Inventive Problem-Solving Skills Effectiveness in RBT Project-Based Learning (PBL)

Tee Tze Kiong[1,*], Noor Syuhaili Mohd. Rusly[1], Nurulwahida Azid[2], Charanjit Kaur Swaran Singh[3], Rahmat Azis Nabawi[4], Muhammad Aris Ichwanto[5] & Andika Bagus Nur Rahma Putra[6]

[1]Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Johor 86400, Malaysia

[2]School of Education, Universiti Utara Malaysia, Sintok 06100, Malaysia

[3]Faculty of Languages and Communication, Universiti Pendidikan Sultan Idris, Perak 35900, Malaysia

[4]Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, Indonesia

[5]Department of Civil Engineering and Planning, Universitas Negeri Malang, Malang 65145, Indonesia

[6]Faculty of Engineering, Universitas Negeri Malang, Malang, Indonesia

*Correspondence: Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Johor, 86400, Malaysia. Tel: 60-196-623-328. E-mail: tktee@uthm.edu.my

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Abstract

Examining how well a TRIZ-based Project-Based Learning (PBL) module fosters creative problem-solving abilities in secondary school students enrolled in Design and Technology (RBT) courses is the goal of this study. The combination of PBL with structured creative problem-solving techniques like TRIZ, particularly in the context of RBT topics, is still largely unexplored, even though PBL has been widely used in Malaysian education. In this quasi-experimental study, 118 Form 2 students were split into two groups: a control group (n = 58) that received traditional instruction and a treatment group (n = 60) that received the PBL intervention. The 12-week TRIZ methodology-based module was presented to the treatment group. The treatment group's mean scores increased by 34% (from 50.72% to 67.93%) compared to the control group's 16% improvement, according to pre- and post-test data. Significantly, the treatment group showed a stronger change in mastery levels and high order thinking abilities in every aspect of problem-solving. The results imply that the TRIZ-based PBL module fosters structured and innovative problem-solving skills more successfully than conventional methods. By giving a scalable methodology for developing 21st-century skills, the study offers new insights by presenting a verified pedagogical framework that incorporates TRIZ into project-based learning for secondary education.

Keywords: Project-Based Learning (PBL), Design and Technology (RBT), Inventive Problem Solving (TRIZ)

1. Introduction

An essential component of education is problem-solving techniques, which guarantee that students are equipped to handle obstacles in the actual world. This method is emphasised in Malaysia's Standard Secondary School Curriculum (KSSM) through Project-Based Learning (PBL) in Design and Technology (RBT) courses (MOE, 2016). The goal of this method is to help students become more capable of critical thinking, problem-solving, and decision-making in both the workplace and everyday life (Ismail et al., 2020).

However, research indicates that many graduates struggle to solve problems in the job since they did not fully grasp these abilities in school (Zakaria et al., 2020). According to Murugan, Azmi, and Noordin (2019), graduates who lack these abilities struggle to adjust to the ever-increasing demands of the workforce, particularly in technology-based businesses that call for sophisticated problem-solving. Thus, mastering problem-solving techniques from an early age has emerged as a key prerequisite in the contemporary educational system (Ribtsun et al., 2023). Though PBL has been incorporated into RBT courses, there is still a big lack of exposure to formal problem-solving techniques, especially when it comes to creative approaches like TRIZ. The effects of TRIZ-based PBL interventions on secondary students' capacity to use creative problem-solving techniques in authentic project settings have not been

specifically assessed in previous research. This study fills that knowledge gap by creating and implementing a particular PBP module that uses TRIZ to evaluate how it affects students' creative problem-solving abilities.

Inadequate teaching tools and a lack of teacher support also frequently cause students to struggle with project assignments (Hanif et al., 2019). Research indicates that, although teachers are crucial in helping pupils grasp systematic approaches to problem-solving, their efficacy is hampered by a lack of professional development opportunities and reference materials (Che Wan Razak, Yee & Kok, 2020). According to Abidin and Hariyono (2020), students who are not sufficiently exposed to problem-solving techniques would also have trouble organising and carrying out projects effectively.

Additionally, the traditional teaching model that is still used in some schools does not emphasise the whole project-based learning aspect (Retno, Sunarno & Marzuki, 2019). Students are less competitive in solving complex problems and are more likely to rely on teachers when they are not given enough opportunities to explore and solve problems practically, so it is crucial to use approaches like TRIZ in RBT to help students identify and solve problems in a methodical and creative way (Gong et al., 2020).

Therefore, by offering more organised modules and teacher training, the education system must increase the application of PBL to guarantee that students can acquire problem-solving abilities more successfully. Numerous studies have demonstrated that students participating in project-based learning have improved their problem-solving abilities, demonstrating the efficacy of this technique (Purwaningsih et al., 2020). Through methodical application, PBP not only helps students become proficient in problem-solving techniques but also cultivates more creative people who are equipped to take on new problems.

Thus, the purpose of this study is to find out how well a TRIZ-integrated Project-Based Learning (PBL) module may help Form 2 students in RBT develop their creative problem-solving abilities. The study's specific goals are to: (1) compare the post-test problem-solving ability of students who received traditional teaching to those who used PBL, and (2) assess how much each group's problem-solving abilities have improved. It is anticipated that students who are exposed to the PBL module will show noticeably more progress. This research is innovative since it incorporates the TRIZ technique into PBL modules in secondary RBT instruction, a combination that hasn't been thoroughly examined in previous studies. This methodical framework bridges the gap between theoretical knowledge and real-world application by giving students formal approaches to creative problem-solving.

2. Literature Review

An approach known as project-based learning (PBL) gives students the chance to investigate, work through issues, and produce work based on challenging assignments (Hanif et al., 2019). This is because students must methodically plan, test, and evaluate their work, PBL has been shown to enhance their critical thinking and creativity (Abidin & Hariyono, 2020). Further supporting this learning is the constructivist theory of John Dewey and Lev Vygotsky, which holds that knowledge is acquired by students via experience and interaction with their surroundings (Grant, 2014).

The application of Inventive Problem-Solving Theory (TRIZ) is used to assist students in determining the underlying cause of the problem, modelling the solution, and assessing the efficacy of their ideas (Rahim et. al, 2020; Tee et al., 2018). Research indicates that TRIZ is not only useful in the field of education but is also utilised in industry to solve complex problems (Lee & Ren, 2024; Gong et al., 2020). PBL is essential in the context of RBT in order to develop inventive problem-solving skills. According to Erdogan and Bozeman (2015), PBL also uses a 21st-century learning paradigm that has four key components: initiation, management, deliverability, and assessment. This is also supported by Belu et. al (2021). In this method, teachers serve as facilitators, allowing students the latitude to experiment and come up with original ideas (Werder & Otis, 2023). Research has indicated that the application of PBP can boost students' enthusiasm and problem-solving abilities (Rohmah et al., 2020).

Research on PBL's ability to enhance problem-solving abilities has also been conducted in several domains, such as technical and vocational education (AlAli, 2024). Research indicates that this method enables students to relate abstract ideas to real-world situations, enhancing their comprehension and problem-solving skills (Wan, So & Zhan, 2020). Furthermore, research indicates that students who participate in project-based learning are more likely to be innovative and come up with original solutions for their assignments (Frizziero et al., 2019). Thus, PBL should be widely used in education to create students who are more creative, innovative, and prepared to face real-world challenges. Overall, literature reviews support the effectiveness of PBL in enhancing students' critical thinking and inventive problem-solving skills (Nuraini & Muliawan, 2020).

While prior research supports the beneficial effects of PBL on students' creativity and problem-solving skills, there is less agreement on how these benefits translate, in structured creative situations such as TRIZ. For instance, whilst Hanif et al. (2019) stress STEM project participation but do not discuss structured methodologies, Frizziero et al. (2019) state that PBL has enhanced innovation in engineering education. Furthermore, contradictory research on the depth of knowledge that students acquire through PBL (e.g., Belu et al., 2021 vs. Erdogan & Bozeman, 2015) points to the necessity for targeted modules that encourage methodical problem-solving. This establishes a gap in existing research and bolsters the case for TRIZ's incorporation into PBL frameworks.

3. Method

The usefulness of a TRIZ-integrated Project-Based Learning (PBL) module in fostering creative problem-solving abilities in approach and Technology (RBT) education was investigated in this study, utilising a quasi-experimental approach with a non-equivalent control group pre-test–post-test modelling. 118 Form 2 students from a Malaysian public secondary school took part in the event. Participants were split into two groups in an intact classroom: the PBL intervention was given to the treatment group (n = 60), and the control group (n = 58) received conventional RBT teaching (Purwaningsih et al., 2020). Using purposive sampling, the school and sample were chosen based on administrative consent, teacher preparedness, and the availability of RBT as a subject.

An organised exam of problem-solving that was based on the TRIZ theory and the Malaysian RBT curriculum made up the research tool. Identification of components, identification of the problem cause, inventive problem-solving approach, and impact assessment of solutions were the four main dimensions that were assessed. After being verified by three subject-matter specialists, the instrument's Cronbach's alpha of .86 indicated high reliability. Using the TRIZ principles, problem definition, root cause analysis, creative solution creation, and outcome evaluation, the 12-week PBL module showed students how to solve problems in structured phases (Abidin & Hariyono, 2020). The treatment group's students worked on group projects under the guidance of the teacher and using guided worksheets, whereas the control group received regular textbook-based instruction devoid of TRIZ or formal project frameworks.

To gauge the impact of the invention, both groups were given pre- and post-tests. IBM SPSS software was used to analyse the data. To determine normality, the Shapiro-Wilk test was employed, and descriptive statistics (means, standard deviations) were computed. Pre- and post-test scores were compared within each group using paired sample t-tests, while post-test scores between groups were compared using independent samples t-tests. The degree of improvement was assessed by calculating the intervention's effect size using Cohen's d. The significance threshold of .05 was used for all statistical tests.

4. Data Analysis

In all, 118 secondary school students in form 2 who were enrolled in design and technology courses participated in the study. The percentage and frequency of responses by group are displayed in Table 1. The treatment group had 60 respondents (50.8 %) and the control group included 58 respondents (49.2 %).

Table 1. Normality Test for the Mean Score of Pre and Post-TG and CG Exams

	Shapiro-Wilk		
	Statistic	**df**	**Sig.**
preTG	.971	60	.159
posTG	.973	60	.194
praCG	.983	58	.577
posCG	.981	58	.490

preTG: mean score of the pre-treatment group test
postTG: mean score of post-treatment group test
pre-CG: mean score of the control group pre-test
postCG: mean score of the post-control group test

Table 1 displays the results of the normality test for the mean scores of the pre-test and post-test for the two groups, TG and CG. The pre-test (0.159) and post-test (0.194) scores of TG are both above .05, or p>.05. This indicates that the score's normalcy is identical to the population's normalcy. The pre- and post-TG test scores so satisfy the normality standards. The pre-test (0.577) and post-test (0.490) results for the CG tests, on the other hand, also

displayed p-value readings above .05. As a result, both the pre- and post-CG exam scores are normal. Therefore, the pre- and post-CG exam scores are likewise typical. This demonstrated that there was no discernible change between the pre-test and post-test mean scores for either group, which were normally distributed.

4.1 Hypothesis 1

Did the treatment group's (TG) and the control group's (CG) mean scores on the post-test of creative problem-solving skills in RBT project-based learning differ significantly?

A descriptive analysis comparing the post-test results between the treatment group and the control group overall is presented in Table 2. At 68 against 58, the mean score of the post-TG exam was greater than that of CG. The results demonstrated that TG students' proficiency differed from CG students', with TG students' proficiency being higher.

Table 2. The Mean Score of the Post-test Between TG and CG as a Whole

Group	Mean	Std. Deviation	N
Treatment	67.93	11.303	60
Control	57.69	12.608	58

The percentage of achievement for TG (68) indicates that the post-TG exam achievement is at the "Honours" level, whereas CG (58) is at the "Good" level, which is one grade higher, according to the reference table of secondary school grades for lower secondary (Table 3). This indicates that TG students outperform CG students on the post-test in terms of their knowledge of creative problem-solving techniques in project-based learning.

Table 3. Secondary School Grades for Lower Secondary

Percent %	Grade	Grade Interpretation
82 – 100	A	Excellent
66 – 81	B	Honours
50 – 65	C	Good
35 – 49	D	Satisfying
20 – 34	E	Reach the minimum level
0 – 19	F	Not reaching the minimum level

The difference between the mean scores of the TG and CG post-tests for the four aspects evaluated is shown in Table 4, where the TG post-test mean score was higher than the CG post-test mean score for each of the four aspects: component identification (2.61), problem cause identification (3.52), inventive problem-solving strategy (5.65), and inventive problem-solving effect (1.81). This indicates that the CG aspect increases the post-test mean score more than the TG aspect does.

Table 4. The Mean Score of the Post-test Between TG and CG for Four Aspects

Aspects	Group	Mean	Standard deviation	N
minApos	Treatment	2.6133	.39465	60
	Control	2.2586	.59236	58
minBpos	Treatment	3.5167	.78139	60
	Control	3.1138	.90698	58
minCpos	Treatment	5.6500	1.38644	60
	Control	4.6241	1.36476	58
minDpos	Treatment	1.8067	.31020	60
	Control	1.5414	.35935	58

minApos: the mean score of the exam after the component identification aspect
minBpos: mean score of the post-test aspect of identifying the cause of the problem
minCpos: the mean score of the exam after the inventive problem-solving strategy aspect
minDpos: mean score of the post-inventive problem-solving impact of the test

The percentage of mean scores and pre- and post-test grades for each TG and CG component are displayed in Table 5. The pre-test mean scores for TG and CG were 50.72 and 49.76, respectively, indicating that both groups were in grade C overall. TG and CG pupils scored "Good" on the pre-test, indicating a high level of proficiency. From the pre-test to the post-test, both groups demonstrated an improvement of one grade in component identification, problem cause identification, and imaginative problem-solving effects. On the other hand, TG improved one grade from D (Satisfactory) to C (Good) in terms of creative problem-solving techniques, whereas CG did not. CG maintained a satisfactory degree of skill in the area of creative problem-solving techniques.

Table 5. Percentage of Mean Score and Pre-test and Post-test Grades for Each Aspect of CG and TG

Group	Percentage of mean test score									
	Component identification		Identifying the root cause of the problem		Inventive problem-solving strategies		Effects of inventive problem-solving		Overall	
	Pre (Grade)	Post (Grade)	Pre (Grade)	Post (Grade)	Pre (Grade)	Post (Grade)	Pre (Grade)	Post (Grade)	Pre (Grade)	Post (Grade)
TG	69.89 (B)	87.11 (A)	53.13 (C)	70.33 (B)	40.30 (D)	56.50 (C)	68.00 (B)	90.34 (A)	50.72 (C)	67.93 (B)
CG	63.56 (C)	75.29 (B)	49.03 (D)	62.28 (C)	43.24 (D)	46.24 (D)	63.45 (C)	77.07 (B)	49.76 (C)	57.69 (C)

4.2 Hypothesis 2

Did the treatment group's (TG) mean scores on the pre- and post-tests of creative problem-solving abilities in RBT project-based learning alter significantly?

Descriptive and inferential analysis were employed to test hypothesis 2. To ascertain whether there was a significant difference between the pre-test and post-TG test mean scores, the t-test was employed. The descriptive analysis of the pre-test and post-TG test is displayed in Table 6. The results demonstrated that TG's post-test score increased by 17 points from 51 (pre-test) to 68 (post-test) following therapy.

Table 6. Analysis of the Overall Pre-test and Post-TG Mean Scores

Group			Mean	N	Std. Deviation	Std. Error Mean
Treatment	Pair 1	minmarkahpra	50.72	60	11.601	1.498
		minmarkahpos	67.93	60	11.303	1.459

minmarkahpra: mean score of the pre-TG exam
minmarkahpos: mean score of the post-TG exam

Table 7. Comparative Analysis of the Mean Score of the Pre-test and the Post-TG Test

Aspects	Pre-TG exam mean score		The average score of the post-TG exam		Grade change	Improved scores	Changes in mastery levels
	%	Grade	%	Grade			
Component identification	69.89	B	87.11	A	B →A	17	Outstanding → Honors
Identifying the root cause of the problem	53.13	C	70.33	B	C →B	17	Good → Honors
Inventive problem-solving strategies	40.30	D	56.50	C	D →C	16	Satisfying → good
Effects of inventive problem-solving	68.00	B	90.34	A	B →A	23	Outstanding → Honors
Overall	50.72	C	67.93	B	C →B	17	Good → Honors

The percentage difference between the pre-test and post-TG test results for each component is analysed in Table 7. The findings demonstrated that TG had improved in every area between the pre-test and the post-treatment assessment. Students' proficiency in identifying components and solving problems was at the honours level for the

pre-TG test, and they demonstrated an improvement in both areas of the post-test. The students' pre-test level of mastery was good (grade C, mean 53.13), and they advanced to honours (grade B, mean 70.33) with a 17-point improvement in order to pinpoint the underlying cause of the issue. As the level went from satisfactory to good, the proportion of mean scores for creative problem-solving techniques increased from the pre-test (40.30) to the post-test (56.50). Thus, when the treatment was administered to the treatment group, all features demonstrated an overall improvement of one degree.

The t-test was used to ascertain whether there was a significant difference between the mean score of the TG pre-test and post-test. The t-test analysis findings for the pre-test and post-test TG mean scores are displayed in Table 8. The data shown indicates that the Sig. (2-tailed) value is.000 ($p<0.05$). This indicates that following treatment, TG's mean score on the pre-test and post-test differs significantly.

Table 8. Analysis of T-Test of the Difference in Mean Score of Pre-test and Post-TG Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Minmarkahpra – Minmarkahpos	-17.217	6.145	.793	-18.804	-15.629	-21.701	59	**.000**

minmarkahpra: mean score of the pre-TG exam
minmarkahpos: mean score of the post-TG exam

The significant difference between the pre-test and post-TG test mean scores for each of the four elements was then ascertained using a t-test. The analysis of the conducted t-tests is displayed in Table 9. All four features have a Sig. (2-tailed) value of $p<0.05$. This indicates that the mean scores for all components, problem causes, creative problem-solving techniques, and creative problem-solving effects were significantly different between the pre-test and post-test.

Table 9. Analysis of t-Test of the Difference in Mean Score of Pre-test and Post-TG Test by Aspect

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	minApra - minApos	-.51667	.49030	.06330	-.64332	-.39001	-8.162	59	**.000**
Pair 2	minBpra - minBpos	-.86000	.71810	.09271	-1.04550	-.67450	-9.277	59	**.000**
Pair 3	minCpra - minCpos	-1.62000	.85466	.11034	-1.84078	-1.39922	-14.682	59	**.000**
Pair 4	minDpra - minDpos	-.44667	.38509	.04971	-.54615	-.34719	-8.985	59	**.000**

minApra: mean score of the exam before the component identification aspect
minBpra: mean score of the pre-test for identifying the cause of the problem
minCpra: mean score of the pre-test aspects of inventive problem-solving strategies
minDpra: mean score of the pre-aspect test of the impact of inventive problem-solving
minApos: mean score of the exam after the component identification aspect
minBpos: mean score of the post-test aspect of identifying the cause of the problem
minCpos: mean score of the exam after the inventive problem-solving strategy aspect
minDpos: mean score of the post-inventive problem-solving impact of the test

4.3 Hypothesis 3

Did the control group's (CG) mean scores on the pre- and post-tests of creative problem-solving abilities in RBT project-based learning alter significantly?

Descriptive and inferential analysis are also used in the testing of hypothesis 3. A significant difference between the pre-test and post-CG test mean scores was assessed using the t-test. The descriptive analysis of the pre-test and

post-CG test is displayed in Table 10. The results demonstrated an overall increase of 8 points on the post-test from 50 (pre-test) to 58 (post-test) following the implementation of traditional learning.

Table 10. The Whole Analysis of the Mean Score of the Pre-test and Post-CG Test

Group			Mean	N	Std. Deviation	Std. Error Mean
Control	Pair 1	minmarkahpra	49.76	58	12.551	1.648
		minmarkahpos	57.69	58	12.608	1.655

minmarkahpra: mean score of pre-CG exam
minmarkahpos: mean score of post-CG exam

The analysis of the percentage difference between the pre-test and post-CG test scores for each component is displayed in Table 11. The findings demonstrated that three areas; component identification, problem cause identification, and imaginative problem-solving effects had improved from the pre-test to the post-test. Students' proficiency in identifying components and solving problems was strong in the pre-CG test, and they demonstrated an increase in honours in both areas of the post-test. The students' pre-test mastery level was satisfactory (grade D, mean 49.03) and improved by 13 points to an excellent level (grade C, mean 62.28) in terms of determining the root of the issue. The mean score for creative problem-solving techniques increased by three points, although grades and mastery levels remained same. Both the pre-test and post-test scores for creative problem-solving techniques stayed at grade D, or satisfactory level. Overall, this indicates that CG pupils' mastery has not improved and is still at a high level.

Table 11. Comparative Analysis of the Mean Score of the Pre-test and the Post-CG Test

Aspects	Minimum score of the pre-CG exam		The average score of the post-CG exam		Grade change	Improved scores	Changes in mastery levels
	%	Grade	%	Grade			
Component identification	63.56	C	75.29	B	C →B	12	Good → Honors
Identifying the root cause of the problem	49.03	D	62.28	C	D →C	13	Satisfying → good
Inventive problem-solving strategies	43.24	D	46.24	D	D →D	3	Satisfying → satisfying
Effects of inventive problem-solving	63.45	C	77.07	B	C →B	14	Good → Honors
Overall	49.76	C	57.69	C	C →C	8	Good → good

An analysis of the t-test for the mean score of the pre-test and the post-CG test is presented in Table 12, which indicates that there is a significant difference between the mean score of the pre-test and the post-test for CG after conventional learning is given to CG. The t-test was used to determine whether the difference in the mean score of the pre-test and the CG post-test was significant.

Table 12. Analysis of T-test of the Difference in Mean Score of Pre-test and Post-CG Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Minmarkahpra - Minmarkahpos	-7.931	5.464	.717	-9.368	-6.494	-11.054	57	**.000**

minmarkahpra: mean score of pre-CG exam
minmarkahpos: mean score of post-CG exam

The t-test was then used to ascertain whether there was a significant difference between the mean scores of the pre-test and the post-CG test for each of the four factors. The analysis of the t-tests that were performed is displayed in Table 13. The mean score of the pre-test and post-CG test differed significantly for all four aspects (component identification, problem cause identification, inventive problem-solving strategies, and inventive problem-solving effects), as indicated by the value of Sig. (2-tailed) for all four aspects, $p<0.05$.

Table 13. Analysis of T-test of the Difference in Mean Score of Pre-test and Post-CG Test by Aspect

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	minApra – minApos	-.35172	.60560	.07952	-.51096	-.19249	-4.423	57	**.000**
Pair 2	minBpra – minBpos	-.66207	.67456	.08857	-.83943	-.48470	-7.475	57	**.000**
Pair 3	minCpra – minCpos	-.30000	.95164	.12496	-.55022	-.04978	-2.401	57	**.020**
Pair 4	minDpra – minDpos	-.27241	.38698	.05081	-.37416	-.17066	-5.361	57	**.000**

minApra: mean score of the exam before the component identification aspect
minBpra: mean score of the pre-test for identifying the cause of the problem
minCpra: mean score of the pre-test aspects of inventive problem-solving strategies
minDpra: mean score of the pre-aspect test of the impact of inventive problem-solving
minApos: mean score of the exam after the component identification aspect
minBpos: mean score of the post-test aspect of identifying the cause of the problem
minCpos: mean score of the exam after the inventive problem-solving strategy aspect
minDpos: mean score of the post-inventive problem-solving impact of the test

4.4 Achievement of Pre-Test and Post-Test of Inventive Problem-Solving Skills in Project-Based Learning

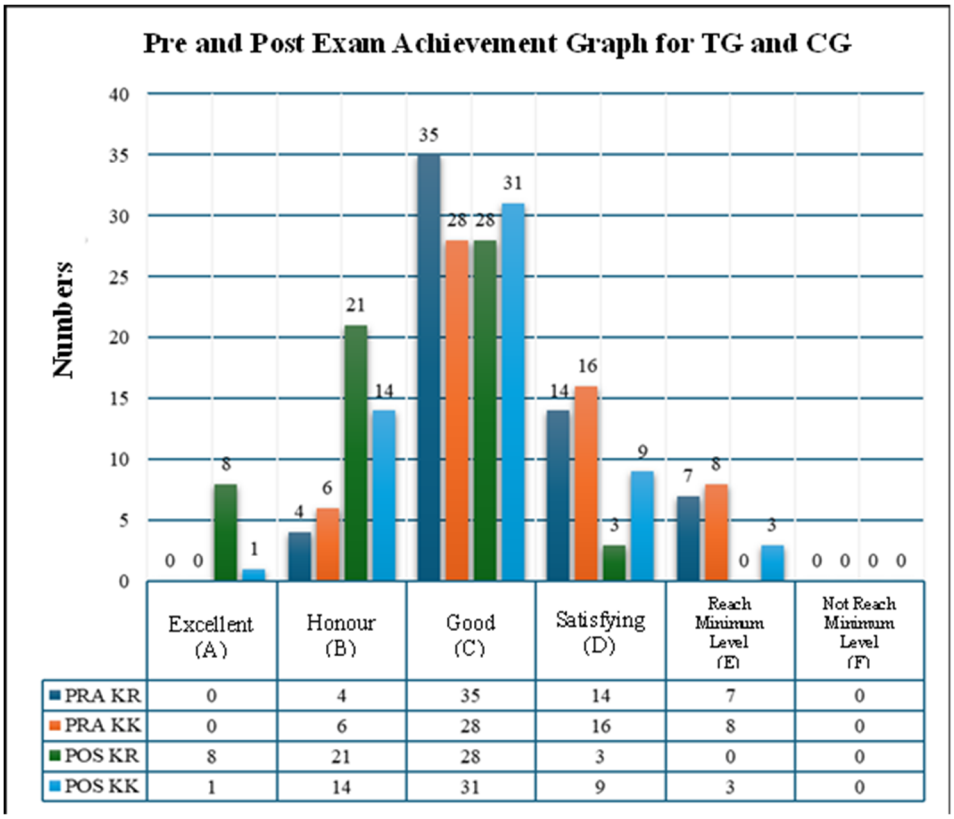

Figure 1. Pre-exam and Post-exam Achievement for TG and CG

Overall, the difference between the TG and CG pre-test and post-test student accomplishment by grade and level is displayed in Figure 1. Most students in both groups received a C (good) on the pre-test and post-test. However, following the post-exam, TG and CG's achievement levels have increased. In the post-examination, TG's performance improved in grade A (8 students) and grade B (21 students), but CG's performance improved in grade A (1 student) and grade B (14 students). TG demonstrated a higher rise in achievement, with 57 pupils mastering grades A, B, and C, compared to CG's 46 kids, despite the increase in both groups. Three pupils are still only proficient in grade E, the bare minimum. It follows that the TG intervention can improve students' proficiency in creative problem-solving techniques in RBT courses.

5. Discussion

In this study, 118 Form 2 students were split into two groups: the treatment group (TG) and the control group (CG). Purwaningsih et al. (2020) found that 58 students in CG used traditional teaching techniques, whereas 60 students in CG received intervention using the Project-Based Learning (PBL) module, which focused on creative problem-solving skills. Examining how well the PBP technique improves students' problem-solving abilities is the goal of this study. Pre-test and post-test statistical analysis revealed that TG's problem-solving abilities significantly outperformed CG's (Abidin & Hariyono, 2020). Though the quantitative benefits are noteworthy, care must be used when interpreting the results. One potential drawback is that the intervention lasted just 12 weeks, which would not have adequately captured long-term skill retention or the transferability of these skills to real-world situations. According to Wijnia et al. (2024), students may demonstrate improvements in performance on organised post-tests without necessarily internalising the creative processes for usage outside of the classroom.

In all areas of issue solving, including component identification, root cause analysis, solution techniques, and solution impact, the results demonstrated that TG's mean post-test score was greater than CG's (Gong et al., 2020). At a value of $p<0.05$, the ANCOVA test analysis verified that this difference was significant, indicating that the PBL module's deployment improved problem-solving skill mastery (Retno, Sunarno, & Marzuki, 2019). These outcomes are consistent with other research showing that project-based learning enhances students' capacity for creative problem-solving (Rohmah et al., 2020; Jaenudin, 2020). Furthermore, even if TG showed improved results, this could be due to the organised scaffolding offered by the PBL module or novelty effects. It is uncertain if comparable outcomes would hold up in a learning setting that is less supervised or more independent. In schools with low resources, where teacher training and module fidelity may differ, this calls into question the intervention's scalability and sustainability (Sahaat & Mohamad Nasri, 2020).

When TG's mean scores from the pre- and post-tests were compared, it was evident that all four problem-solving skills had significantly improved. In contrast to the CG, which increased by 8 points using the traditional technique, students in the TG demonstrated an increase in mean scores of 17 points following the intervention (Tee et al., 2018). This demonstrates how the PBL approach not only fosters a deeper understanding of the issue among students but also motivates them to use more methodical and successful approaches to problem-solving (Wijnia et al., 2024; Frizziero et al., 2019). The area with the biggest increase was in creative problem-solving techniques, indicating that PBP participants were better at coming up with original answers to the issues they encountered (Boss & TGauss, 2022; Hanif et al., 2019). Traditional teaching approaches are not entirely ineffectual, as seen by CG's poor comparative performance. Teacher-centered instruction is still important for basic learning, especially in situations where students are not yet independent learners, according to the CG's modest advances. Therefore, it may be oversimplified to draw a comparison between PBL and traditional approaches; future studies should look at hybrid models that combine both organised guiding and exploratory learning to accommodate varying learning requirements and school capacity.

The results of the study also indicate that students in the TG are more comfortable completing project assignments than students in the CG (Nuraini & Muliawan, 2020). According to Wang, So, and Zhan (2020) and Hussein (2021), this is because PBP implementation entails active and collaborative learning, which enables students to engage more, discuss, and work through issues in groups. According to the study, TG's performance has improved mostly as a result of having more freedom to experiment with different approaches to problems and receiving more methodical direction from teachers when completing projects (Sahaat & Mohamad Nasri, 2020). Thus, project-based learning enables students to enhance their soft skills and self-confidence in addition to their problem-solving abilities (Safitri et al., 2024). Furthermore, qualitative data that could have offered more profound insights into the learning process, like teacher observations or student reflections, were not included in this study. Future interventions could be improved by knowing, for instance, how students view the TRIZ process or the difficulties they encountered when

completing a project. Verifying whether cognitive engagement and confidence in problem-solving increased in tandem with performance scores would also be made easier with the inclusion of such qualitative data.

All things considered, this study demonstrates that the PBL technique outperforms traditional approaches in enhancing students' problem-solving abilities (Almulla, 2020; Purwaningsih et al., 2020). The findings demonstrate that using TRIZ in RBT through project-based learning enables students to solve problems more successfully by applying their knowledge (Rahim & Iqbal, 2020; Gong et al., 2020). Thus, it is advised that PBL modules be added to the curriculum to guarantee that students have stronger and more creative problem-solving abilities, better equipping them to handle obstacles in the actual world (Abidin & Hariyono, 2020). The TRIZ technique was helpful in this particular situation, but its efficacy might differ depending on the discipline and student population. In addition, to testing the PBL module in a variety of age groups and educational contexts, further study is advised to examine the ways in which organised problem-solving models interact with factors such as gender, prior achievement, and cognitive style. While the results support the efficacy of the TRIZ-based PBL module, the study shows that in order to completely comprehend the effects of inventive problem-solving pedagogy, careful interpretation, cross-context replication, and the incorporation of mixed-methods techniques are necessary.

6. Conclusion

This study makes a unique contribution by presenting and assessing a Project-Based Learning (PBL) module designed for secondary RBT teaching that incorporates TRIZ. Contrary to earlier research that generally endorsed PBL, this study explicitly shows how structured creative tactics greatly improve students' capacity to recognise, evaluate, and resolve difficult problems. The findings support TRIZ-based PBL modules' widespread use in order to develop students' deeper problem-solving skills.

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Authors contributions

Tee Tze Kiong and Noor Syuhaili Mohd. Rusly were responsible for study conception, design, and data collection. Analysis and interpretation of results were carried out by Tee Tze Kiong, Noor Syuhaili Mohd. Rusly, Nurulwahida Azid, Charanjit Kaur Swaran Singh, and Rahmat Azis Nabawi. The manuscript was drafted by Muhammad Aris Ichwanto and Andika Bagus Nur Rahma Putra. All authors read and approved the final manuscript. All authors contributed significantly to the study, and there are no special agreements concerning authorship.

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Competing interests

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Data sharing statement

No additional data are available.