

Revisiting Team-Based Learning in a Fluid Mechanics Module: Enhancing Students' Competences

M. Teresa Sena-Esteves¹[0000-0003-0108-1159], Margarida Ribeiro¹[0000-0002-2119-3484], Cristina Morais¹[0000-0001-6464-601X], Isabel Brás-Pereira¹[0000-0002-8530-3849], Anabela Guedes¹[0000-0001-5929-1592], Filomena Soares²[0000-0002-4438-6713] and Celina P. Leão²[0000-0003-3725-5771]

¹ CIETI Research Centre, Polytechnic of Porto, Porto, Portugal

² ALGORITMI Centre, School of Engineering, University of Minho, Guimarães, Portugal
cpl@dps.uminho.pt

Abstract. This study investigates the evolution of students' perceptions and experiences with Team-Based Learning (TBL) over three academic years (2021/22, 2022/23 and 2023/24) applied to the Fluid Mechanics course' viscosity module of the second year of a chemical engineering degree, 1st semester. Through questionnaire data and qualitative evaluation, competences acquired and changes in teamwork and critical thinking were analyzed, based on a sample of 151 out of 167 enrolled students. Results reveal a shift in competence emphasis over time, with "Team work" initially prominent but more evenly distributed later. While students increasingly prefer individual study, TBL fosters collaboration and critical thinking. TBL assessment indicates consistency across years, with minor variation. The study underscores TBL's positive impact on student preparation and professional development.

Keywords: Active Learning, Engineering Education, Students' Competences, Team-Based Learning.

1 Introduction

There is a focus on the effectiveness of Team-Based Learning (TBL) in the context of engineering education [1]. TBL can be defined as an instructional approach that promotes collaborative learning and active student engagement within a small (typically consisting of 4-7 members) but structured team-based environment to collectively tackle complex problems or tasks related to the subject matter being taught [2]. TBL combines individual preparation, team discussion, and application exercises to foster critical thinking, problem-solving skills, effective communication, and teamwork [1, 3]. This shift aligns with the preferences of the present generation of students, who favor a more interactive, group activity, and lively environment of teaching and learning over more conventional lectures, as noted by Rajeswarie *et al* [4]. Not only does such an environment reflect today's learning style, it also greatly enhances the critical thinking and problem-solving skills essential to an engineering education [5].

The interactive nature of TBL makes it easier for teachers to manage the delivery of large amounts of information within a limited time frame. Unlike conventional teaching

methods, TBL's use of small working groups ensures that students remain focused, actively involved, and feel a greater sense of responsibility towards their peers and teacher. This peer interaction inherent to the TBL process not only promotes a collaborative environment but also significantly enhances critical thinking. As students engage in discussions and problem-solving activities, they develop deeper understanding and more effective learning strategies, ultimately leading to better educational outcomes [6].

Together with critical learning, learner autonomy is also crucial for the success of TBL. TBL is important in fostering teamwork and communication within groups, boosting academic performance, and preparing for professional challenges. The positive impact of TBL on engineering students' autonomy and critical thinking skills contributes deeply to their academic success and readiness to tackle real-world problems, thus underscoring the method's relevance and utility in technical education [7].

Considering the previous insights and the recognition that TBL promotes an environment where students can develop greater autonomy and achieve more positive outcomes, this paper revisits the TBL design for a module in a chemical engineering course. The aim is to explore the significance of TBL in engineering education by addressing two key research questions: RQ1: What specific skills have students acquired over the last three academic years (2021/22, 2022/23, and 2023/24)?, and RQ2: How have opportunities for teamwork and critical thinking evolved over the past three academic years? By examining these questions, this analysis aims to clarify the critical role of TBL on improving engineering students' learning and outcomes.

2 Overview of Fluid Transport Systems Module and TBL Implementation

This section presents an overview of the Fluid Transport Systems (STFLU) course and the implementation of the Team-Based Learning (TBL) methodology. STFLU, a 2nd-year course in the Chemical Engineering program at Instituto Superior de Engenharia do Porto (ISEP), includes one hour of lectures and three hours of practical classes per week, with an average enrollment of 50 to 65 students annually. The course aims to provide foundational knowledge in Fluid Mechanics, covering mass and energy balances and the design of fluid transport systems, including pumps, flow meters, compressors and fans.

Since 2020/21, TBL has been integrated into the module on fluid viscosity, replacing the first mini-test (IT1) and maintaining its 8% weight in the final grade. Students were organized into 20 study groups, provided with relevant bibliography, and tasked with self-studying the module. Following the individual assessment, students reconvened into larger groups for a collective assessment. This method aimed to enhance skills such as teamwork, problem-solving, time management, and communication.

In the last three academic years of 2021/22, 2022/23, and 2023/24, teachers discussed the assessment results with each group, and the final grade for the module was a weighted average of individual (75%) and group (25%) scores. Feedback was collected through questionnaires. During the 2020/21 academic year, due to the COVID-

19 pandemic, evaluations were conducted online via Zoom and Moodle. The detailed methodology and additional data can be found in previous studies [8,9].

3 Material and Methods

To achieve the main objectives of this study, data were collected based on students' perceptions through the purpose-designed questionnaire. This questionnaire aimed to collect students' views on TBL methodologies and the competences they believed they acquired. The responses included both quantitative data from closed-ended questions and qualitative insights from open-ended questions. Difference in behaviour and perceptions through the three academics year period was analysed using the ANOVA test (F). The statistical software SPSS 28.0 [10] and ORANGE 3.37.0 [11] were used.

3.1 TBL questionnaire description

The questionnaire used in this study was designed to assess various dimensions of students' perceptions regarding the effectiveness of TBL as a pedagogical methodology, drawing on previous research [8,9]. Comprising six main sections, the questionnaire covers diverse aspects of student experiences. However, to align with the primary focus of this paper, specific items from sections P1 and P2 (concerning to student characteristics and behaviour), P4 (about students' assessment of TBL methodology), P5 (about students' motivation in TBL) and P6 (regarding the identification of positive attributes and areas for improvement in TBL methodology, articulated in students' own words) will be emphasized in the current analysis.

P1. Student's characterization (gender, age, academic year, class timetable, class attendance);

P2. Analysis of slides and solved exercises (ASE):

ASE1 - How far in advance did you start analysing the slides and the solved exercises?

ASE2 - How much time did you spend analysing the slides and the solved exercises?

ASE3 - Have you analysed the slides and the exercises solved in a team?

ASE4 - Place where you analysed the slides and the solved exercises: Which?

P3. Analysis of the bibliography made available for the TBL activity (CSA); 3 items with a "No/Yes" answer and an open question;

P4. Assessment of TBL methodology (MET); 7 items evaluated according to a 5-point Likert scale of agreement (1—strongly disagree, 2—disagree, 3—neither agree nor disagree, 4—agree, 5—strongly agree);

P5. Motivation to participate in a TBL activity; 3 items with a "No/Yes" answer;

P6. Two open-ended questions:

TBL1: Mention one (or more) positive aspect of using the TBL methodology.

TBL2: Mention one (or more) aspect to improve in the use of the TBL methodology.

The questionnaire was distributed to students at the conclusion of each TBL activity in the first semester of academic years 2021/22 through 2023/24. Before starting to fill in the questionnaire, were briefed on the study's objectives. Participation was voluntary, and students completed the questionnaire in approximately 5 minutes.

3.2 Students' characterization

The study analyzed data from a sample of students of Fluid Transport Systems (STFLU) course (n=151) that agreed to answer the questionnaire, over three academic years: 2021/22, 2022/23, and 2023/24. In each of these academic years, the course was attended by 57 (of the 65 enrolled students), 46 (of the 53 enrolled students), and 48 (of the 49 enrolled) students, respectively, with both daytime and evening classes included (Table 1). These numbers represent a percentage of 87% to 98% of the enrolled students. The demographic profile of the students remained consistent across the three years, predominantly consisting of second-year undergraduate students in Chemical Engineering.

Table 1. Main Students' Characteristics (1: 2021/22; 2: 2022/23; 3: 2023/24).

Main Statistics					
Number of students (n=151)	1	57			
	2	46			
	3	48			
Gender (%)	Male; 1	24.6			
	2	37.0			
	3	33.3			
	Female; 1	75.4			
	2	63.0			
	3	66.7			
Age	Mean; 1	19.7	St. Deviation; 1	3.2	
	2	19.5	2	1.5	
	3	19.6	3	1.9	
Slides and Solved exercises (ASE) (%)	1	4-6 week	2-3 days	2-3 days	day be- fore
	1. How far in advance ...; 1	19.3	24.6	49.1	7.0
	2	41.3	39.1	17.4	2.2
	3	20.8	25.0	35.4	18.8
	2. How much time ...; 1	1-2 h	2-3 h	3-4 h	>4 h
	17.5	40.4	28.1	14.0	
	2	8.7	41.3	28.3	21.7
	3	14.6	29.2	33.3	22.9
	3. Have you analyzed ...; 1	group	ind.		
54.4	45.6				
2	73.9	23.9			
3	43.8	56.3			
4. Place ...;	1	home	ISEP	both	other
	3.5	79.0	17.5		
	2	23.9	28.3	43.5	4.3
3	8.3	91.7			

There exists a higher proportion of female students, from 75% to 63% of the total participants. This gender distribution is noteworthy as it reflects a common trend towards gender balance in the field of Chemical Engineering. In terms of age, most students (approximately 75%) were between 18 and 19 years old, which is consistent with

the typical age range for second-year undergraduate students. The average age was 19.6 years, with the distribution remaining fairly uniform across the three years under study.

Regarding the four items in ASE (slides and solved exercises) over the three academic years, a variability was observed in students' reviewing practices. In the 2021/22 academic year, 19.3% of students began their study at least one week in advance, increasing to 41.3% in 2022/23, and decreasing to 20.8% in 2023/24. Conversely, the percentage of students who started their study 2-3 or 1 day before decreased from 7.0% in 2021/22 to 2.0% in 2022/23, and then increased to 18.8% in 2023/24.

In analyzing the time students spent reviewing the slides and completed exercises over the three academic years, a clear trend emerged. Students in the last academic year (2023/24) dedicated significantly more time to their review compared to those in the first year (2021/22). Specifically, the percentage of students who spent more than three hours on review increased from 42.1% in 2021/22 to 56.2% in 2023/24.

In the last academic year (2023/24), the majority of students (56.3%) preferred to study individually, contrasting with the previous two years (2021/22 and 2022/23) where a higher proportion of students opted to study in group (54.4% and 73.9%, respectively). Throughout the three academic years, students regularly preferred to study in the ISEP environment, despite some variations in specific study locations over time.

4 Results and Discussion

This section explores students' responses to specific questionnaire items designed to address the two research questions RQ1 and RQ2, as outlined at the end of Section 1.

4.1. Students' perceptions about competences acquired with TBL

While numerous studies have investigated the impact of TBL on students' competences and learning outcomes, little attention has been paid to how students' perceptions of the competences acquired through TBL may evolve over time. In this study, the potential changes in students' identification of keywords related to their perceptions of competences acquired through TBL across three academic years was explored. Moreover, by examining how students' perceptions may vary through time considering the last three academic years, insights into the lasting effects and evolving perspectives on TBL among students in our educational context were gained. Through the analysis of qualitative data collected through student surveys and questionnaires carried out at different times points over the three academic years, we tried to identify any trends or shifts in the keywords used by students to describe their experiences with TBL. Understanding these changes can inform instructional practices and curriculum design to better align with students' evolving needs and expectations.

Overall, this study contributes to the growing body of literature on TBL by providing insights into the longitudinal dynamics of students' perceptions and experiences, ultimately enhancing our understanding of the effectiveness and sustainability of TBL in engineering education. To explore the competences that students perceive as acquired through the implementation of TBL over a three-year period, students responded to the open-ended question "TBL1: Mention one (or more) positive aspect of using the TBL methodology", allowing them to freely express their thoughts. Given the qualitative

nature of the responses, the students' answers were categorized and grouped into codes, representing common themes to facilitate analysis. Initially, three authors independently identified a preliminary set of codes based on recurring themes in the data. Subsequently, the authors collaboratively refined these codes, making minor adjustments as necessary. Fig. 1 illustrates the distribution and evolution of 11 competences identified through the students' responses to the open question about their perceptions of competences acquired through the implementation of TBL over three academic years.

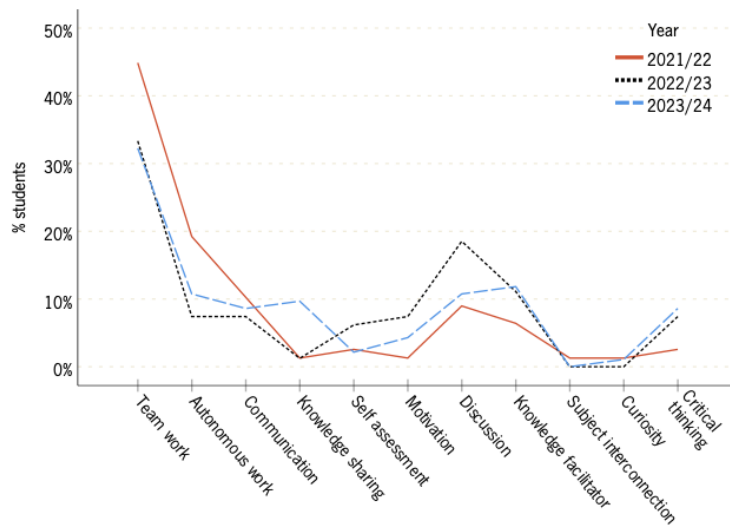


Fig. 1. Evolution of 11 competences identified by students using TBL over three academic years.

In the initial year (2021/22), the “Team work” competence raised out prominently among students' answers. However, in the final year (2023/24), this discrepancy narrowed, and the competences were distributed more evenly across the identified categories. In the 2021/22 academic year, the four competences that accounted for 83.4% of the total distribution, in addition to “Team work” (44.9%), were “Autonomous Work” (19.2%), “Communication” (10.3%), and “Discussion” (9.0%). In 2023/24, “Team-work” (32.3%) remained the competence identified with the highest percentage, although with a lower percentage compared to 2021/22, followed by “Knowledge Facilitator” (11.8%), “Autonomous Work” (10.8%), “Discussion” (10.8%), and “Knowledge Sharing” (9.7%), which together accounted for 75.4% of the total distribution. The next two competences identified were “Critical Thinking” and “Communication”, with 8.6% each.

These competences identified by the students underscore the positive impact of TBL on their awareness and preparation for professional development [1]. Moreover, both “Communication” and “Team work” are essential for effective collaboration and professional success. Students consistently highlighted the importance of teamwork as a critical skill acquired during the projects [12].

4.2. Students' TBL assessment

By linking the 7 items defined in P4 (Assessment of TBL methodology, MET) to the competences previously identified, it is possible to see how different aspects of the TBL methodology contribute to the development of various skills among students. To know:

MET1: “This activity took a lot of time outside of class.”, related to autonomous work, highlighting the need for independent work outside of class time.

MET2: “It improved my attention and participation in group activities.”, related to teamwork. This statement is directly related to improving participation in group activities, which is a key aspect of teamwork.

MET3: “It allowed me to assess whether I understood the material.”, related to critical thinking; assessing one's own understanding requires critical thinking to evaluate comprehension.

MET4: “This activity motivated me for collaborative work.”, related to teamwork and directly relates to the motivation for collaborative work, highlighting teamwork.

MET5: “This activity stimulated my intellectual curiosity.”, related to critical thinking as intellectual curiosity is part of critical thinking, as it drives the desire to explore and understand new concepts.

MET6: “This activity provided me with study materials.”, related to knowledge facilitator; providing study materials is part of facilitating knowledge acquisition.

MRT7: “The TBL methodology is a useful tool to support teaching.”. This statement is a general endorsement of the methodology and is not directly related to any specific competence.

Bearing in mind that a 5-point Likert scale of agreement was used, Table 2 presents the main descriptive statistical measures for the seven items assessed (Assessment of TBL Methodology, MET_i) across the three academic years (2021/22, 2022/23 and 2023/24), while Fig. 2 illustrates the distribution of the corresponding means.

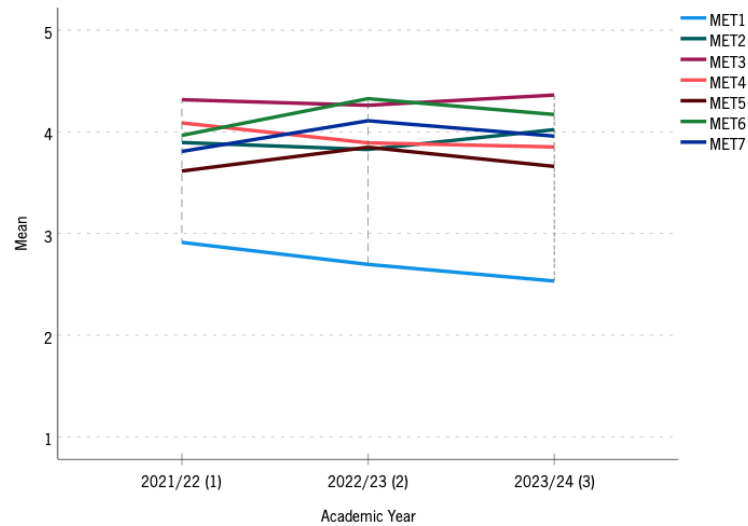
A one-way ANOVA test was carried out to analyze the differences in students' assessment of TBL methodology across the three academic years, determining whether there were statistically significant differences in the mean scores of identified competences among the three years and exploring these differences further a post-hoc analysis was conducted. Before conducting the ANOVA, Levene's test was used to assess the homogeneity of variances. The test indicated that the assumption was met for all competences except for MET6, as the variances were not significantly different ($p > 0.05$).

Despite observing variations in the mean values of TBL assessment by students across the three academic years (2021/22, 2022/23, and 2023/24), these differences were not statistically significant for most items ($p > 0.05$). This suggests that, although there may be observable trends in the data, these trends do not indicate a significant change in the overall impact of the students' assessment of the TBL methodology during the period under study. However, for MET6 the difference observed was significant ($p < 0.05$), as can be visualized in Fig. 3. This observation is in line with the results of the one-way ANOVA and post-hoc tests, that indicated the 2022/23 academic year with the lowest mean value (3.96), compared to the mean for the last two academic years (4.33 and 4.17).

Over the three academic years, there was a notable increase in the percentage of students who expressed motivation for more classes conducted in a TBL format, from 57.9% to 89.6%.

Table 2. SPSS output with the main MET items descriptive statistics.

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
MET1	2021/22	57	2.91	1.106	.147	2.62	3.21	1	5
	2022/23	46	2.70	.963	.142	2.41	2.98	1	5
	2023/24	48	2.50	.989	.143	2.21	2.79	1	5
	Total	151	2.72	1.035	.084	2.55	2.88	1	5
MET2	2021/22	57	3.89	.920	.122	3.65	4.14	1	5
	2022/23	46	3.83	.709	.105	3.62	4.04	2	5
	2023/24	48	4.04	.683	.099	3.84	4.24	3	5
	Total	151	3.92	.788	.064	3.79	4.05	1	5
MET3	2021/22	57	4.32	.805	.107	4.10	4.53	1	5
	2022/23	46	4.26	.575	.085	4.09	4.43	3	5
	2023/24	48	4.38	.672	.097	4.18	4.57	2	5
	Total	151	4.32	.696	.057	4.21	4.43	1	5
MET4	2021/22	57	4.09	.714	.095	3.90	4.28	3	5
	2022/23	46	3.89	.767	.113	3.66	4.12	2	5
	2023/24	48	3.88	.789	.114	3.65	4.10	1	5
	Total	151	3.96	.756	.062	3.84	4.08	1	5
MET5	2021/22	57	3.61	.675	.089	3.43	3.79	2	5
	2022/23	46	3.85	.729	.108	3.63	4.06	3	5
	2023/24	48	3.69	.719	.104	3.48	3.90	2	5
	Total	151	3.71	.708	.058	3.59	3.82	2	5
MET6	2021/22	57	3.96	.680	.090	3.78	4.15	2	5
	2022/23	46	4.33	.634	.094	4.14	4.51	3	5
	2023/24	47	4.17	.842	.123	3.92	4.42	2	5
	Total	150	4.14	.733	.060	4.02	4.26	2	5
MET7	2021/22	57	3.81	.833	.110	3.59	4.03	1	5
	2022/23	46	4.11	.823	.121	3.86	4.35	2	5
	2023/24	47	3.96	.806	.118	3.72	4.19	2	5
	Total	150	3.95	.826	.067	3.81	4.08	1	5

**Fig. 2.** Mean values of the students' assessment of TBL methodology, METi, in a 5-point Likert scale of agreement distribution along the three academic years.

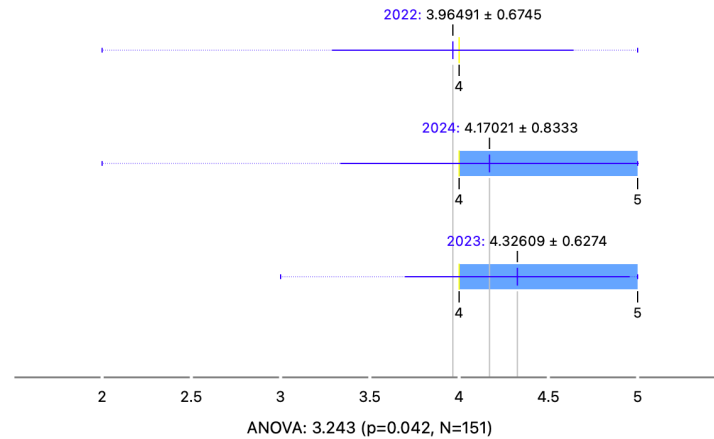


Fig. 3. Box-plot distribution for item MET6 along the three academic years.

5 Conclusions

The findings of this study shed light on the changing perceptions of TBL among engineering students over three academic years (2021/22, 2022/23, and 2023/24). Despite minor variations, students consistently value TBL's role in enhancing critical thinking, teamwork, and motivation. This underscores the importance of continued integration of TBL methodologies in engineering education to align with students' evolving preferences and foster essential competences for their future success. The results also reveal a notable shift in the distribution of competences developed through TBL. Initially dominated by "Team work", there has been a transition towards a more balanced development encompassing "Knowledge Facilitator" and "Critical Thinking". These changes emphasize the dynamic nature of competence development through TBL, suggesting that TBL's impact on student skills extends beyond immediate educational outcomes and contributes substantially to lifelong learning and adaptability.

Furthermore, the study highlights the need for ongoing research and improvement of TBL practices to optimize student learning outcomes. By understanding how students' perceptions of TBL evolve over time, teachers can adapt teaching methodologies and curriculum designs to better meet students' needs in today's dynamic educational landscape. By elucidating the effectiveness and sustainability of TBL in engineering education, this study informs educational practices and policies aimed at improving the learning and success of engineering students.

Future research should delve deeper into the dynamic changes in competence development, particularly examining the factors influencing the redistribution of key competences over successive years. Investigating the causal relationships between specific TBL interventions and competence improvements will provide deeper insights into how curricula can be optimized. Such research will ensure that TBL methodologies are continually refined and aligned with the changing preferences and needs of students, thus enhancing the overall effectiveness and sustainability of TBL in engineering education.

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