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The Impact of a Collaborative Problem-based Learning on Performance in Inverse Matrix Learning, Critical Thinking Skills, and Student Anxiety

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ABSTRACT

The main aim of this study was to evaluate the efficiency of collaborative Problem-Based Learning (PBL) approaches, whether carried out in group settings or in pairs, by examining student performance in understanding inverse matrix concepts, their proficiency in critical thinking, and their levels of anxiety. Using a quasi-experimental approach with a pretest-post-test non-equivalent comparison-group design, the study focused on students from XI Science classes at Kasihan 1 State High School, with classes XI Science 2 and XI Science 3 selected randomly as samples. Pretest and post-test measures were administered to both groups, evaluating their performance in matrix learning, critical thinking, and anxiety levels. The effectiveness of collaborative PBL was analyzed using independent sample t-tests. Results indicated that collaborative PBL, whether in group or pair formats, led to improvements in students' achievement in inverse matrix learning, critical thinking skills, and a decrease in anxiety levels. Additionally, collaborative group PBL proved to be more effective than collaborative pair PBL across these variables.

Keywords: Problem Based Learning, Learning Achievement, Critical Thinking Skills, Anxiety Level

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INTRODUCTION

Mathematics, as a crucial element of educational curricula, has a significant impact on developing competent individuals [1]. Continuously evolving, mathematics not only maintains its relevance but also offers diverse applications in various fields of work and study learning [2]. Amid rapid advancements in science and technology, mathematics remains fundamental, adeptly accommodating the ever-changing landscape of development [3]. Its importance is rooted in the profound structural analysis and logical reasoning it provides, which drive numerous innovations and breakthroughs across scientific domains.

Progress in mathematics often leads to new opportunities for innovation and applications in various life aspects [4]. However, [5] noted that many students fail to recognize the practical

utility of mathematics in everyday life. Furthermore, mathematics is often seen as daunting, especially among high school students, who struggle with understanding concepts and frequently receive poor grades, particularly in matrix inversion [6]. Enhancing students' understanding and critical thinking in mathematics is essential.

The drop in average scores in matrix inversion topics may result from high school students' lack of training in processing information and performing matrix operations effectively [7]. This aligns with [8], who observed that junior high students generally grasp numeric notation easily, but struggle with the algebraic language involving variables and matrix arrays in high school [9], [10]. This difficulty underscores the need for targeted efforts to improve students' performance in matrix inversion.

At Kasihan 1 State High School in Bantul Regency, many students in class XI Science scored below the minimum passing grade of 70 in the 2023/2024 End of Semester Assessment. This low performance may be linked to mathematics anxiety. Interviews with mathematics teachers revealed that some students feel anxious and fearful about math lessons and exams. Addressing this anxiety is crucial for improving academic performance.

Research by shows a correlation between students' anxiety and their performance in mathematics; anxious students tend to perform worse. This anxiety can be exacerbated by ineffective teaching methods [11]. According to [12], attributes mathematics anxiety primarily to outdated teaching methods. Therefore, a shift in teaching models is necessary to reduce students' anxiety [13], [14]. Traditional teacher-centered methods need to be replaced with models that encourage active student participation.

The core principle of learning activities is to provide students with opportunities to explore and develop their skills, attitudes, knowledge, and abilities, preparing them to face life's challenges positively [15]. Thus, empowering students' potential to achieve competence is the main focus. According to [16], an independent curriculum supports active learner engagement in searching, constructing, and utilizing knowledge. The learning process includes observation, questioning, information gathering, association, and communication [17]. Therefore, teachers should implement strategies that enable active student participation in understanding mathematics.

Problem-Based Learning (PBL) places students at the center of the learning process, where they tackle complex, real-world problems. They work independently or in groups to analyze problems, gather information, identify solutions, and develop their understanding through problem-solving [18]. PBL fosters not only concept comprehension but also critical thinking, collaboration, and problem-solving skills relevant to real life [19]. [20] outlines five phases of PBL: introducing the problem, organizing learning, facilitating inquiry, creating and presenting work, and assessing the process.

PBL differs from traditional methods by emphasizing student-centered learning and active problem-solving. Studies, including those by [21], [22], have shown that PBL significantly enhances critical thinking skills. [23] further supports this, indicating that PBL positively impacts the development of critical thinking. Critical thinking involves analyzing, evaluating, and synthesizing information, which is crucial for understanding, analyzing, and solving problems independently.

[24] defines critical thinking as the ability to recognize, generalize, and evaluate reasoning accurately. [25] adds that critical thinkers can pose relevant questions and clearly formulate problems. In mathematics, critical thinking entails integrating knowledge, applying reasoning, and using cognitive strategies to generalize, prove, or evaluate situations reflectively [26]. Thus, developing critical thinking is vital, especially in overcoming difficulties in mathematics.

Interviews with the mathematics teacher of the XI Science Class at Kasihan 1 State High School revealed that improving students' critical thinking skills has not been a priority.

Preliminary research on January 5, 2024, indicated that most students struggle with non-routine problems requiring critical thinking. They prefer tasks similar to textbook examples. Therefore, focused efforts are needed to enhance critical thinking in mathematics education.

PBL is a suitable model for enhancing critical thinking skills despite its challenges [27]. It begins with a problem, allowing students to grasp concepts and principles while actively solving it [28]. [29] suggest that PBL can be done collaboratively, encouraging interaction and mutual learning. [30] describe PBL as involving formulation, sharing answers, listening, and generating ideas in group work.

Combining PBL with collaborative learning in mathematics education appears promising. Research by [31] shows that collaborative learning positively impacts critical thinking through discussion, clarification, and evaluation. This study aims to examine the effectiveness of collaborative PBL in group and pair settings, assessing which format better enhances learning outcomes in matrix inversion, critical thinking skills, and reduces anxiety at Kasihan 1 State High School.

METHOD

Sample and Population

This study employs a quasi-experimental methodology due to the influence of various factors on learning outcomes in matrix inversion, critical thinking skills, and student anxiety. The sample is selected randomly from the XI Science classes at Kasihan 1 State High School during the academic year 2023/2024, consisting of 4 classes. These classes were already established for daily learning activities. From these, two classes XI Science 2 and XI Science 3 are randomly chosen for the sample. Treatments are assigned through random selection: XI Science 2 receives PBL instruction with a collaborative group approach (4 to 5 students per group), while XI Science 3 receives PBL instruction with a collaborative pair approach.

Data Analysis

The research used a pre-test and post-test non-equivalent comparison-group design, where classes were tested both before and after the intervention. The study assessed learning achievement in matrix inversion, critical thinking skills, and student anxiety using various methods. Specifically, the matrix inversion learning achievement was measured using a 20-item multiple-choice test, with scores ranging from 0 to 100. Critical thinking skills were evaluated through a test consisting of 2 essay questions, also scored on a scale of 0 to 100. Student anxiety levels were gauged using a 25-statement questionnaire, with total scores categorized based on predefined ranges according to [32]. To evaluate the effectiveness of the intervention on each variable, the researchers employed one-sample t-tests. Furthermore, to compare the effectiveness of two PBL approaches collaborative group-based and collaborative pair based MANOVA test with Hotelling's Trace criteria was conducted at a significance level of 5%. If significant differences were found between the two treatment groups in the MANOVA results, further analysis using independent sample t-tests was conducted to determine which approach was more effective across the three dependent variables. Before conducting the MANOVA, two assumptions needed to be satisfied: multivariate normality was assessed using Mahalanobis Distance, and multivariate homogeneity was tested using Box's M test, both performed with SPSS-25 software.

RESULTS AND DISCUSSION

Result

The data gathered for this research encompass the outcomes from tests evaluating matrix

inversion learning achievement, critical thinking abilities, and student anxiety levels. The subsequent table illustrates the statistical summary of the data derived from the matrix inversion learning achievement test.

Table 1. Matrix Inversion Learning Achievement Test Results

Description	Collaborative Group-Based PBL		Collaborative Pair-Based PBL	
	Pretest	Post-test	Pretest	Post-test
Mean	61,88	86,41	51,72	72,5
Ideal Maximum Value	100,00	100,00	100,00	100,00

Based on the table above, the mean pretest score for the Collaborative Group-Based PBL class is 61.88, while for the Collaborative Pair-Based PBL class it is 51.72. Furthermore, the mean post-test score for the Collaborative Group-Based PBL class is 86.41, whereas for the Collaborative Pair-Based PBL class it is 72.50. It is important to note that the ideal maximum score for all four tests is 100.00. Next, Table 2 will present the data from the critical thinking skills test.

Table 2. Critical Thinking Skills Test Results

Description	Collaborative Group-Based PBL		Collaborative Pair-Based PBL	
	Pretest	Post-test	Pretest	Post-test
Mean	57,25	86,61	56,47	75,00
Ideal Maximum Value	100,00	100,00	100,00	100,00

The table shows that the average initial test score for the Collaborative Group-Based PBL class is 57.25, compared to 56.47 for the Collaborative Pair-Based PBL class. In terms of the average score after the test, it reaches 86.61 for the Collaborative Group-Based PBL class and 75.00 for the Collaborative Pair-Based PBL class. It should be noted that the maximum score achievable is 100. Table 2 provides a general overview of the data on students' critical thinking skills. However, for a detailed examination of each aspect of students' critical thinking skills, please refer to Table 3.

Table 3. Percentage of Each Critical Thinking Skills Indicator

Indicators of Critical Thinking Skills	Collaborative Group-based PBL		Collaborative Pair-based PBL	
	Pretest	Post-test	Pretest	Post-test
Focus	70%	97%	66%	77%
Reason	66%	92%	62%	86%
Inference	49%	80%	42%	55%
Situation	56%	97%	56%	91%
Clarity	71%	92%	72%	77%
Overview	43%	72%	51%	70%

Based on the data presented in the table, there is clear evidence of improvement in scores for each critical thinking indicator. In the Collaborative Group-Based PBL class, the most substantial increase was observed in the Situation indicator, with a percentage rise from pretest to post-test reaching 41%. Similarly, in the Collaborative Pair-Based PBL class, the highest increase also occurred in the Situation indicator, showing a percentage rise from pretest to post-test of 35%. This suggests that instructional methods employing collaborative PBL settings have the potential to enhance students' critical thinking abilities. Next, Table 4 will

present data on pretest and post-test results regarding student anxiety from both classes.

Table 4. Student Anxiety Questionnaire Results

Description	Collaborative Group-Based PBL		Collaborative Pair-Based PBL	
	Pretest	Post-test	Pretest	Post-test
Mean	85,30	37,87	80,50	56,62
Ideal Maximum Value	100,00	100,00	100,00	100,00

Based on the data provided, it can be concluded that before the trial, students in both the Collaborative Group-Based PBL approach class had an average anxiety questionnaire score of 85.30, categorized as high anxiety. In comparison, students in the Collaborative Pair-Based PBL approach class had an average score of 80.50, also classified as high anxiety. After the treatment, the average anxiety questionnaire score decreased significantly in both classes: students in the Collaborative Group-Based PBL approach class decreased to 37.87, falling into the low anxiety category. Similarly, students in the Collaborative Pair-Based PBL approach class had an average score of 56.62 after the treatment, which is also categorized as low anxiety. This data indicates a notable decrease in average anxiety scores from before to after the treatment in both classes. For a more detailed analysis of the questionnaire data both before and after the treatment across different aspects of student anxiety, please refer to Table 5.

Table 5. Percentage of Each Aspect of Student Anxiety

Description	Collaborative Group- based PBL		Collaborative Pair-based PBL	
	Pretest	Post-test	Pretest	Post-test
Material	87,05%	33,93%	87,05%	60,71%
Learning Process	85,42%	38,02%	77,60%	56,25%
Teacher	96,88%	42,71%	91,15%	47,92%
Exam	77,60%	43,75%	71,35%	67,71%

Based on Table 5, it is evident that in both the collaborative group-based PBL class and the collaborative pair-based PBL class, the most significant decrease in student anxiety occurred in the teacher aspect, with reductions of 54.17% and 43.23%, respectively. This suggests that both collaborative learning approaches group-based and pair-based PBL are effective in reducing student anxiety towards teachers.

Following this observation, the data from the research were analyzed to evaluate the effectiveness of each learning group on algebra learning achievement, critical thinking skills, and student anxiety levels. The effectiveness assessment employed a one-sample t-test. To compare the effectiveness between the learning groups, a univariate test was conducted. Prior to conducting independent sample t-tests and univariate tests using Bonferroni criteria, a MANOVA test was performed to ensure multivariate assumptions were met, including assessing the significance of Hotelling's Trace. Details regarding the analysis of multivariate normality and homogeneity assumptions, both pre- and post-treatment, can be found in Tables 6 and 7.

Table 6. Multivariate Normality Test Results

Achievement	Collaborative Group-based PBL	Collaborative Pair-based PBL
Pretest	68,12	62,89
Post-test	70,29	67,11

Table 7. Box's M Test Results

Achievement	Box's M	F	Sig.
Pretest	10,36	1,63	1,33
Post-test	11,78	1,89	0,08

Based on the analysis results, it has been confirmed that both the initial and final tests exhibit normal distributions, and the respective data groups share the same covariance matrix, as evidenced by the Box's M test results. With these assumptions satisfied, MANOVA (Multivariate Analysis of Variance) was conducted to assess differences in means across groups both before and after treatment, utilizing Hotelling's Trace as a criterion. The detailed MANOVA results before and after treatment are documented in Table 8. This table likely includes statistical outputs such as Wilks' Lambda, Pillai's Trace, Hotelling's Trace, and Roy's Largest Root, which are used to evaluate the significance of differences in mean scores across multiple dependent variables (such as algebra learning achievement, critical thinking skills, and student anxiety levels) between the collaborative group-based PBL class and the collaborative pair-based PBL class. For a comprehensive understanding of the MANOVA results and their implications for the effectiveness of each learning group, refer to Table 8, which provides a detailed breakdown of the statistical findings.

Table 8. MANOVA Test Results

Achievement	F	Sig.
Pretest	24,07	0,00
Post-test	5,77	0,02

Based on the analysis provided, it has been determined that before the intervention, the significance value (*p-value*) of F was greater than 0.05. This suggests that H_0, which states there is no difference in initial abilities between students in classes using collaborative group-based PBL and collaborative pair-based PBL, was accepted. This observation was derived from assessments of matrix inversion learning achievement, critical thinking skills, and student anxiety levels.

However, after the intervention, the significance value of F dropped below 0.05. This led to the rejection of H_0, indicating that there is a statistically significant difference in the effectiveness of learning between the collaborative group-based PBL and collaborative pair-based PBL classes. This difference was observed in terms of matrix inversion learning achievement, critical thinking skills, and student anxiety levels.

To further evaluate the effectiveness of each learning group, a one-sample t-test was conducted. Additionally, a univariate test was performed to compare the effectiveness of each learning group specifically on algebra learning achievement, critical thinking skills, and student anxiety levels post-treatment. The results of these tests, including the t-values from the independent sample t-tests, will be presented sequentially in Table 9. This table will provide a detailed summary of how each learning group performed in terms of these outcomes after the intervention, highlighting any significant differences between them.

Table 9. Effectiveness Test of One Sample T-Test

Class	Achievement	Sig.
Collaborative Group- Based PBL	Matrix Inverse Learning Achievement	0,00

	Critical Thinking Skills	0,00
	Student Anxiety	0,00
Collaborative Pair-Based PBL	Matrix Inverse Learning Achievement	0,00
	Critical Thinking Skills	0,00
	Student Anxiety	0,00

Based on the table provided, the significance values (*p-values*) of t-tests for all assessment aspects-matrix inversion learning achievement, critical thinking skills, and student anxiety levels-are less than 0.05. This indicates that H_0, which suggests no difference between collaborative group-based PBL and collaborative pair-based PBL methods in terms of these outcomes, is rejected. Therefore, collaborative group-based PBL and collaborative pair-based PBL methods show effectiveness in enhancing matrix inversion learning achievement, critical thinking skills, and reducing student anxiety levels.

To further assess the effectiveness of collaborative group-based PBL classes specifically, independent sample t-tests were conducted for each learning group to compare their achievements in matrix inversion learning, critical thinking skills, and levels of student anxiety. The detailed results of these t-tests are presented in Table 10. This table provides a comprehensive overview of the statistical findings, indicating the magnitude and direction of differences between the two learning approaches across the evaluated criteria.

Table 10. Learning Group Results on Achievement

Achievement	Sig. (2 tailed)
Matrix Inverse Learning Achievement	0,016
Critical Thinking Skills	0,000
Student Anxiety	0,000

Based on the provided table, it is clear that the significance value for matrix inversion learning achievement is 0.016, which is below the conventional threshold of 0.05. This rejection of H_0 indicates that collaborative group-based PBL is significantly more effective than collaborative pair-based PBL in terms of enhancing matrix inversion learning achievement. Similarly, the significance values for critical thinking skills and student anxiety are both reported as 0.000, which is less than 0.05. This rejection of H_0 for both aspects indicates that collaborative group-based PBL is significantly more effective than collaborative pair-based PBL in enhancing critical thinking skills and reducing student anxiety levels. Therefore, the results from the table confirm that collaborative group-based PBL shows superior effectiveness compared to collaborative pair-based PBL across all assessed criteria: matrix inversion learning achievement, critical thinking skills, and student anxiety levels.

Discussion

Various educational models need to be developed to improve the quality of education. Currently, no single learning model is perfectly suited to the characteristics of mathematical fields due to the complexity and interconnection of branches like geometry, calculus, algebra, and statistics [33]. Thus, research is required to evaluate the suitability and effectiveness of learning models in enhancing outcomes in specific study areas. This study focuses on implementing mathematics learning using a Problem-Based Learning (PBL) approach, particularly for matrix inversion. It examines the effectiveness of collaborative PBL in both group and pair settings, evaluated through learning achievement in matrix inversion, critical thinking skills, and student anxiety levels. Additionally, the study aims to identify the differences in effectiveness between these two learning models.

Results from the one-sample t-test indicate that group-based collaborative PBL effectively improves matrix inversion learning achievement, enhances critical thinking skills, and reduces student anxiety levels. This is attributed to the relevance of the material to students' daily lives, which fosters active participation through group discussions. This finding is consistent with [34], who found that groups of 4 to 5 students facilitate idea exchange and balanced capabilities, thereby increasing overall knowledge.

Group learning methods are believed to alleviate student anxiety about understanding mathematics material [35]. Students struggling with the material can receive help from groupmates who grasp it better. In another class, pair-based collaborative PBL also showed effectiveness in improving matrix inversion learning achievement, critical thinking skills, and reducing student anxiety levels. Factors contributing to this include increased student activity and responsibility, as each student must share knowledge with their partner. Pairing encourages students to be more accountable and not rely on others, as can happen in larger groups. This aligns with [36], who argue that pairing methods encourage students to explore their abilities more actively and maximize their efforts.

The results of the Hotelling's Trace test revealed significant differences in the effectiveness of group-based and pair-based collaborative Problem-Based Learning (PBL) in various aspects of algebra learning, such as learning achievement, critical thinking skills, and students' anxiety levels. Further analysis using independent sample t-tests showed that group-based collaborative PBL had a greater impact on algebra learning achievement compared to the pair-based approach. However, in terms of critical thinking skills and students' anxiety levels, both approaches yielded similar outcomes. This effectiveness was further reinforced by post-treatment tests, which demonstrated nearly equal achievements between the two methods in these two aspects. These findings indicate that while both group-based and pair-based PBL have their respective strengths, the group-based approach is superior in enhancing academic achievement.

The greater effectiveness of the group-based collaborative PBL approach can be attributed to several key factors that support successful learning outcomes. One of these factors is the group's ability to generate more ideas through dynamic discussions. Within a group, students are given opportunities to share information and experiences, which ultimately enhances collective understanding. Such discussions are particularly beneficial for students with lower levels of comprehension, as they can receive additional explanations from their peers. Furthermore, learning in a group fosters a supportive and cooperative environment, where every member bears the responsibility of contributing to collective success. As a result, group-based PBL not only promotes academic progress but also helps students develop essential social skills, such as communication, collaboration, and empathy.

This study provides significant contributions to understanding the effectiveness of collaborative PBL models in mathematics education, particularly in teaching matrix inversion. The findings highlight notable differences between group-based and pair-based approaches, which can serve as valuable considerations for educators in designing classroom teaching strategies. By selecting the most appropriate method, teachers can enhance students' learning outcomes, improve their critical thinking skills, and create a more comfortable learning environment that reduces students' anxiety levels [37], [38]. Additionally, these findings offer guidance for the development of more effective collaborative learning models in the future, addressing the increasingly complex challenges of modern.

CONCLUSION

Based on the research findings and discussion, the following conclusions were obtained: (1) Mathematics learning using the PBL model, both group collaborative and pair

collaborative approaches, has been proven to increase matrix inversion learning achievement, increase critical thinking skills, and reduce learning achievement. student anxiety level; (2) Mathematics learning with a collaborative group approach using PBL is considered more effective than the collaborative pair approach in terms of matrix inversion learning achievement, critical thinking skills, and students' anxiety levels. Researchers suggest using collaborative PBL in other mathematics materials.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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