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A Comparative Study on the Role of Bloom's Taxonomy-based Assignments and Project-based Learning on Student Performance in an Undergraduate Fluid Mechanics Course

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Abstract

This paper compares and evaluates the role of two group-based active learning strategies, Bloom's Taxonomy-based learning (BTL) and project-based learning (PBL), on student knowledge, and comprehension in an undergraduate Fluid Mechanics class. Problems in engineering textbooks are typically designed to require learners to recall facts or apply concepts to solve for numerical answers. Based on Bloom's Taxonomy framework, these textbook problems are categorized at the lower cognitive levels of R*emember* and A*pply*, which may not fully facilitate students' deep learning. The authors designed and developed Bloom's Taxonomy-based assignments to include problems at three additional Bloom's Taxonomy cognitive levels of U*nderstand*, A*nalyze*, and E*valuate*. Our previous works and others have separately shown that implementing BTL and PBL in addition to textbook problems could deeply engage students in the learning content and enhance students' critical thinking skills and knowledge comprehension. However, to the best of our knowledge, the impact of these two teaching pedagogies has not been evaluated concurrently. In this study, we conduct a comparative analysis between two groups of students (n = 200) to determine the role of BTL and PBL in a similar class setting. Both groups were taught in active learning classrooms with online polling, in-class group discussions, and in-class assignments. The BTL group was exposed to Bloom's Taxonomy-based assignments, while the PBL group was involved in a group-term project. Our results show that both BTL and PBL students demonstrated comparable problem-solving skills and statistically similar performances on the common formative and summative assessments. However, students in the BTL section performed better on problems at higher cognitive levels. Our comparative analysis provides insights into how the type of group-based assignments impact overall student learning outcomes.

Introduction

In recent years, there has been a worldwide push to move away from a traditional lecture, with the instructor positioned at the front of the classroom presenting material using a PowerPoint presentation or writing on the whiteboard and students passively listening, to more interactive student-centered learning methods like flipped classrooms, active learning, gamification or game-based learning, in-class hands-on learning experiments, etc. Some benefits of these engaging methods include a greater understanding of fundamental concepts, higher knowledge retention, development of collaboration skills, and better performance on summative assessments [1]-[3].Active learning involves a variety of instructional methods that require students to actively 'do something', such as participating in discussion or completing an in-class activity (rather than passively taking notes or following instructor directions), to foster higher-order thinking [4].

Project-based learning (PBL) is an inquiry-based active learning method that involves students collaboratively working on authentic real-world problems to develop solutions or end products [5]. Particularly in theoretical engineering classes (in which students might not be required to concurrently enroll in the corresponding laboratory section), this method emphasizes the applicability of the knowledge gained in the classroom to the surrounding society beyond the context of simplified numerical problems from the textbook [6]. Additionally, researchers have demonstrated that PBL hones students' critical thinking skills, fosters communication and teamwork abilities, and encourages students to take ownership of their learning [3].

Cooperative learning, which also has collaborative work at its core, like PBL, is another subset of active learning that utilizes small group in-class activities to maximize student learning [7]. Our previous research has demonstrated that minimal modification of homework, take-home quizzes, and in-class activities to include problems at Bloom's taxonomy categories of *Understand*, *Analyze*, and *Evaluate* (which typically only include questions at *Remember* and *Apply* levels), when implemented in an active learning environment, significantly improved student understanding, performance in a summative assessment, and overall student learning experience [8]. We also found that active learning is integral to ensure that targeted Bloom's Taxonomy questions improve student learning/metacognition, and similar implementation in a traditional/instructor centered classroom is not as beneficial [9]. The multi-tiered Bloom's Taxonomy model, first developed in 1956 by Benjamin Bloom and collaborators, and later revised in 2001, hierarchically categorizes learning into six cognitive levels: *Remember*, *Understand*, *Apply*, *Analyze*, *Evaluate*, and *Create* [10]. Problems from the first five categories test the ability of students to *remember* factual knowledge, *understand* fundamental ideas/ concepts, *apply* these concepts in various contexts to solve numerical problems, *analyze* ideas by comparing different solution approaches, and support decisions or justify choices (i.e., *evaluate*) using knowledge gained in class respectively.

The goal of this study is to compare and evaluate the role of two group-based assignments, i.e., Bloom's Taxonomy-based learning (BTL) and Problem-based learning (PBL), on student knowledge, and comprehension in a large undergraduate Fluid Mechanics class. We aim to investigate whether the exposure to real-world engineering problems in the PBL class section translates into better performance on formative and summative assessments than the implementation of targeted small-group Bloom's taxonomy in-class activities in another class section. To the best of our knowledge, the limited comparative literature in this domain does not involve analysis of student performance on formative and summative assessments incorporating problems at various Bloom's Taxonomy levels [11]-[12]. Our study aims to fill that gap. We hope the results from this analysis will guide instructors to choose between these two instructional methods or even implement a combination of these two in undergraduate engineering classes for optimized student learning and satisfaction.

Methods

This study was conducted in a required undergraduate Fluid Mechanics course in the Mechanical Engineering Department at Texas A&M University in Fall 2023. The class consisted of ~85% junior mechanical engineering students and ~15% junior and senior students from nuclear engineering and architectural engineering. This study includes two sections of the course taught by two different instructors (Table 1). Both instructors have similar teaching philosophies, pedagogical approaches, and more than three years of experience teaching Fluid Mechanics courses.

Table 1. Details of the two class sections participating in the study: the number of students, type of assignments (i.e., homework, in-class activities, projects), and instructors assigned to each section.

Sections	**No. of students**	**Homework (HW)**	**In-class activities (ICA)**	**Team Project**	**Instructor**
Bloom's Taxonomy-based Learning **(BTL)**	100	Modified problems at *five* Bloom's Taxonomy levels	Problems at *five* Bloom's Taxonomy levels	Not Assigned	A
Project-based Learning **(PBL)**	100	Textbook problems at *two* Bloom's Taxonomy levels	Problems at *two* Bloom's Taxonomy levels and *team project*-related tasks	Assigned	B

Both sections had the same number of students (100 students/section) and were taught in an active learning environment. Students engaged in learning through individual online polling and small group-based in-class activities. The homework and in-class activities in the Bloom's Taxonomy-based learning (BTL) section consisted of problems at five Bloom's Taxonomy categories – *Remember, Understand, Apply, Analyze, and Evaluate* levels. On the other hand, the homework and in-class activities problems in the Project-based learning (PBL) section only focused on two Bloom's Taxonomy categories – *Remember and Apply*, in addition to problems related to the assigned team project.

A team-based (4 students/team) semester-long project was assigned in the PBL section. The main goal of this project was to motivate students to develop a deep understanding of content knowledge and promote various skills (e.g., creativity, critical thinking, collaboration, and communication) by working on real-world, ill-structured problems in small teams. Additionally, this project was explicitly designed to foster students' entrepreneurial mindset, empowering them to enhance their technical knowledge with a proactive, exploratory, and impact-driven approach. The title of the team project was 'Aggieland Piping System Design', and the objective was to develop a sustainable and cost-effective piping system design that ensures a reliable water supply to the campus's residents while optimizing resource utilization and financial investments. There were three project deliverables collected throughout the semester, as listed below:

- *Deliverable 1 - Preliminary Investigation*: Students asked critical questions about the problem, researched and identified specific requirements needed in the design to meet customer needs, and provided a 1-page writeup.
- *Deliverable 2 - Preliminary Design*: Students sketched their preliminary design and provided evidence of the technical feasibility of their design using concepts learned in class (e.g., the Bernoulli equation).
- *Deliverable 3 - Final Design Report*: Students submitted a final report, which primarily included a description of the problem, design requirements, design drawings, summary of technical calculation results, and bill of materials.

Assessments

To investigate the effect of BTL and PBL on student learning, the average student scores in a common quiz and a final exam were compared. The same take-home, open-book, time-limited (1-hour) quiz was administered in both sections. It covered the topic of viscous flow in pipes, which is also the focus of the in-class activities (ICAs) and modified homework of the BTL section, and the ICAs and team project in the PBL section. The quiz included mandatory problems at *Remember* and *Apply* levels, and bonus questions at *Understand, Analyze, and Evaluate* levels. The quiz problems are listed in Appendix A.

Since the final exam was scheduled on a different day towards the end of the semester for each section, the exam problems were different but designed to be at a similar difficulty level. All exam problems were given at the *Apply* cognitive level.

The grading distribution for both sections was 70% on formative and summative exams (i.e., 20% on Midterm 1, 20% on Midterm 2, and 30% on the Final Exam), 5% on in-class activities, 10% on homework, and 15% on other assignments. The remaining 15% of the grades for the BTL section were for quizzes, while for the PBL section, it was 5% for quizzes and 10% for team projects.

Statistical Analysis

A comparison between scores from the BTL and PBL sections was conducted using a nonparametric, the Mann-Whitney U test, at a 95% confidence level. A value of $p < 0.05$ was considered to be statistically significant.

Results

In-class activities

In-class activities (ICA) were administered in two formats — online individual polls and team-based in-class assignments. Both sections attempted the polls containing questions at two cognitive levels of Bloom's Taxonomy – *Remember and Apply*, at random times throughout the class. Grades from these polls were not recorded. Additionally, the BTL section attempted three team-based in-class assignments. Each ICA contained problems at different cognitive levels – *Understand* (ICA 1)*, Analyze* (ICA 2)*, and Evaluate* (ICA 3). On the other hand, the PBL section completed four team-based in-class assignments. These ICAs were all related to the deliverables of the term project.

Table 2. Percentage of students in the BTL and the PBL groups who earned credit in the in-class discussion-based assignments.

In-Class Assignments	BTL Group	PBL Group
ICA 1	77%	92%
ICA 2	90%	98%
ICA 3	94%	94%
ICA 4	Not applicable	98%

Overall, both sections had great class participation and engagement. More than 90% of students in both sections (except ICA 1 in the BTL group) participated and earned credit in the in-class discussion-based assignments (Table 2). The low participation in ICA 1 for the BTL section could potentially have been due to many students missing lectures on that particular day to study for an exam for another course.

Homework

A homework assignment on viscous flow in pipes was given to both sections. The homework assignment for the BTL group was modified to include problems at five Bloom's Taxonomy cognitive levels, while the PBL group had problems at two cognitive levels (similar to problems found in textbooks). Figure 1A shows that no significant difference was found between the homework scores of these groups. Since 80% of the homework was graded for completion and 20% for accuracy in both sections, this finding suggests that students from both sections might have spent similar effort completing the homework. It might be worth noting that although most students were able to complete the homework problems, only 91%, 73%, and 40% of the BTL students received full (accuracy) credits in the modified problems at the *Understand, Analyze, and Evaluate* levels, respectively (Figure 1B). Thus, with higher cognitive levels requiring higher-order thinking, the percentage of students who received full credit on those problems was found to decrease.

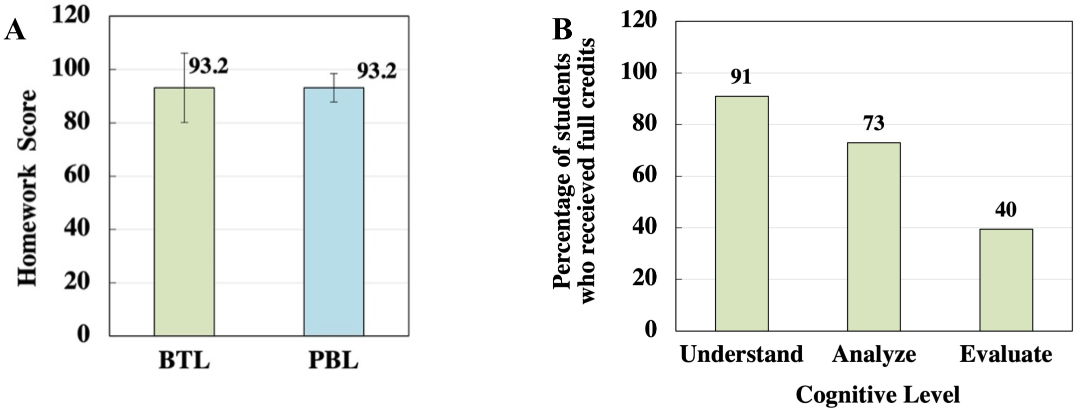

Figure 1. (A) The average homework score of the BTL and PBL sections and (B) Percentage of students in the BTL section who earned full credit in the modified homework problems.

Team project

Each team in the PBL section submitted three deliverables (as described in the method section) for the term project. The average score of all teams across the three tasks is 89%, with the average in Task I being slightly higher than Tasks II and III. The consistent scores demonstrate that students diligently kept up with the assigned work throughout the semester. A slight decrease in scores from Tasks I to III is anticipated as the requirements, expectations, and content depth were progressively made more challenging throughout the semester.

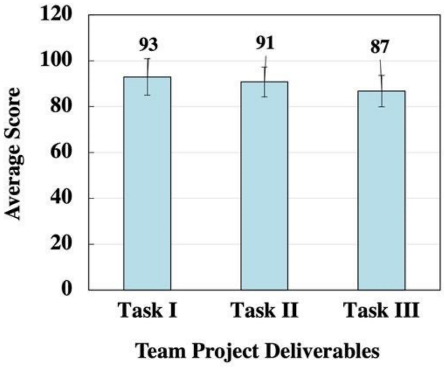

Figure 2. The average score of three deliverables in the team project for the PBL section.

Quiz

A common quiz was given to the BTL and PBL sections. The quiz consisted of a mandatory section (10 points) and a bonus section (3 points). The mandatory section included problems at two cognitive levels, *Remember* and *Apply,* whereas the bonus problems were at three different cognitive levels: *Understand, Analyze, and Evaluate* (Appendix A). Figure 3A shows the average scores on the mandatory problems and the total score, including the mandatory and bonus problems. No significant difference was found between the average score of the mandatory problems in the BTL and PBL sections. However, the total score (including bonus points) of the BTL group is significantly higher than the PBL group. This result suggests that the BTL students performed better on the bonus questions at Bloom's Taxonomy cognitive levels, which are not typically included in textbook problems. Specifically, the percentages of the BTL students who received partial or full credits on the bonus problems are higher than the PBL students in all problem categories (Figure 3B). Similar to the trend observed in the homework assignment, the percentage of students who received credit was found to decrease as the cognitive levels changed from a lower level (*Understand*) to a higher level (*Evaluate*) for both sections. However, this downward trend is more evident in the PBL section — ~ 21% (from 83% to 66%) — than in the BTL section ~ 8% (from 91% to 84%). A greater number of BTL students were able to exercise critical thinking skills than the other section, likely because the BTL students had previously been exposed to these types of problems during the in-class activities and homework. This finding suggests that although the two collaborative learning formats may not significantly impact students' problem-solving skills, they can distinctly influence students' knowledge comprehension and deep learning of the course content.

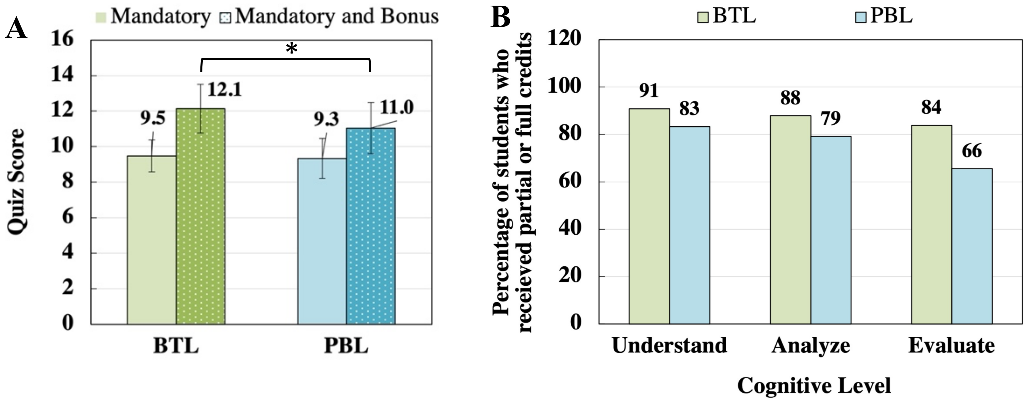

Figure 3. (A) The average quiz score of the BTL and PBL sections. The solid bar represents the total score of the mandatory problems focusing on two cognitive levels (*Remember and Apply*). The patterned bar denotes the total score of all problems (mandatory and bonus problems) at five cognitive levels (*Remember, Understand, Apply, Analyze, and Evaluate*). (B) Percentage of students in the BTL and PBL sections who received either partial or full credit in the modified problems (*Understand, Analyze, and Evaluate*). * represents a significant difference at 95% confidence ($p < 0.05$).

Exam

The final exam was comprehensive, consisting of problems on various topics covered over the duration of the semester, including viscous flow in pipes. Since the final exam was scheduled on a different day for each section, the exam problems (all at the *Apply* level) were different but designed to be at a similar difficulty level. The average score of the problem(s) covering the focused topic was compared and has been shown in Figure 4. There is no significant difference between the exam scores of the two student sections. This finding is consistent with the result of the formative assessment (Figure 3A). Both active learning modes appear to promote students' problem-solving skills similarly.

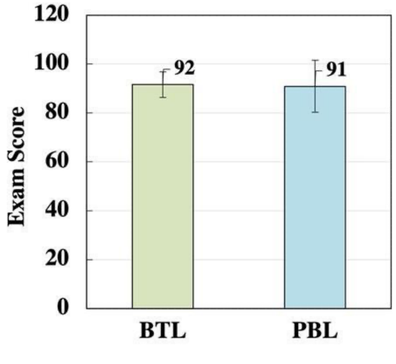

Figure 4. The average score of the final exam problem(s) on the viscous flow in pipes of the BTL and PBL sections.

In the future, a questionnaire primarily focused on the curiosity dimension [13], one of the entrepreneurial mindsets based on the Kern Engineering Entrepreneurial Network (KEEN) framework [14] and other related categories, including connection, creating value, engineering thought and action, collaboration, communication, and character will be developed and given to students before and after the semester. Our preliminary study suggests that the changes in students' mindsets in most categories are greater in the PBL section compared to the BTL section (data not shown). However, a further thorough analysis will need to be conducted to make generalized claims. The enhanced positive effect in the PBL section could likely be due to connecting the theoretical learnings from the course to real-world problems and the design of the team project toward entrepreneurially minded learning.

Limitations

The two class sections analyzed in this study were taught by two different instructors. While both have similar education backgrounds, use almost identical lecture notes, and designed assessments to be at the same difficulty level, there are inherent differences in lecture delivery styles, teaching philosophies, and years of teaching experience, which might have influenced the results. Secondly, the homework and take-home quiz were graded by a different undergraduate grader for each section while exams and in-class activities were graded by the respective graduate teaching assistants for each section. While each of them followed detailed grading rubrics provided by the instructors, personal grading philosophies (such as taking the time to comprehend the reasoning behind and allocate appropriate credit for partially correct answers or being more/less liberal with partial credit) could have influenced the outcomes of the study. Due to departmental logistical limitations, it is currently not possible to have the same grader for each assignment across multiple sections. Further, the innovations were implemented in one out of the nine chapters covered in this course, which led to limited results and the inability to glean general trends across assessments covering all the course content. Additionally, the number of students in each group for the project in the PBL section and the number of students in each group for the in-class assignments in the BTL section were not pre-designed by the instructors to be the same. To elaborate, these groups varied from two to four students in the BTL section and differed across each activity depending on which table students decided to sit at on a particular lecture day, while the students in the PBL section typically worked with the same members (4 students/team) for all ICAs.

Conclusion

This study assesses how two collaborative active learning strategies - Bloom's Taxonomy-based learning (BTL) and project-based learning (PBL) – affect students' performance in an undergraduate Fluid Mechanics course. In the BTL class, students were exposed to small-group in-class activities and assignments that helped promote their learning in cognitive levels (i.e., *Understand, Analyze, and Evaluate*) beyond typical problem-solving skills. In the PBL class, students were assigned a semester-long team project that required them to work on open-ended, real-world, and entrepreneurially-minded learning problems. Overall, students in both sections had statistically similar performance in *Apply* level problems in the formative and summative assessments. However, a greater number of BTL students performed better in problems at higher cognitive levels, where critical thinking skills are needed. These findings suggest that these active learning strategies effectively promote student learning and problem-solving abilities. However, additional student learning outcomes, such as critical thinking skills and entrepreneurial mindsets, could be correlated with the types of assignments and activities administered in the class. Instructors may choose to design a course with combined active learning strategies to optimally achieve multiple learning outcomes.

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Appendix A – Example of Formative Assessment (Quiz) covering problems at five Bloom's Taxonomy categories

Problem 1 [2/10 pts, 1 point each] – ***Remember Level***

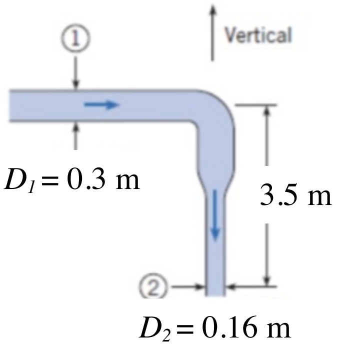
State TRUE or FALSE. For a false statement, explain why it is false.

(a) For a given loss coefficient, the minor head loss through a pipe component in viscous flow is directly proportional to the square of the velocity.

(b) There is a steady laminar flow of water in a horizontal pipe of length l. As the volumetric flowrate increases, the pressure drop over the length l will decrease.

Problem 2 [8/10 pts] – ***Apply Level***

Gasoline ($\rho = 800$ kg/m^3, $\mu = 6.7 \times 10^{-4}$ kg/m·s) steadily flows in a vertical pipe shown below at a velocity of 2 m/s at section 1. The pressure at section 1 is 124 kPa, and the total head loss between sections 1 and 2 is 2.75 m. (1 kPa = 1000 kg/m·s^2, g = 9.81 m/s^2)



2.1 Calculate the Reynolds number at section 1. Is this flow *laminar* or *turbulent*? [2 pts].
2.2 Calculate the gasoline velocity at section 2 (in m/s) [2 pts].
2.3 Calculate the pressure at section 2 (in kPa). Assume $\alpha = 1.0$ at all locations [4 pts].

Bonus Questions (for problem 2)

(a) *Explain* the reasoning behind the assumption for kinetic energy coefficients (given in 2.3) equal to 1.0 at all locations. [1 pt] – ***Understand Level***

(b) Suppose the total head loss was not provided in problem 2. How would your solution procedure for 2.3 be different? What additional information would you need? 'Solution procedure' refers to the steps you take in the correct order and the equations and assumptions you use to solve the problem. [1 pt] – ***Analyze Level***

(c) If the pipe shown above was aligned horizontally, evaluate (without performing any numerical calculations), if the pressure at section 2 (calculated in 2.3) would increase/decrease/stay the same. Include an explanation to support your answer. Assume all other parameters remain the same as in the original problem. [1 pt] – ***Evaluate Level***