was small, making reliable statistical analysis difficult. With the retention question, students were asked whether they had additional probability or statistics courses, and those that did were eliminated from the analysis. There were then 22 responses from the students in the control group, and only 14 observations from the two PBL groups. Both the exam questions and retention questions for all groups were randomly shuffled together, and all were freshly remarked in order to ensure consistent grading. Responses were graded on a 5-point scale, with an additional quarter of a mark granted for answers that were correct and executed very well; a quarter mark was deducted from those who got the correct answer, but notably struggled to do so. Moreover, each response was marked as to whether the answer demonstrated each of three qualities: (a) knowledge of the formula, (b) understanding of the concept, and (c) clear use of reasoning. For each of those qualities, the question was marked with “showed the quality,” “indicated a lack of that quality,” or “it could not be discerned from their answer.” For instance, a “blank” answer or the straight execution of a memorized formula would leave one “not able to discern” whether or not the student had a “clear use of reasoning” in solving the problem. On the other hand, combining unrelated numbers in random acts of math in the hopes of hitting the formula would suggest “indicated a lack” of reasoning.

Results

Scatterplots of the results are provided in Figures 1 and 2. Figure 1 shows the grade on the retention question as a function of the grade on the original exam question for the control group.

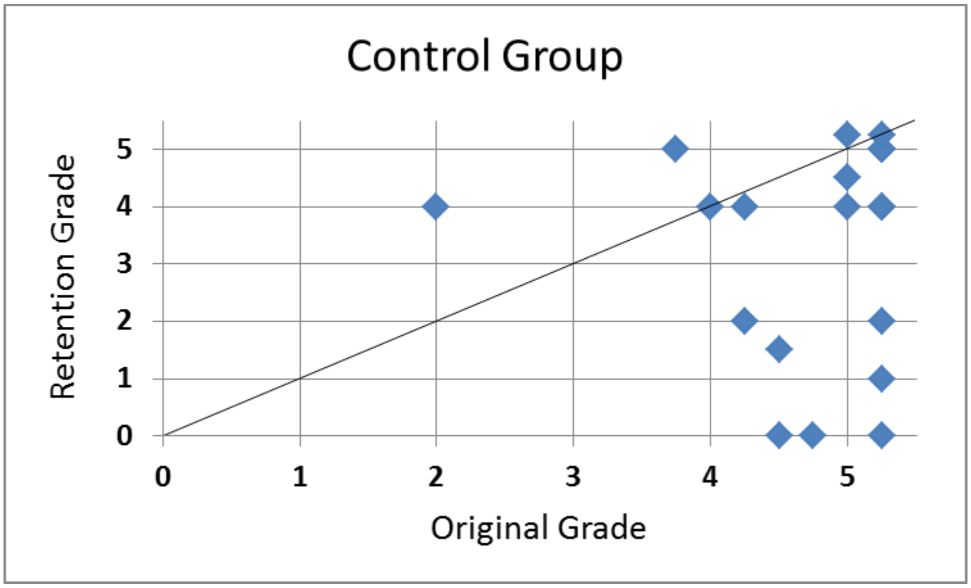

Figure 1. Student scores on the retention question versus their score on the nearly identical original question from the final exam for the control group with no PBL sessions. The average decrease is 1.4.

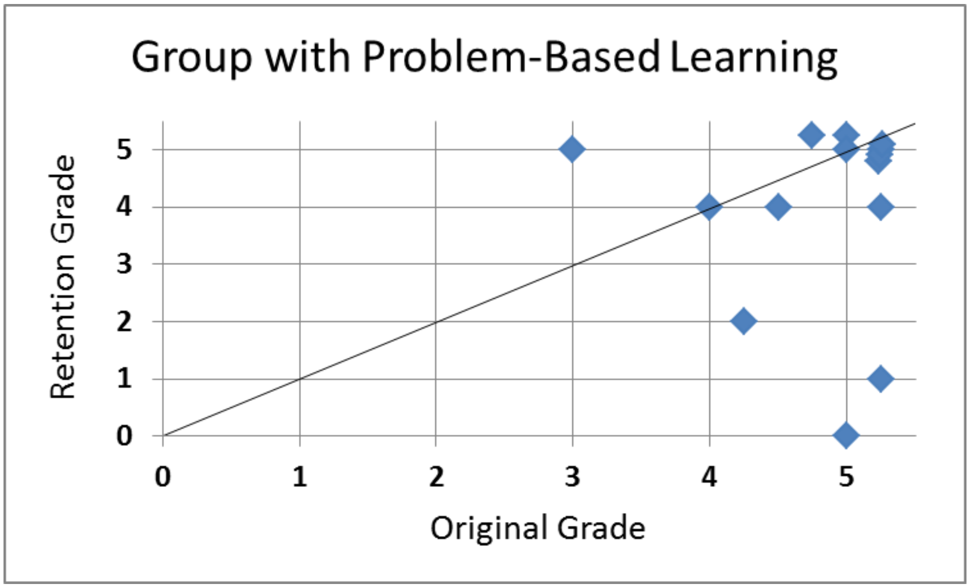

Figure 2. Student scores on the retention question versus their score on the nearly identical original question from the final exam for the group with PBL sessions. The average decrease is 0.8.

Students performed well on the original question, but their results were more varied when the question was repeated one year later. On average, the grade on the question decreased by 1.4 marks, with a standard deviation of SD=1.99. Two students in the control group and one student in the PBL group performed better on the retention question than the exam question. In these instances, students attempted to use the formula on the original exam but did so incorrectly. However, on the retention question, when the formula was long forgotten, these students did better relying on conceptual understanding or reasoning.

The average drop in performance on the retention question was not as large for the group with PBL experience. As seen in Figure 2, the average decrease in performance on the question was 0.8, with a standard deviation of SD=1.86. A one-tailed T-test on the mean change in performance for the two groups was conducted. Unfortunately, while the improvement in retention for the PBL group is suggestive, the T-test produces a p-value of about 0.20, so that the improvement cannot be said to be statistically significant.

The results on demonstrating (a) knowledge of formula, (b) understanding the concept, and (c) reasoning are provided in Figures 3, 4, and 5 respectively. The raw numbers are presented in bar form, rather than as proportions, because of the small number of participants. In each case, the numbers of students who did or did not demonstrate the quality appear at the left, with the number of students for which it could not be discerned appears at the right.

For knowledge of formula (Figure 3), reliance on the formula was quite pronounced for the control group, with 17 of the 22 students successfully using the formula on the exam. On the retention question, 15 of the 22 again tried to use the formula, but failed to do so successfully. None of the students in the control group successfully recalled the formula one year later (although 15 attempted to do so). In contrast, only 8 of the 14 students in the PBL group tried to use the formula to answer the problem on the original exam. On the retention question, 9 of the 14 students tried to use the formula to answer the question. Of those, only two were successful in correctly recalling the formula. The results strongly suggest that students do not retain knowledge of the formula one year after completing the course.

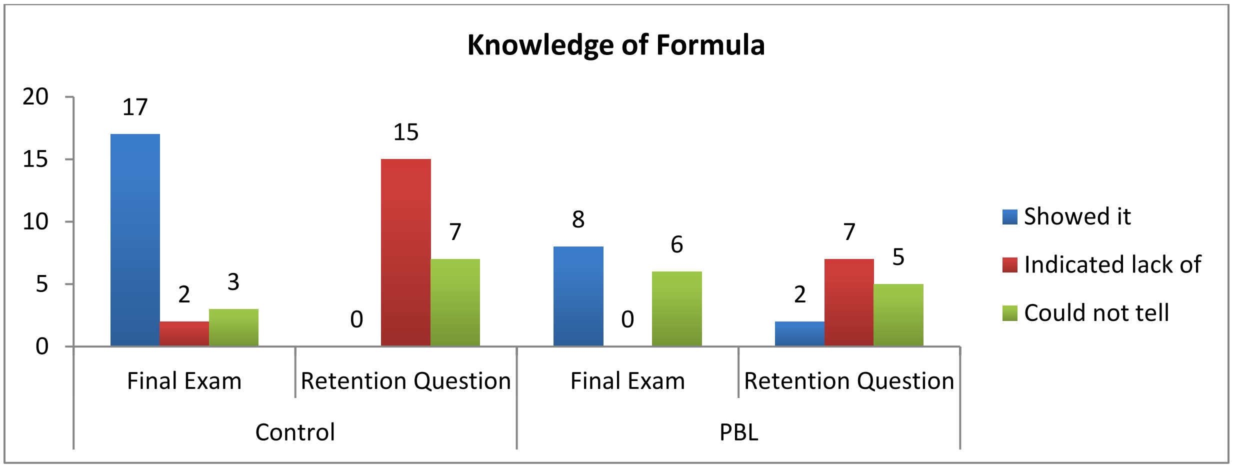

Figure 3. Counts of students who demonstrated knowledge of the Bayes' Theorem formula, who demonstrated a lack of such knowledge, or for whom one could not tell, in that order.

Conceptual understanding was well-demonstrated by both groups on their final exam (Figure 4). Only two students in the control group, and none in the PBL group, showed a lack of conceptual understanding. While there were some answers for which conceptual understanding could not be discerned, the large number of students seemed to understand the concept at exam time. One year later, conceptual understanding decreased for both the PBL and control groups. In the control group, 8 of the 22 showed that they no longer understood the concept, while the same was true for 4 of the 14 with PBL experience.

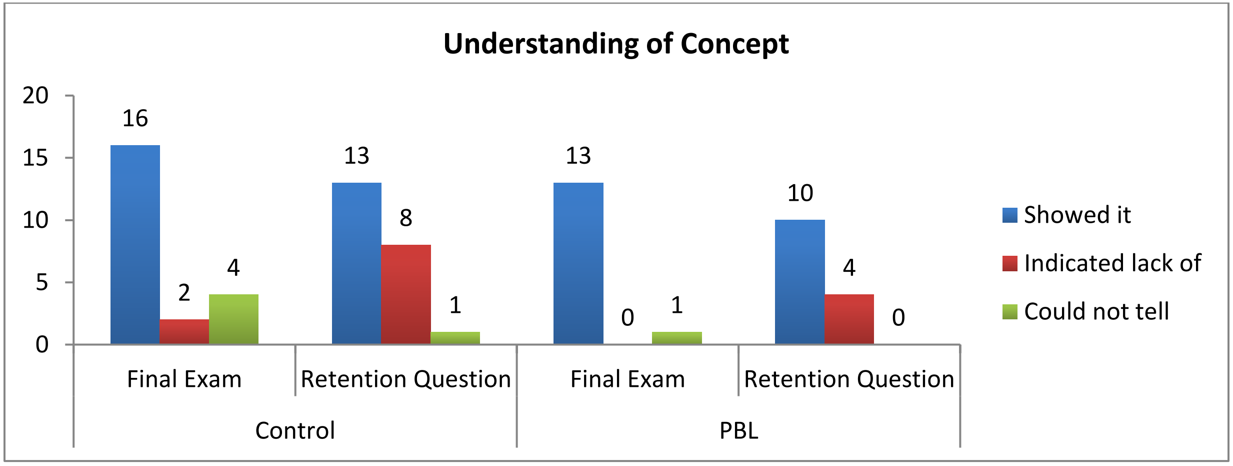

Figure 4. Counts of students who demonstrated understanding of the concept behind the question, who demonstrated a lack of such understanding, or for whom one could not tell, in that order.

It is interesting to see how many students in the control group retained that understanding. Conceptual understanding was higher in the PBL group, but the small sample size makes statistical significance elusive.

Both groups were evenly split between those that demonstrated use of reasoning on the final exam, and those for whom it could not be discerned (for instance, with a textbook execution of the solution procedure) (Figure 5). On the retention question, when the formulaic approach was long forgotten, forcing reliance on other solution approaches, 7 of the 22 students in the control group showed a lack of reasoning in their solution approach, tending more towards "random acts of math." The same was demonstrated with only 2 of the 14 students with PBL experience.

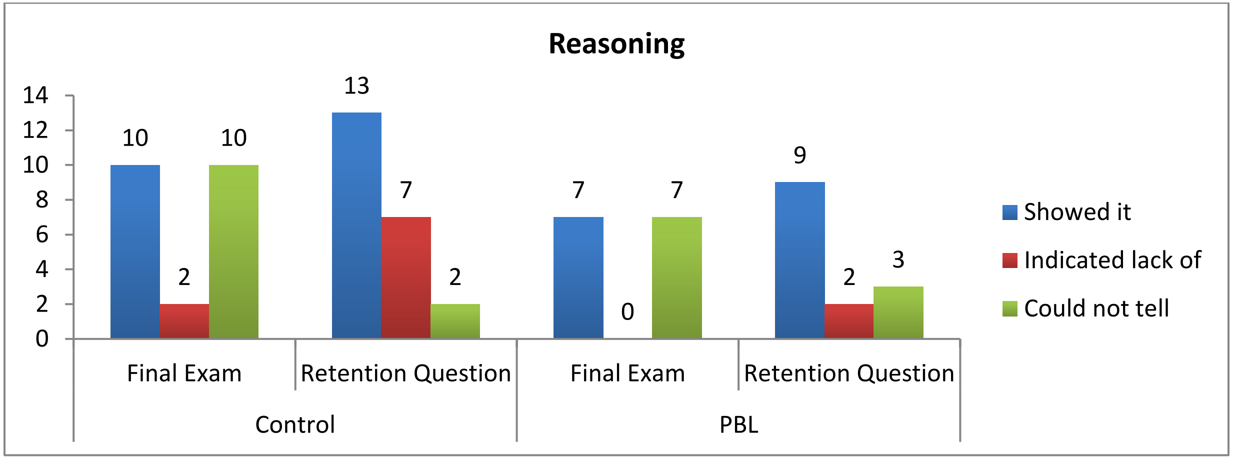

Figure 5. Counts of students who demonstrated good reasoning skills in answering the question, who demonstrated a lack of such reasoning, or for whom one could not tell, in that order.

Findings from Student Feedback

In addition to the quantitative findings, student feedback was sought during the course. In general, student feedback was very positive about the PBL experience. During the term, survey questions were handed out to the class in order to ask what did and did not work well with the PBL approach. Students most often reported enjoying working on the problems together in small groups. They appreciated being able to bounce ideas off one another and the opportunity to hear different perspectives on the problem. The students identified the low-pressure environment, where they would not be graded on the numerical result, as contributing to a positive learning experience.

Students also reported that doing the PBL activities in advance enabled them to more easily follow and understand the subsequent lectures. Students claimed that they felt the PBL exercises helped them to better think critically, and for some, they felt it helped increase their confidence in their reasoning and problem solving.

When asked what could be improved, the single most common response was that they wanted the TA to take them through the answers to the problem in explicit fashion. It appeared that, while they enjoyed the PBL experience, there was still a strong desire for a structured "tell me what to do" type of lesson. This was in spite of a discussion on the value of PBL provided at the beginning of the term. It was not clear, however, that providing more explicit direction would be of actual benefit to the students. For instance, Derek Muller (2012) reported with his TED talk on science videos that [explicit direction] may not lead to more successful learning. As one student reported, "I really liked the problem-solving aspect of tutorial. Very rewarding to 'discover' concepts. However, the culture became 'I don't understand so I'll just wait for the TA to tell us the answer,' which was disappointing."

Not all students came away from the PBL experience feeling that they had improved their reasoning and problem-solving ability. One student reported, “I sometimes feel the smarter people in the group end up understanding quickly and give me ‘problem-solving-it is’ and I leave worried and more confused then (sic) before.” Students reported that the experience varied with the composition of the group, supporting our decision to have used randomized groups, so that no one student was regularly working with a less effective group. One student suggested that one improvement might be to provide the group leader with a sheet of discussion starters.

Student feedback was also obtained from the retention exercise where students were asked to provide their feedback upon doing the retention question. It was interesting that some of the students who answered the retention question correctly did not seem to be able to identify the source of their understanding. Some actually apologized that they could not remember how they were “supposed to do” the problem. Nonetheless, those that reasoned out the solution tended to use the same reasoning that was developed in the course.

Conclusion

The results of the retention study are indicative of the PBL experience improving student retention of concepts in an introductory probability and statistics course. This is consistent with the majority of findings on PBL reported earlier. However, with a p-value of 0.20 the improvement is not statistically conclusive. Nonetheless, student response to the approach was positive, and the results are promising. Students who had the PBL experience appear to be less dependent on a formulaic approach, and better at using and retaining conceptual knowledge and reasoning. If nothing else, the evidence is strong that the formulas are long-forgotten one year after the course has finished. If students are anticipated to more likely retain conceptual understanding and an ability to reason and problem-solve, a PBL approach to learning the material seems an appropriate strategy. Students report appreciating the opportunity to work together to reason and problem solve in a low-pressure environment. And yet, there is still a desire on the students part to be shown how they are “supposed” to solve the problem, although appeasing that desire may not necessarily be to their benefit.

Acknowledgements

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