Beyond Scores: Early Findings on TBL's Impact in Engineering Education

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Abstract. This paper presents the preliminary findings of an ongoing study investigating the influence of Team-Based Learning (TBL) on the academic performance of engineering students, particularly its impact on their grasp of subject matter and ability to solve real-world problems. Quantitative data analysis explored correlations between students' entry-level academic scores and their performance in a course incorporating TBL. The initial results suggest that there is no significant correlation, indicating that entry scores may not predict success in this TBL-integrated course. The analysis coverages multiple academic years, offering a comprehensive perspective on how trends and outcomes evolve over time. This study contributes to the discourse on effective educational practices in engineering education by examining the potential of TBL to enhance learning outcomes. Given the study's ongoing nature, these findings are provisional but pave the way for more detailed future analyses.

Keywords: Team-Based Learning (TBL), Academic performance, Engineering Education, Statistical Analysis.

1 Introduction

Educational methods in engineering have continuously evolved to meet the demands of a rapidly changing technological landscape. Among these methods, Team-Based Learning (TBL) has emerged as a powerful pedagogical approach that emphasizes collaborative learning and practical application of theoretical knowledge [1]. Implementing TBL in a course significantly enhanced student performance, fostered the development of essential soft skills such as teamwork and communication, and increased student engagement by creating an interactive and collaborative learning environment that better prepares students for professional work [2].

The significance of exploring innovative educational strategies in engineering education must be balanced. Traditional lecture-based teaching methods have often been criticized for not fully engaging students or adequately preparing them for the practical challenges they will face in their professional careers [3,4]. In response, TBL has been proposed as a method that not only increases student engagement but also enhances their ability to apply knowledge in practical settings [5].

Vlachopoulos *et al*., in their work [6], highlight critical findings, revealing a significant enhancement in students' learning experiences and study hours and a strong positive correlation between TBL assessments and final grades. These results underscore the predictive power of TBL on student performance. Such insights are invaluable for educators aiming to adopt collaborative learning methodologies that boost student engagement and experience and improve learning outcomes, teamwork, and communication skills.

Following these thoughts, the present study focuses on a specific module within a engineering fluids course, redesigned to incorporate TBL to assess its effectiveness in improving student learning outcomes. The rationale for selecting this course lies in the complex nature of fluid mechanics, which requires a deep understanding of both theoretical concepts and their practical applications — an ideal domain for implementing active learning strategies.

Our main objective is to analyze how introducing TBL influences students' final marks, reflecting their grasp of the subject matter and their ability to solve real-world engineering problems. The study hypothesizes that TBL can provide a more equitable educational experience, improving outcomes for all students regardless of their academic background. By analyzing the effectiveness of TBL, this research seeks to contribute valuable empirical evidence to the ongoing discussion about best practices in engineering education, particularly in the application of active learning strategies that emphasize collaboration and real-world problem-solving. Also, this study aims to enrich the discussion on best practices in engineering education by providing empirical evidence for active learning strategies and offering insights that could enhance course effectiveness and student engagement across various technical disciplines.

2 Material and Methods

This section outlines the Fluid Transport Systems curricular unit, the setting for data collection, and details the data gathered.

2.1 Implementation of TBL in the Fluid Transport Systems Course

This paper seeks to analyze the impact of the TBL approach on the academic performance of 2nd-year students of the 1st cycle Chemical Engineering program at Instituto Superior de Engenharia do Porto (ISEP). Since the academic year of 2020-21, the module on fluid viscosity in the Fluid Transport Systems (STFLU) course has integrated TBL. The curriculum is designed to equip students with essential principles of Fluid Mechanics, including mass and energy balances, alongside practical knowledge in designing fluid transport mechanisms like pumps, flow meters, compressors, and fans. This innovative approach replaced the initial mini-test about Viscosity and Newton’s Law (one of the first topics addressed in the STFLU course) while preserving its 8% contribution towards the final course grade. The students were divided into 20 study groups and were provided with selected readings to facilitate self-directed learning. The assessment process involved an initial individual test followed by a group evaluation, promoting essential skills such as collaboration, problem-solving, effective time management, and communication.

Over the subsequent three years (2021-22 to 2023-24), the instructional team engaged in detailed discussions with each group to deliberate on their assessment performances. The module's final score was computed as a weighted average, with individual evaluations accounting for 75% and group contributions 25%. While student feedback about students' acquired competences and level of satisfaction were captured through questionnaires [7,8], the primary focus of this study is not on evaluating student perceptions but rather on examining the impact of the TBL module on final grades and analyzing the influence of higher education institution (HEI) access in the student's final marks obtained.

2.2 Students' characterization

Over the four academic years, 2020/21 to 2023/24, 183 students attended the classes of Fluid Transport Systems (STFLU) course: 31 in 2020/21, 58 in 2021/22, 46 in 2022/23, and 48 in 2023/24. The proportion of female students ranged from 62% to 77% of the total participants, highlighting a significant trend toward gender balance in Chemical Engineering. Additionally, most students were between 18 and 19 years old (around 75%), aligning with the typical age range for this educational stage, with an average age of approximately 19.6 years.

2.3 Dataset Description

The dataset used in this preliminary study correspond to the data gathered regarding the students who have taken STFLU course for the last four academic years (2020-21 to 2023-24) of the Chemical Engineering program.

A total of 9 features concerning students' evaluation obtained in the developed TBL activities, individually or in group, were defined as an input, e.g., TBL1, 8% in the final grade, corresponding to the TBL activity in the viscosity module, TGI total of group and individual components weighted average 25%, Total Individual Assessment, TIA, Final Grade, FG, and students' access mark to HEI, SAM_HEI.

Table 1 summarizes each feature and its characterization. At the end of the semester, students whose achievement TIA grade falls below 9.5 out of 20 are classified as unsuccessful. In contrast, those surpassing 9.5 or equal are considered successful and approved. The students' characteristics, gender (G), and age (A) were considered, as was the year (Y). For simplicity, from this point onward, Year 1 will refer to the 2020/21 academic year, continuing consecutively up to Year 4 for the 2023/24 academic year.

Table 1. Features' identification and main characteristics.

Feature identification	Feature description	Feature Range Grade
TBL1	TBL activity in viscosity module (8%)	0... 20
TGI	Group + Individual component (25%)	0... 20
TIA	Sum of all moments of assessment performed in the whole semester	0... 20

FG	Final student grade (TIA rounded to the nearest whole integer)	0... 20
SAM_HEI	Students' access mark to HEI	0... 20
IFS	Individual Final Status (Selected feature)	0 (<9.5); 1 (9.5 <>13.0); 2 (13.5<>15.0); 3 (>15.5)
Students' characteristics		
G	Gender	Female (F; 2); Male (M; 1)
A	Age	Integer (>18)
Y	Academic year	1 (2020-21); 2 (2021-22); 3 (2022-23); 4 (2023-24)

The open-source software Orange [9] was utilized, providing a user-friendly interface for data analysis and visualization, along with capabilities for constructing and assessing machine learning models.

3 Results and discussion

In this section, the outcomes of the analysis on the impact of Team-Based Learning (TBL) on student performance is presented.

Figure 1 presents a scatter plot displaying the relationship between the Team-Based Learning activity module score (TBL1) and the total assessment (TIA) accumulated over the semester, segmented by individual final status (IFS). The TBL1 is plotted on the y-axis, ranging from approximately 0 to 18, while the TIA is shown on the x-axis, ranging from about 4 to 18.

Data points are color-coded based on the IFS, ranging from 0 to 3, where each color represents a different status level:

- Blue (0): Represents students who did not meet the minimum requirements (<9.5);
- Red (1): Represents students who met basic requirements (9.5 <>13.0);
- Green (2): Represents students who exceeded expectations (13.5<>15.0);
- Orange (3): Represents students who demonstrated exceptional performance (>15.5).

The plot uses different shaded areas to indicate the density and clustering of data points, showing how TBL activity scores correlate with total assessment scores across different levels of student achievement throughout the semester. This visual representation helps identify patterns or trends in student performance relative to their engagement and success in the course activities, with varying correlation lines indicating the relationship between TIA and TBL1 scores within each group. These correlations range from positive to no correlation, highlighting how different student groups perform in relation to each other, with some clusters clearly visible in the background shading. It is possible to observe that a positive correlation is observed between the two variables (black line), suggesting that higher engagement in TBL activities may lead to higher overall assessment scores (r=0.47, p<0.001).

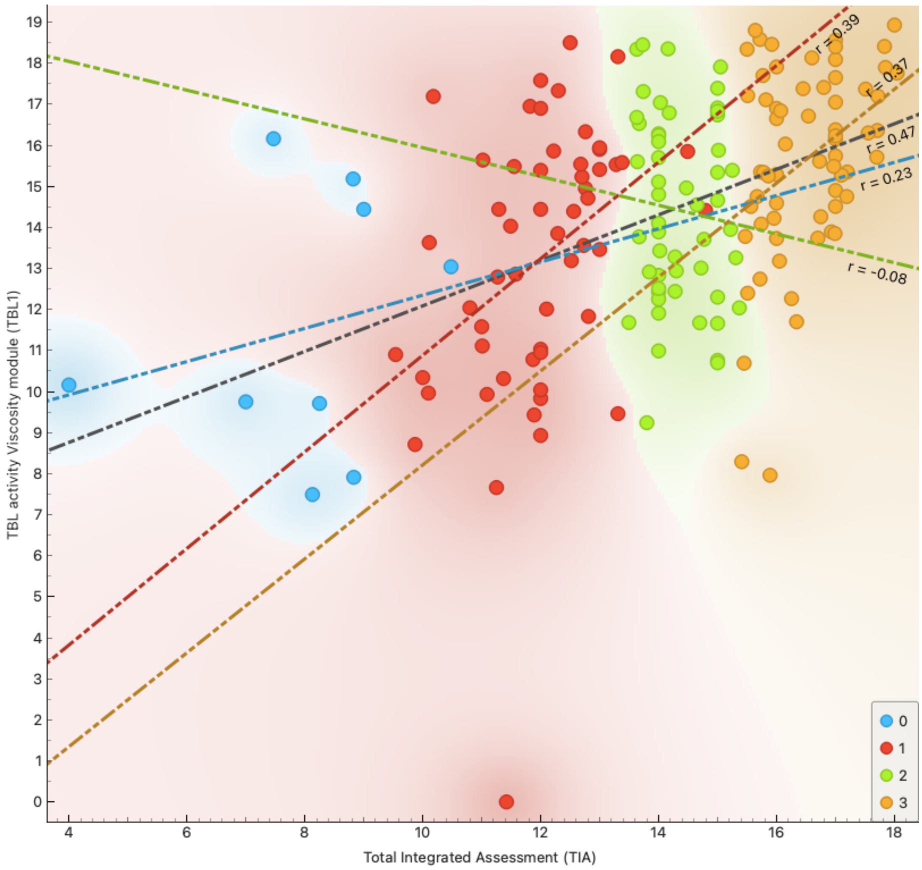

Fig. 1. Distribution of Team-Based Learning activity module score (TBL1) and the total assessment (TIA) accumulated over the semester by individual final status (IFS) where 0 (<9.5); 1 (9.5 <>13.0); 2 (13.5<>15.0); 3 (>15.5).

However, despite the overall positive trend, some extreme behaviors were observed, particularly in status level 2 (green, r=–0.08). Additionally, a few students who performed poorly in the TBL activity still passed the course through the final exam. This divergence from their peers may suggest unique challenges or exceptional abilities, underscoring the varied impact of TBL on individual performance.

While the analysis presented in Fig. 1 focuses on the relationship between the Team-Based Learning (TBL) module grades and total assessment scores, it is important to note that the final grades include components from other contents of the course not covered in this study. These components could potentially influence overall performance. Despite this, the findings provide valuable insights into the impact of the TBL module on students' learning outcomes, underscoring the importance of this educational approach in enhancing critical thinking and problem-solving skills essential for engineering students. The analysis remains significant as it highlights trends and patterns that are crucial for understanding and improving the effectiveness of the TBL methodology within the broader educational context.

Fig. 2 depicts a scatter plot that explores the relationship between students' access marks to Higher Education Institutions (SAM_HEI) and their Total Integrated Assessment (TIA) scores in the STFLU course, which incorporates Team-Based Learning. The x-axis represents the SAM_HEI scores ranging from 13 to 18, and the y-axis shows the TIA scores ranging from approximately 7 to 18. Data points are color-coded by academic year with colors from blue (1: 2020-21) to orange (4: 2023-24) representing consecutive years, allowing for visual analysis of trends over time.

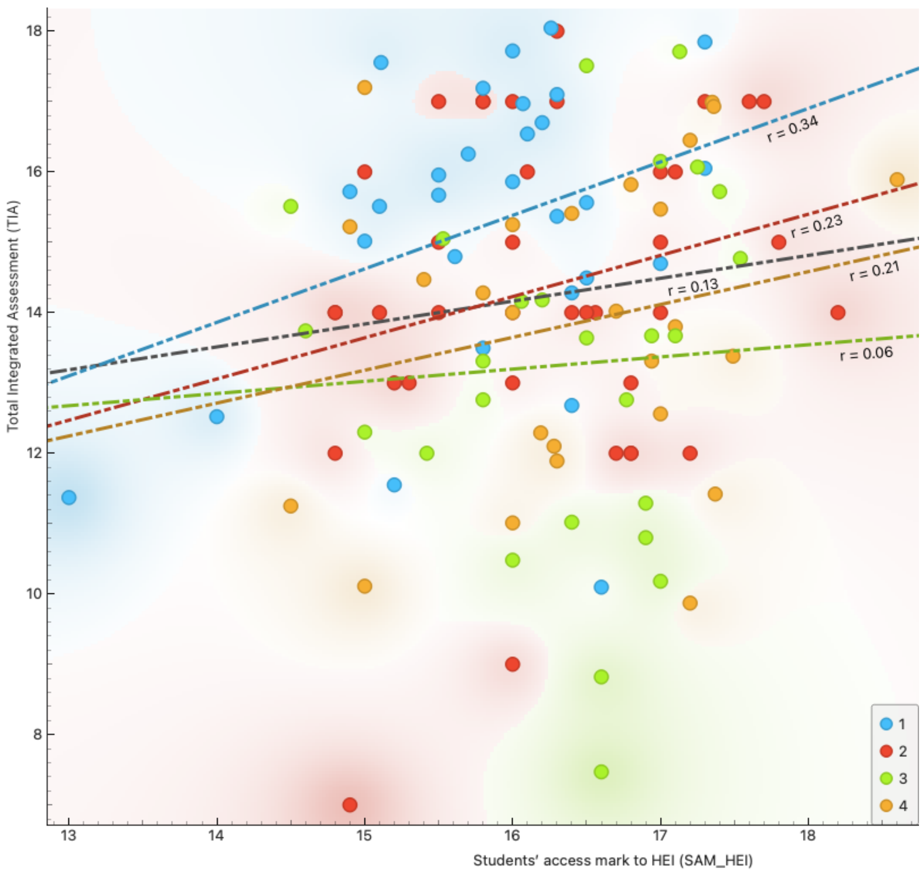

Fig. 2. Distribution of Total Integrate Assessment (TIA) and students' access marks to Higher Education Institutions (SAM_HEI), by the four academic years (blue 2020/21 to orange color 2023/24).

The overall correlation coefficient is displayed, suggesting an inexistent correlation between the two variables (black line, r=0.13, p=0.17>0.05). This result highlights that the initial access scores may not be reliable predictors of academic success in this context, suggesting that other factors could play a more pivotal role in influencing student performance in the course [10].

This conclusion is supported by the comparison of final academic marks across the four academic years, as illustrated in the box-plot in Fig. 3. Each box in the graph represents the distribution of final grades for a specific year, labeled from 1 to 4. Year 1 (15.37 ± 2.0) shows the highest average final mark, suggesting a potentially stronger cohort or different instructional methods that year. Year 2 (14.18 ± 2.6) and Year 4 (14.31 ± 2.1) display similar mean scores, although Year 2 exhibits slightly more variability in student performance. Year 3 (13.18 ± 2.7) records the lowest average mark, suggesting a significant drop in performance compared to other years. The differences between these groups (years) are statistically significant (ANOVA F=4.94, p<0.005), indicating that the observed differences in marks across the years are unlikely due to random variation. The study indicates a substantial effect size, reinforcing the relevance of these findings.

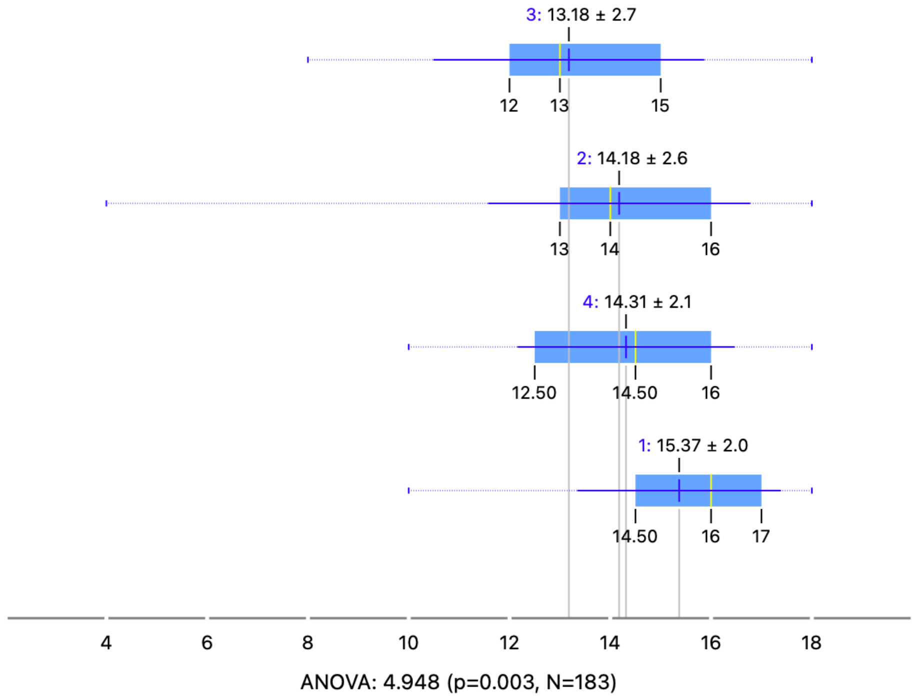

Fig. 3. Distribution of total assessment score (TIA) accumulated over the semester, by academic year (Year 1: 2020/21, Year 2: 2021/22, Year 3: 2022/23, and Year 4 for the 2023/24 academic year).

4 Final Considerations

This initial study explored the impact of Team-Based Learning (TBL) on the academic performance of engineering students. It specifically looked at the relationship between students' initial academic preparedness, as indicated by their access marks, and their performance outcomes in a TBL-enhanced course. Although the analysis is still in its early stages, it has provided important insights into the effectiveness of TBL in engineering education, particularly in terms of its potential to create a more level educational playing field.

The preliminary findings from the study suggest that there is no clear correlation between students' entry scores and their subsequent performance in the course. This suggests that the traditional metrics of academic readiness may not be as predictive of success in TBL settings as previously believed. This outcome underscores the potential for TBL to level the educational playing field by providing all students, regardless of their initial academic standing, the change to excel through enhanced engagement and collaboration.

The goal is to provide actionable insights that can be used by educators to refine their teaching strategies and by institutions to design more effective engineering education programs.

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