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Learner Autonomy in Team-based Learning: A Case Study of Mechanical Engineering Education

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Abstract : Team-based learning (TBL) has been increasingly applied in engineering and science education over the past decade. This study explores a particular TBL approach used in a mechanical engineering module for second-year undergraduates in Taiwan. The results of a survey on these students' learner autonomy (LA), perceptions of TBL, engagement with TBL, self-reported contributions and concerns about TBL activities were analyzed along with their academic performance. The results suggested that LA played a crucial role in TBL, especially contribution to group work, and that classroom implementations should therefore make it a priority to boost LA. In addition, positive reciprocity was found to be operating during group work. Group differences were found in issues the students expressed concern about. Students who cared about fairness had higher LA and were more likely to contribute to team tasks whilst some students could have been less engaged in group activities due to poor organizational structure. Several challenges were also observed in this study. They included passive learners, classroom-management problems, free-riding, and limited resources. Based on our findings, we recommend that engineering instructors encourage student-teacher communication by using bonus-point incentives, student experts, peer evaluation and group competitions.

Keywords : Learner autonomy, Team-based learning, mechanical engineering education, Taiwan.

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1. Introduction

Traditional teacher-centered learning is efficient, insofar as it enables the simultaneous presentation of large amounts of information to large numbers of students. However, it also implies that students work alone, meaning that they do not learn to collaborate with their peers; and when lectures are boring, efficiency gains may be partially or wholly reversed through students' inattention. The student-centered learning approach has been shown to be more effective than its teacher-centered counterpart, especially for acquiring 21st century skills in engineering (Radzali et al., 2018). When a class is student-centered, students and instructors share the focus and interact as equals, enabling students to develop problem-solving, collaboration and communication skills, and thus enhance their employability.

A large body of literature has developed the concept of student- centered learning both theoretically and practically. Recently, the most-used student-centered learning approaches in engineering education have included problem-based/project-based learning (Mitchell & Rogers, 2020; Wu & Wu, 2020), inquiry-based learning (Aurachman, 2020; Mitchell & Rogers, 2020), team-based learning (TBL) (Beneroso & Erans, 2020; Lino-Neto et al., 2021) and flipped classrooms (Bhat et al., 2020; Gren, 2020). Though originally developed as a teaching method for business schools, TBL has gained prominence in engineering education over the past decade as a practical and effective means of developing collaboration and communication skills, and the number of publications on this approach doubled each year between 2011 and 2015 (Najdanovic-Visak, 2017).

TBL is an innovative student-centered method that aims to inspire students, in part by transforming the instructor's role into that of an autonomy supporter. In it, students can learn via observation, communication, self-reflection, and peer evaluation. However, TBL has been demonstrated to enhance not only learner autonomy (LA), but also teamwork skills (Hass et al., 2021). In addition, studies have suggested that TBL can improve students' academic performance (Carrasco et al., 2021; Koles et al., 2010). There is no prescriptive formula for TBL, other than there must be a task for teams to complete, or some other objective for them to attain. It is in part due to this flexibility that TBL has become so popular, both in experimental-lecture and workshop formats.

LA is defined as students taking control of and responsibility for their own learning (Dam, 1990). Self-reliant learners can learn efficiently by setting learning directions for themselves and developing an independent, proactive approach. LA could play a critical role in the planning of teaching activities. Duarte et al. (2016) has suggested that students with higher LA could be less dependent on the teacher in the completion of classroom tasks. Littlewood (1996) made the important observation that autonomy can be subdivided into two key components: learners' ability, and their willingness. This study therefore categorizes LA into the same two dimensions, as shown in Figure 1. The former indicates learners' interest in learning, and the latter, their self-assessed capacity. Learners in the first quadrant had high LA, and those in the third quadrant, low LA. Those in the second and fourth quadrants, meanwhile, lacked either willingness or ability to learn.

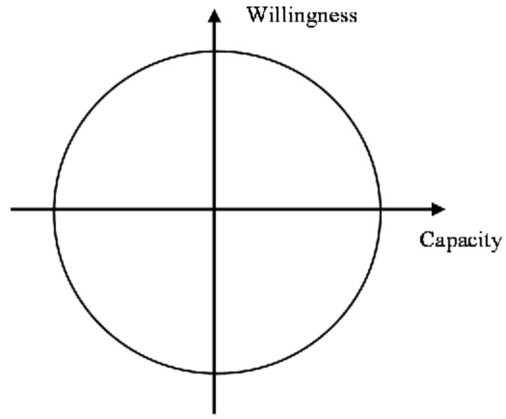

Fig.1: Learner autonomy (Source: this study)

Despite TBL having been used all over the world for many years, investigations of its connections to individual learning have remained rare (Salimath et al., 2018). Studies of its implementation in higher education in Taiwan have also been limited, in that they have focused on the fields of health and medical care (Tsai et al., 2020; Wang & Hsieh, 2010; Wu & Chiu, 2021). The present study therefore aims to address these knowledge gaps by examining a case of TBL in engineering education in Taiwan. Specifically, it evaluates students' learning-autonomy attitudes, perceptions of TBL, teamworking performance, and learning satisfaction, as well as the relationships among those factors, students' self-reported TBL contributions, and their academic performance as measured by test scores. The remainder of this study is structured as follows. Section 2 introduces the TBL approach used in mechanical engineering education in Taiwan. Section 3 describes our student survey data and data-analysis approaches and outcomes. Lastly, section 4 discusses the advantages and disadvantages of implementing TBL in a Taiwanese engineering-education context.

2. Team-based Learning In Mechanical Engineering Education

This study investigates a mandatory module in static mechanics as taught from September 2020 to January 2021 at a university of science and technology in southern Taiwan. This theoretical course consisted of two hours of lectures and one hour of MATLab coding exercises per week for 16 weeks. In light of prior TBL research contexts mentioned above, it is important to note that this module was not classified as an experimental-lecture course by the university or by its instructor (who was also the present paper's second author) . One textbook was assigned, but the instructor added a wider reading list and created lecture slides featuring his own illustrations. All course materials were made available on the university's digital-communication system, Flipclass, in line with scholars' recommendations that e-learning ecosystems should seamlessly integrate support for all phases of the TBL process (Littlewood, 1996).

The lectures provided an overview of the principles of applied mechanical engineering and analysis of the relevant calculations. Their specific content included mass points, rigid bodies, force and force systems, analysis and calculation of moments, free-body diagramming, calculations of the center of gravity and other positions, friction, moment of inertia, and solving balance equations.

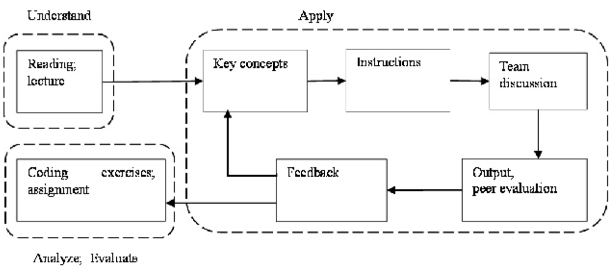

Fig. 2: Team-based learning procedure (Source: this study)

The sequence of course activities as actually implemented is shown in Figure 2. Before any TBL activity, to familiarize them with a "big picture" of its topic, students were given pre-class readings and in-class lectures, in keeping with the understand level of Bloom's taxonomy (Bloom, 1956). The sizes of each student team ranged from four to six members, roughly in line with the optimal team size of five to seven, which according to prior research [9] facilitates a good flow of intra-team communication while avoiding "free-riding", i.e., nominal participation by students who contribute little or nothing to the team effort yet receive the same grade as the other members.

The TBL approach used in this course consisted of key concepts, instruction, discussion and output. This stage corresponds to the apply level of Bloom's taxonomy. The key concepts were selected from the textbook. Hard copies of the task instructions, illustrated by the instructor, were handed out in class, as part of a broader effort to keep the students fully informed about their tasks as well as about the relevant learning content. To maintain good classroom management, the lecturer developed classroom rules and announced them in the first class. To ensure that teamworking was of a high quality, tasks were structured following the '4S' strategy proposed by Michaelsen and Sweet (2008) that the problem must be significant; that all groups work on the same problem at any given time; that choice in the problem is specific; and that all teams' reports are handed in simultaneously.

After a key concept and its associated 5~10 tasks were introduced, each team worked together to complete selected textbook exercises. The instructor supported the self-managed teams by offering real-time feedback that included clarifications of concepts and examples related to the tasks. Each task was discussed in a fixed timeframe that varied according to its presumed difficulty. After the allotted time had elapsed, all teams simultaneously wrote/drew their task output on their respective small whiteboards, and nominated one representative each to present the whiteboard content to the rest of the class. To motivate the students via a spirit of healthy competition, each team was asked to evaluate other teams' work. The instructor then revealed the optimal task outcomes and corrected common misperceptions that had been voiced during the real-time feedback. The same procedure was repeated across all tasks.

At the final stage, corresponding to the analyze and evaluate levels of Bloom's Taxonomy, students applied their knowledge in their individual MATLab coding exercises and assignment. The assignments were assessed on a five-point scale. This TBL learning process was repeated five times in the semester. Although TBL has previously been demonstrated to foster inclusion (Huitt et al., 2015), it remains unclear whether and how LA influences students' perceptions of TBL. To explore these dynamics, we examined 1) the relationship between LA and TBL experiences, and 2) the impact of LA and TBL on students' academic performance.

3. Student Feedback

A. Participants

The focal course was divided into two classes, one containing 52 sophomores, and the other, 57 sophomores from the department of mechanical engineering at a university of science and technology in southern Taiwan. The participants, all of whom had already developed a basic knowledge of engineering, consisted of 40 students from the smaller class and 35 from the larger one. To facilitate our analysis of the relationship between their perception of the instructor's chosen TBL approach and their academic performance across the course's five assignments, mid-term, and final exam, our four-part survey covered learner autonomy, TBL perceptions, engagement in team works, and one open-ended reflection prompt. To encourage detailed reflection on what had been learnt in the course and what could be done to improve it, the five best reflections from each class were selected by an external reviewer based on two criteria – specificity, and the feasibility of recommended course changes – and their writers awarded between NT$100 and NT$300 (about US$3-US$9) in gift certificates. To avoid bias, students' identities were not revealed to the reviewer.

Following Littlewood (1996), this study considers five components of LA: learning goals, learning style, learning strategy, learning motivation and interest in reference readings. Table 1 reports the students' LA. Setting learning goals, though fundamental to this construct, was a practice reported by fewer than a quarter of the sampled students. Some tasks – notably, finding and reading relevant prior literature (hereafter, "reference reading") – were easier for unambitious learners: with 40% of the participants noting that they would engage in reference reading only if they found the topic interesting. Among those with low LA, more than half reported being interested in learning but had low capacity for it. In terms of capability, reference reading was the only item that more than half the students reported themselves to be capable of doing. From the perspective of motivation, almost 15% of the participants claimed that they could have found reference-reading material, but chose not to do so.

Table 1 : Learner-autonomy Item Responses

Item	I can do it and I did it	I don't know how to do it but want to learn	I can do it, but I did not	
Q1. I can set my learning goals	17 (22.7%)	49 (65.3%)	8 (10.7 %)	1 (1.3%)
Q2. I know my learning style	26 (34.7%)	44 (58.7%)	5 (6.7%)	0 (0%)
Q3. I have my own learning strategy	30 (40%)	41 (54.7%)	4 (5.3%)	0 (0%)
Q4. I have clear learning motivation	26 (34.7%)	40 (53.3%)	8 (10.7%)	1 (1.3%)
Q5. If a topic is interesting, I will engage in reference reading	32 (42.7%)	31 (41.3%)	11 (14.7%)	1 (1.3%)

(Source: this study)

Table 2 presents the subjects' perceptions of TBL. They were asked to respond on a five-point Likert scale ranging from 1 = strongly agree to 5 = strongly disagree. The mean score for clear learning goals was the highest for any item in this section, indicating that many students did not fully grasp the learning goals. That being said, however, many students rated the problem sets they were provided with as clear, and student interaction as having been efficiently encouraged. This implies that many students were more aware of the course's explicit tasks rather than the implicit meanings behind those tasks.

A Pearson's product-moment correlation was run to assess the relationships among the items designed to capture LA. We found strong positive correlations between Q6 and Q7 ($r(73)=0.774$, $p<0.0005$) and between Q7 and Q10 ($r(73)=0.782$, $p<0.0005$). These findings imply that providing sufficient information and fair, systematic assessment could help students tobetter understand learning goals.

Table 3 presents our data on engagement in team activities, about which the students were asked to respond on the same five-point Likert scale mentioned above. In general, the participants were satisfied with the teamworking they had engaged in, with most agreeing that they had experienced good communication and helped their teammates.

Table 2 : Descriptive Statistics, Team-based Learning Perception

Item	Mean (Standard Deviation)
Q6. Sufficient information was provided before team-based learning (TBL) activities	1.88 (0.96)
Q7. Clear learning goals were provided in TBL	1.91 (1.04)
Q8. Clear problem sets were provided in TBL	1.61 (0.82)
Q9. Reference reading was provided for those learners who took an interest in a topic in TBL	1.79 (0.84)
Q10. A fair and systematic assessment of students' individual and teamwork abilities was used in TBL	1.87 (0.96)
Q11. Students' interaction was encouraged efficiently in TBL	1.63 (0.82)

(Source: this study)

Regarding reciprocity, more students reported offering help to others than receiving it. That being said, the strong association between Q13 and Q14 (r(73)=0.757, p<0.0005) implies that students who felt communication with their teammates was good were more likely than others to claim that they had received help from peers. From the strongly positive association between Q14 and Q16 (r(73)=0.768, p<0.0005), it can be assumed that students who experienced good communication would have also found a deeper and wider scope of learning through TBL than when working on their own.

Table 3 : Descriptive Statistics, Engagement in Team Activities

Item	Mean (Standard Deviation)
Q12. When my teammates were struggling in learning, I offered help	1.6 (0.77)
Q13. I achieved better outcomes with my teammates' help	1.83 (0.99)
Q14. We had a good communication in our team discussions	1.6 (0.79)
Q15. The answers on the whiteboard were consented to by all team members	1.75 (0.97)
Q16. The learning outcomes of team-based learning were deeper and wider in scope than those of individual work	1.8 (0.87)

(Source: this study)

In their open-ended comments on the focal course, most students noted that TBL had helped their learning. The remarks reproduced below are a representative selection.

'Through TBL, I have not only learnt how to solve problems but also improved my communication through the process of teaching one another. But some free-riders on my team only wanted to pass without making any effort. On the other hand, those who would like to learn could benefit from TBL. I would suggest assessing students' individual understanding after TBL. I think those free-riders would be forced to learn due to their fear of presentations.' (student A)

'In TBL, my teammates helped to check my analysis and calculations for any mistakes. Sometimes I'd make a mistake when I was alone. If TBL will be used in future courses, I would suggest running team competitions. For example, randomly appointed team representatives could present solutions to the task with suggestions from teammates. The team that first gets the correct answer wins and gets bonus points.' (student B)

'It's my first time taking a TBL class. I think the main problem in TBL is that sometimes only a few team members are engaged and do the work while others do nothing. This could be addressed by [the instructor] randomly assigning team representatives to present their teams' work. Because everyone has an equal chance of being called, […] all students would be pushed to learn […]' (student C)

'I think TBL is good, but only a few students engaged actively. In open discussion time, a lot of small talk tool place, and the people who really did the teamworking were almost always the same from one task to the next. I suggest that bonus points be offered to those teams who arrive at their answers first and show that they understand the process. Also, team formation can be shuffled to achieve the goal of learning together.' (student D)

'In TBL, I learned how to coordinate with classmates. In the discussions, I was given opportunities to interact with people I hadn't talked to before. We could understand each other's ideas and ways of solving problems. The discussions were very fun, because our ideas were diverse, and our ways of solving problems were diverse too. And through them, we found the best solution by gathering more ideas. I hope we can have more TBL activities, and it could be even better to use it in evaluation. It helps low-level students to improve by learning with high-level ones.' (student E)

'I think students will be motivated only if the high quality of the course and the future benefits of taking it are clearly articulated. If students aren't motivated, running TBL is useless because there will be no meaningful discussion within teams. Students who wanted to learn were disappointed because the class was full of small talk.' (student F)

Table 4 : Descriptive Statistics, Academic Performance

Item	Mean Score (Standard Deviation)
Mid-term exam	51.9% (18.5)
Final exam	35.2% (23.9)
Assignment 1	3.35/5 (1.26)
Assignment 2	2.92/5 (1.48)
Assignment 3	3.34/5 (1.56)
Assignment 4	3.45/5 (0.94)
Assignment 5	3.19/5 (1.54)

(Source: this study)

In the open-ended data taken as a whole, based on keywords, we identified five common issues: communication (29 students), organization (24), teamwork (17), free-riding (11), and whiteboard usage (5). The keyword free-riding usually appeared in negative comments (such as those by students A and C quoted above), whereas whiteboard usage and teamwork usually appeared in positive ones (such as that from student D). The valences of two other keywords, communication and organization, were mixed. For example, some students thought their teams were poorly formed and full of small talk (student F) while others thought the class was organized well and featured good communication (students B and E). Several suggestions for improving team formation were also provided, and included individual assessment (student A) and team competitions (student B).

Students' academic performance on the exams and assignments is reported in Table 4. While the mid-term and final exams covered multiple topics, assignments covered specific topics only. As compared to their performance on the exams, the participants' performance on assignments was relatively inconsistent, probably due to variation in their personal learning interests.

B. Data Analysis

For purposes of data analysis, we created four variables. The first, LA, is the average of the five items in Table 1, which were assigned two points if the student reported both capacity and interest, one point if s/he only reported one or the other, and no points if s/he reported neither. PU and GW, the averages of the items in Tables 2 and 3, are respectively indicators of TBL perceptions and engagement in team activities. Both are inverse indicators: i.e., a lower score means more positive perception or engagement. SE is an indicator of self-evaluation in teamworking, computed as self-reported contributions to group work minus the fair contribution, i.e., 100 divided by the number of group members. In other words, positive SE equates to a claim by the respondent that his/her contribution was greater than what was fair. Average SE was 35.3, with a minimum of -15.7 and a maximum of 83.3, meaning that most of the students thought their own quantity of contributions was disproportionately high. A strong and positive correlation was found between GW and PU ($r(75)=0.836, p<0.0000$), implying that students who had more positive perceptions of TBL were more likely than others to be engaged in team activities. In addition, the correlation between LA and SE ($r(73)=0.268, p<0.022$) suggested that LA level was positively, albeit weakly, associated with students' contributions to teamwork.

C. Group Differences

Significant analysis of variance (ANOVA) results are presented in Tables 5 and 6. Table 5, which reports the group differences in LA, indicates that those participants who were able to set clear learning goals and adopt learning strategies, but who were not willing to do so, contributed significantly less to their teams' work than those who actually used such goals and strategies. This finding suggests that willingness to learn is an important factor in TBL. Students' capacity to learn, however, had a non-significant relationship to their self-reported TBL contributions.

Regarding the participants' academic performance across five assignments, the mid-term and the final exam, those who claimed to be willing to but unable to set learning goals, and those who claimed they were able but not willing, earned significantly higher scores on assignment 2. Those who had higher LA as evidenced by their adoption of learning strategies performed better than the group with no willingness on assignment 2, and better than the group with no capacity on the mid-term.

Table 5 : Significant Inter-group Differences In Learner Autonomy

Factor	Cate.	Subg.	Freq.	Mean	s.d.	Prob.
SE	Q1	1	16	48.8	21.5	3 vs. 1 (-32.5, $p = 0.019$)
		2	48	33.5	25.7	
		3	8	16.4	26.9	
		4	1	57.5	0	
	Q3	1	29	41.1	26.2	3 vs. 1 (-38.3, $p = 0.040$)
		2	41	33.6	25.4	
		3	3	2.78	6.94	
		4	0	0	0	
A2	Q1	1	17	3.41	1.23	3 vs. 2 (1.55, $p = 0.024$)
		2	49	2.57	1.51	
		3	8	4.13	0.83	
		4	1	2	0	
	Q3	1	30	3.40	1.16	3 vs. 1 (-1.9, $p = 0.037$)
		2	41	2.71	1.54	
		3	4	1.5	1.91	
		4	0	NA	NA	
Mid-term	Q3	1	30	58.4	17.3	2 vs. 1 (-11.6, $p = 0.022$)
		2	41	46.7	18.3	
		3	4	56.8	15.0	
		4	0	NA	NA	

Note. A2= Assignment 2; Cate. = category; Subg.= subgroup; Freq. = frequency; s.d. = standard deviation; Prob. = probability; SE = indicator of self-evaluation; NA = not applicable. (Source: this study)

Table 6 : Significant Inter-group Differences In Feedback Keyword Usage

Factor	Cate.	Item	Freq	Mean	s.d.	Prob.
AL	FR	0	64	1.30	0.30	1 vs. 0 (0.303,
		1	11	1.60	0.30	p = 0.003)
SE	FR	0	62	31.9	25.4	1 vs. 0 (22.58,
		1	11	54.5	23.1	p = 0.008)
PU	TW	0	58	1.88	0.77	1 vs. 0 (-0.43,
		1	17	1.45	0.51	p = 0.035)
	COM	0	46	1.96	0.76	1 vs. 0 (-0.46,
		1	29	1.5	0.61	p = 0.008)
GW	TW	0	58	1.81	0.73	1 vs. 0 (-0.42,
		1	17	1.39	0.50	p = 0.028)
	COM	0	46	1.89	0.75	1 vs. 0 (-0.45,
		1	29	1.44	0.53	p = 0.007)
	ORG	0	51	1.60	0.61	1 vs. 0 (0.35,
		1	24	1.95	0.84	p = 0.046)
Mid-term	TW	0	58	49.5	18.8	1vs0 (10.52,
		1	17	60.1	15.0	p=0.038)
	COM	0	46	48.24	19.5	1vs0 (9.52,
		1	29	57.8	15.2	p=0.029)
	ORG	0	51	55.2	17.0	1vs0 (-10.36,
		1	24	44.9	19.8	p=0.022)
A1	ORG	0	51	3.14	1.39	1vs0 (.639,
		1	24	3.78	.77	p=0.039)
A4	COM	0	46	3.27	1.10	1vs0 (.452,
		1	29	3.72	0.49	p=0.041)
A5	ORG	0	51	2.91	1.55	1vs0 (.859,
		1	24	3.77	1.37	p=0.023)

Note. FR = Free-riding; TW = Teamwork; COM = Communication; ORG = Organization; A1= Assignment 1; A4= Assignment 4; A5= Assignment 5; Cate. = category; Freq. = frequency; s.d. = standard deviation; Prob. = probability; AL = indicator of learner-autonomy; SE = indicator of self-evaluation; PU = indicator of TBL perceptions; GW = indicator of engagement in team activities; NA = not applicable

Table 6 reports group differences in issues the students expressed concern about. AL and SE were significantly higher in those who mentioned the free-riding issue in their open-ended reflections, implying that students who cared about fairness had higher LA and were more likely to contribute to team tasks.

Those who mentioned "teamwork" and "communication", meanwhile, showed more positive perceptions of and higher engagement in TBL activities. Interestingly, those who mentioned "organization" had higher GW scores. This suggests that some students could have been less engaged in group activities due to poor organizational structure. In terms of their academic performance, students who mentioned either "teamwork" or "communication" earned more mid-term scores than those who did not mention. Those who mentioned "communication" also earned higher scores on assignment 4 than those who did not. Students who mentioned "organization" did not exhibit any consistent academic-performance pattern: earning higher scores on assignments 1 and 5, but lower scores on the mid-term than those who did not mention.

D. Classroom Implications

The above results suggest that higher leaner-autonomy could not only enhance students' contributions to teamwork, but also their academic performance. In particular, as compared to those who were capable of being autonomous but unwilling, those who were both capable and willing were more engaged in TBL and earned higher grades. Hence, instructors are advised to pay extra attention to motivating students and developing their learning autonomy while conducting TBL.

As noted above, the sampled students whose open-ended feedback indicated they were concerned about free-riding had higher leaner-autonomy and contributed more to TBL activities. However, the association between the open-ended feedback was insignificant in their TBL perceptions, engagement in team activities, and academic performance. On the other hand, those who mentioned teamwork and communication felt more positive perceptions of TBL and higher engagement in team activities. In addition, students' low engagement could have been due to a sense that the course's organizational structure was poor, for two main reasons: excessive small talk and poorly formed teams. Instructors are therefore advised to build efficient team-discussion platforms by introducing individual assignments, team leaders and inter-team competitions. It is worth mentioned that the low performance of those who mentioned organization on the mid-term and the same students' high scores on assignments 1 and 5 might have been due to topic coverage: i.e., all assignments were on specific topics, whereas both exams covered multiple topics.

4. Discussion And Conclusion

Among various teaching approaches, TBL has been found to be an effective method of motivating students and developing crucial skills. For instructors, it can help transform lecture-oriented classes into student-oriented ones. TBL can also be used in conjunction with other teaching approaches, such as flipped classrooms and project-based learning. Moreover, teamworking ability is an essential prerequisite for employability.

This study has presented a TBL approach used in mechanical engineering education. Its data highlight the strengths of TBL, include peer learning, the coordination of skills enhancement, and LA improvement. Its three key findings are as follows. First, LA was closely associated both with students' contributions to their teams' projects and with their academic performance. Motivating students and developing their LA would therefore be a good foundation for TBL implementation. Second, each team member benefited from teamwork: slow learners were assisted by and learned from their peers, while fast learners developed higher-level thinking through teaching others. Lastly, many students reported that TBL encouraged their interactions, led to good communication during team discussions, and motivated them to achieve higher levels of LA.

That being said, however, several challenges were also observed in this TBL case study. They included passive learners, classroom-management problems, free-riding, and limited resources. Our recommendations for TBL instructors are provided below in light of these challenges.

First, though active engagement and accountability are required in TBL, instructors should expect resistance from passive students. TBL is not easy to start when students do not obey the rules or participate in discussions. Sometimes, our sampled students struggled with what to do or how to do it, and even establishing simple within-team communication was not easy for them. As suggested in some prior studies (Gullo et al., 2015; Rajalingam et al., 2018), this issue might be resolved by identifying "student experts" within the class and turning them into content experts who can assist others. Similarly, it has been suggested that the appointment of student representatives in each TBL classroom could help students and instructors alike by facilitating discussion (Whitley et al., 2015).

Second, classroom-management issues were observed by the instructor, including mobile-phone use and extensive small talk. As mentioned earlier, many students also reported problems with team organization, echoing prior findings (Kibble et al., 2016). In practice, TBL can support and improve self-regulated learning if classroom management and team formation are effective (Restall & Clark, 2021).

Third, free-riding emerged from our data as a major issue, in part because most teams were coordinated by all their members, and only a minority of teams appointed formal leaders. To eliminate the problem of free-riding, Seidel and Godfrey (2005) recommended using a range of tools including confidential peer assessment, oral interviews and specific work and submission instructions for some projects. Among these, peer evaluation has also been highly recommended by other scholars (Cestone et al., 2008).

Finally, even if TBL course designers follow recommendations to use a "backwards design" process to identify what resources by considering activities that will occur before, during, and after class (Whitley et al., 2015), limited campus resources could lead to low attendance rates. This prompted the suggestion that e-learning ecosystems, seamlessly integrated to support all phases of the TBL process, be created (Rajalingam et al., 2018). Students in the present study also reported benefits of using materials provided on their university's cyber system, Flipclass. In addition, as noted above, the TBL approach can usefully be mixed with other learning approaches. For example, to motivate passive learners in mechanical engineering education, the application of new technology such as augmented reality has been found to help recent TBL implementations (Kumar et al., 2021; Monroy Reyes et al., 2016; Opriş et al., 2018; Selek & Kıymaz, 2020; Wang et al., 2018) and such combinations of teaching approaches are fruitful avenues for future research.

Another challenge identified in this study is the transformation of the wider learning environment. The pandemic in 2020 involved a dramatic shift in the norms of lecture delivery from offline to online. Several recent studies have claimed that online or blended TBL sessions could enhance learning performance in medical and computer-science education (Al-Neklawy & Ismail, 2022; Anas et al., 2022; Patil et al., 2022). The present study was conducted while Taiwan's authorities had relaxed social-distancing measures, aside from mask-wearing. Further investigation of the influence of online TBL sessions on LA in engineering education would therefore also be useful.

To conclude, this study has demonstrated that a TBL approach used in mechanical engineering education in Taiwan could be implemented in both practical and theoretical courses, and that LA plays a crucial role in TBL. We recommend that instructors who would like to adopt TBL should focus on boosting LA due to its significant association with students' contributions to group work. In addition, positive reciprocity was found in such work. Instructors could usefully encourage within-team communication by using bonus-point incentives, student experts, and inter-team competitions.

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