JURNAL LITERASI PENDIDIKAN FISIKA

Volume 7 No. 2
Page: 174 - 185
November 2026

Comparative Analysis of Students' Mathematical Thinking Skills and Learning Outcomes between Matrix Inverse and Substitution-Elimination Methods in Dynamic Electricity

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Abstract

Dynamic electricity is a physics topic that students often find challenging, especially in solving two-loop circuit problems that require mathematical reasoning. This study examined the differences in students' mathematical thinking skills and learning outcomes between the matrix inverse method and the substitution-elimination method in senior high school dynamic electricity learning. A quasi-experimental design, specifically the Posttest-Only Control Group Design, was employed within a quantitative research approach. The experimental class comprised 31 students taught using the matrix inverse method, while the control class consisted of 33 students taught using the substitution-elimination method. Data were collected through a five-item essay test based on reasoning, generalization, critical thinking, problem-solving, and communication indicators. Data analysis was conducted using the Mann–Whitney test and independent-samples t-test. The results indicated significant differences in mathematical thinking ability (sig. 0.016 < 0.05) and learning outcomes (sig. 0.005 < 0.05). The experimental class achieved higher mean scores in mathematical thinking ability (66.90) and learning outcomes (68.42) compared to the control class (58.82 and 56.42). The findings demonstrate the potential of the matrix inverse method to enhance students' mathematical thinking skills and learning outcomes when learning dynamic electricity.

Keywords: Dynamic Electricity, Inverse Matrix, Mathematical Thinking Ability, Learning Outcomes.

Article History:
Received: 5 May 2026 *Accepted: 26 June 2026* *Published: 20 October 2026*

How to cite:
Zahro, R.F., Supriadi, B., Ratnaningsih, S., & Fadilah, T.N. (2026). Comparative Analysis of Students' Mathematical Thinking Skills and Learning Outcomes between Matrix Inverse and Substitution-Elimination Methods in Dynamic Electricity. *Jurnal Literasi Pendidikan Fisika (JLPF)*, 7(2), 174-185. https://doi.org/10.30872/jlpf.v7i2.6564

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INTRODUCTION

The subject of physics, especially dynamic electricity, is often considered difficult because students are required to understand physical concepts while simultaneously applying mathematical procedures in problem solving. This condition is reflected in students' low learning outcomes in dynamic electricity material. Halmuniati et al. (2022) reported that students' average learning outcome score was only 26.67, indicating that most students had not achieved the Minimum Mastery Criteria (MMC). Similarly, Simamora (2021) found that students' average score in physics learning was 45.51. Several studies have also reported that students commonly experience difficulties in understanding current direction, voltage relationships, and the application of Kirchhoff's laws in multi-loop circuits because these concepts require simultaneous conceptual and mathematical reasoning (Handayani & Huda, 2024; Muliadi & Yuliani, 2025).

One factor contributing to this condition is students' limited mathematical thinking ability. In physics learning, students are required to think logically, systematically, and analytically in order to represent physical situations in mathematical form and solve them correctly. Kahar (2017) reported that students' mathematical thinking ability was still categorized as low. This condition reflects a discrepancy between the demands of dynamic electricity learning and students' mathematical abilities in constructing models and solving physics problems.

Many factors contribute to low mathematical thinking skills and learning outcomes among students. One of the main factors stems from procedural physics learning patterns, where students are directed to follow mechanical steps to solve problems without understanding the meaning of concepts and the relationships between components in a problem (Afryani et al., 2021). This type of learning pattern encourages students to focus on memorizing formulas and procedures instead of developing a deeper conceptual understanding, making it difficult for students to apply mathematical representations to more complex physics problems (Yopi et al., 2021). On the other hand, dynamic electricity problems are commonly solved using the substitution-elimination method to solve systems of linear equations. This method remains mathematically valid and effective for solving linear equation systems. However, in the context of three-variable systems commonly found in two-loop electrical circuits, the method may become more challenging for some students because it requires them to determine appropriate substitution and elimination steps independently (Hariati & Septiadi, 2019). As a result, students may experience difficulties in algebraic manipulation and variable elimination processes, particularly when the relationships among equations are not fully understood (Siregar et al., 2024). These challenges can affect students' accuracy in solving dynamic electricity problems and may contribute to difficulties in mathematical thinking processes.

Students face greater difficulties when dealing with 2-loop circuits. In these circuits, students must analyze the relationship between current and voltage in several branches of the circuit simultaneously. The analysis of 2-loop circuits is based on the application of Kirchhoff's 1st and 2nd laws. According to Kirchhoff's First Law (Kirchhoff's Current Law/KCL), the currents at a node are balanced, such that the algebraic sum of incoming currents equals that of outgoing currents (Handayani & Huda, 2024). Systematically, this law can be written in the form $\sum I_{in} = \sum I_{out}$. Meanwhile, Kirchhoff's Second Law (Kirchhoff's Voltage Law/KVL) explains that the total algebraic value of voltage changes, including increases and decreases, within a closed loop must be equal to zero (Handayani & Huda, 2024). Mathematically, this can be expressed as follows $\sum \varepsilon + \sum I.R = 0$. Applying KCL and KVL simultaneously in two-loop circuits yields interconnected linear equations that require systematic procedures for efficient problem solving. In two-loop dynamic electricity circuits, the application of Kirchhoff's laws produces a system of three linear equations with three variables representing electric currents in each branch. Solving this system requires students to manage multiple interconnected equations simultaneously, which is often challenging in conventional calculation methods (Ilmi et al., 2023). One alternative method that can be used to solve this system is the matrix inverse method.

The matrix inverse method is considered suitable for two-loop circuit problems because Kirchhoff-based equations can be directly represented in matrix form. Through this representation, the relationships among current variables can be organized systematically into coefficient matrices, variable matrices, and constant matrices. This matrix representation enables students to organize relationships among variables more systematically, allowing simultaneous solutions to be obtained in a more efficient and structured manner.. Previous studies by Purwanti et al. (2025) showed that the matrix inverse method can support problem solving in physics contexts involving systems of linear equations. However, studies integrating this method specifically into dynamic electricity learning are still limited. In addition, most previous studies focused mainly on cognitive learning outcomes without specifically examining students' mathematical thinking abilities during the problem-solving process.

The matrix inverse method is based on the concept of inverse matrices, which produce an identity matrix when multiplied by their original matrices. According to Ani et al (2023) An inverse exists for a matrix when the matrix is square and its determinant is non-zero. In the present study, the matrix inverse

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method was used as an alternative approach to solve systems of linear equations arising from dynamic electricity problems.

Based on interviews with physics teachers, students experience difficulties in solving dynamic electricity problems due to unclear problem-solving steps and limited variation of solution methods. This condition leads to low learning outcomes and weak mathematical thinking skills among students. Therefore, a more structured and systematic learning approach is required so that students can not only obtain correct answers but also comprehend the mathematical reasoning process involved in solving problems. The matrix inverse method is considered to have the potential to address this problem because it offers organized steps that can help students minimize calculation errors. Based on these considerations, this study aims to compare students' mathematical thinking ability and learning outcomes between students who learned using the matrix inverse method and those who learned using the substitution-elimination method in dynamic electricity learning.

METHODS

This research was conducted at a senior high school in Jember during the first semester of the 2025/2026 academic year. This study used a quantitative, quasi-experimental approach with a posttest-only control group design, as illustrated in Figure 1.

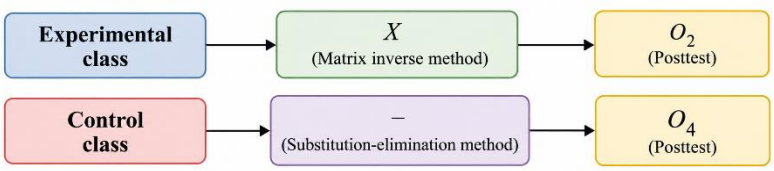


Figure 1. *Posttest-only control group design*

The research participants were divided into two classes, namely an experimental class and a control class. The experimental class received instruction using the matrix inverse method, while the control class was taught using the substitution-elimination method. In contrast, the control group received instruction using the substitution-elimination method and was assessed using a posttest (O4) to compare the results with the experimental group. The learning implementation in both classes was conducted over four meetings consisting of a total of eight instructional hours.

In the experimental class, the matrix inverse method was applied to solve systems of linear equations obtained from Kirchhoff-based dynamic electricity problems. According to Supriadi et al. (2025), the matrix inverse method can be implemented through several stages. The procedure begins by expressing the system of linear equations in the form of a matrix equation, AX = B. In this representation, matrix A denotes the coefficient matrix, matrix X indicates the variable matrix, and matrix B represents the constant matrix. The next step involves calculating the determinant of matrix A to verify the existence of its inverse. Afterward, the cofactor matrix and adjoint matrix are obtained as intermediate steps in determining the inverse matrix through the inverse matrix formula. The final step is calculating the values of the variables by multiplying the inverse matrix with the constant matrix. The procedure of the matrix inverse method used in this study can be summarized as follows:

a. Calculate the determinant of the coefficient matrix A.
b. Calculate the cofactor matrix of matrix A using Equation (1)

$$K_{ij} = (-1)^{i+j} M_{ij} \quad (1)$$

c. Calculate the adjoint matrix A by transposing the cofactor matrix using Equation (2)

$$adj\ (A) = [K]^T \quad (2)$$

d. Calculate the inverse of matrix A by applying the inverse matrix formula using Equation (3)

$$A^{-1} = \frac{1}{det\ det\ (A)} adj\ (A) \quad (3)$$

e. Determine the value of the variable by multiplying the inverse of matrix A by the constant matrix, using Equation (4)

$$X = A^{-1}B \quad (4)$$

The research population included six classes of grade XII science students from a senior high school in Jember during the 2025/2026 academic year. The samples were selected through a cluster random sampling technique. Two classes were selected as samples from the six existing classes through a random selection process. Class XII MIPA 5 was assigned as the experimental class, which learned dynamic electricity using the matrix inverse method, while class XII MIPA 3 was assigned as the control class, which learned employing the substitution-elimination method.

A written test consisting of five essay questions was administered to collect data on students' mathematical thinking abilities and learning outcomes. The indicators of mathematical thinking ability included reasoning, generalizing, critical thinking, problem solving, and communicating (Shidqiya & Sukestiyarno, 2022). The instrument was validated by physics education experts before being implemented in the study. In addition, a scoring rubric was used to assess students' responses consistently based on each indicator. The validation process focused on the suitability of the content, clarity of the questions, and alignment with the indicators of mathematical thinking ability. At the conclusion of the learning activities, both the experimental and control classes were given an equivalent essay test to evaluate students' abilities. In addition to the written test, brief interviews were conducted with several students to support the interpretation of students' problem-solving processes and mathematical thinking performance during the discussion of the results. The score for each mathematical thinking ability indicator was calculated using Equation (5).

$$Score\ total\ for\ each\ indicator = \frac{Total\ Score\ Obtained\ for\ Each\ Indicator}{Maximum\ Score\ for\ Each\ Indicator} \times 100 \quad (5)$$

where the indicator score represents the total score students obtained on each mathematical thinking ability indicator. Meanwhile, students' learning outcomes were calculated using Equation (6).

$$Learning\ Outcome\ Score = \frac{Total\ score\ obtained}{Maximum\ total\ score} \times 100 \quad (6)$$

where the total score obtained represents the score achieved by students, while the maximum total score represents the highest possible score on the test.

Data distribution was examined through the Shapiro–Wilk test, followed by the Independent Samples t-test when the normality requirement was fulfilled (Sig. > 0.05). However, when the data did not follow a normal distribution (Sig. < 0.05), the Mann–Whitney test was employed as a non-parametric statistical analysis. The normality test was conducted separately for each mathematical thinking ability indicator and for the total score; therefore, different statistical tests were applied depending on the distribution of the data.

RESULTS AND DISCUSSION

This section presents the results of students' mathematical thinking ability and learning outcomes after the implementation of the matrix inverse method and the substitution-elimination method in dynamic electricity learning. The findings are discussed based on each indicator of mathematical thinking ability, followed by the analysis of overall learning outcomes between the experimental and control classes.

Mathematical Thinking Ability

The results of students' mathematical thinking ability were measured by summing up each indicator, which included reasoning, generalizing, critical thinking, problem solving, and communicating. Details of the classes are provided in Table 1.

Table 1. Mathematical thinking ability for each indicator

Mathematical Thinking Ability Indicators	Control Class (33 Students)		Experimental Class (31 Students)	
	Score	Mean	Score	Mean
Reasoning	193	5,8	304	9,8
Generalizing	515	15,6	457	14,7
Critical Thinking	569	17,2	475	15,3
Problem Solving	379	11,5	432	13,9
Communicating	285	8,5	406	13,1

Based on Table 1, students' mathematical thinking skills show variations in each indicator between the experimental and the control classes. The experimental class achieved higher scores in reasoning, problem solving, and communicating than the control class. Meanwhile, in generalizing and critical thinking, the experimental classes achieved lower scores than the control classes. The experimental classes obtained a total score of 2,074, with an average score of 66.9, whereas the control classes achieved a total score of 1,941, with an average score of 58.82. The maximum score for each indicator was 20 based on the scoring criteria used in the assessment rubric

Before conducting statistical tests, it was necessary to test the normality of each indicator and the scores of each student. The analysis revealed that of the normality test on the mathematical thinking ability data, it was found that the overall data for the mathematical thinking ability indicators in both sample classes obtained a sig value < 0.05, meaning that the mathematical thinking ability scores for each indicator were not normally distributed. Therefore, testing for each mathematical thinking ability indicator was continued with the Mann-Whitney nonparametric test. The results of the Mann-Whitney test for each mathematical thinking ability indicator can be seen in Table 2.

Table 2. Mann-Whitney test of mathematical thinking ability

Indicator	Mann-Whitney	Z	Sig. (2-tailed)
Reasoning	343.0	-2.323	.020
Generalizing	437.5	-1.008	.314
Critical Thinking	345.0	-2.336	.019
Problem Solving	315.5	-2.670	.008
Communicating	172.0	-4.600	.000

Based on Table 2, five indicators of mathematical thinking skills have a sig value < 0.05. This indicates that a significant difference exists between the two samples across the four indicators. Meanwhile, the generalizing indicator has a sig value > 0.05. Therefore, no significant difference was found between the two classes. The discussion of each mathematical thinking ability indicator is as follows:

Reasoning

The reasoning aspect involves students' ability to identify the information provided and the required solution in a problem before determining the appropriate answer, as stated by Shidqiya & Sukestiyarno (2022). The Mann–Whitney analysis presented in Table 2 revealed a significant difference between the two groups for this indicator, with average scores of 9.8 for the experimental class and 5.8 for the control class. Most learners in the experimental group were able to recognize and record the given information and the required points of the problem, while only a limited number of students in the control class exhibited a similar ability. Samples of students' responses are illustrated in Figure 2.



(a) (b)

Figure 2. (a) Reasoning indicator for DAA students in the experimental class; (b) Reasoning indicators for ARM

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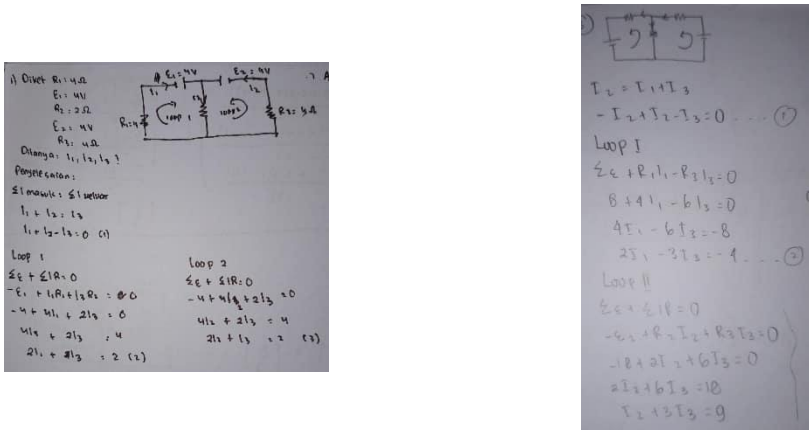
students in the control class

The interview results showed that writing down known and unknown information made it easier for students to complete the next stage. This finding indicates that structured problem-solving steps play an important role in supporting students' reasoning ability. Based on interview results, students stated that writing down known and unknown variables helps them organize information and plan their solution steps more effectively. This result is consistent with Melinda et al. (2024), who found that identifying known and unknown elements is a crucial step in problem solving. In addition, this supports the idea that systematic approaches in learning can improve students' analytical thinking. However, some students still ignored this step and proceeded directly to calculations, which could potentially lead to misinterpretation of the question. This indicates that structured methods not only guide procedural steps but also support cognitive organization in problem solving.

Generalizing

Generalizing is the second indicator in mathematical thinking skills that requires students to demonstrate mathematical ideas through image analysis to establish the current flow direction and the direction of the loops, and the laws that apply to dynamic electrical circuits. This is in line with Shidqiya dan Sukestiyarno (2022) that the generalizing indicator emphasizes the ability to express mathematical ideas correctly, both in visual and mathematical symbol forms (Marliani & Puspitasari, 2022). The data in Table 2 show comparable results between the two groups on this indicator, with the experimental class averaging 14.7 and the control class 15.6, indicating no significant difference.

Figure 3 shows the results of student work on generalizing indicators. Part (a) shows the experimental class students who described the direction of the loop and current density and wrote down the general equation of Kirchhoff's law, while part (b) shows the control class students who described the direction of the loop and current density but only wrote down one general equation of Kirchhoff's law. The majority of experimental class students only solved questions 1–3 correctly, while control class students solved all questions correctly. Research by Lorenza et al. (2024) states that generalizing requires students to draw patterns from existing cases and then express them in a consistent general form. Thus, the summary of the results in the experimental class was lower than that of the control classes even though the experimental classes worked on the questions accurately and correctly. This result indicates that the matrix inverse method emphasizes procedural computation rather than conceptual representation. As a consequence, students tend to focus on obtaining numerical solutions without fully constructing general relationships between variables in the circuit. This finding may indicate that students in the experimental class focused more on procedural computation than on developing broader abstraction and generalization skills in representing physical concepts mathematically.



(a) (b)

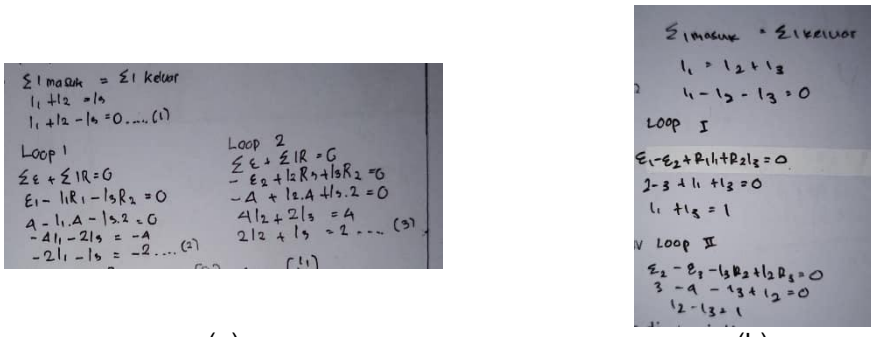
Figure 3. (a) Generalizing indicators for MRMU students; (b) Generalizing indicators for AHA students

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Critical Thinking

In this study, the critical thinking indicator refers specifically to students' ability to construct mathematical models in the form of systems of linear equations based on circuit representations. This indicator requires students to analyze circuit diagrams and transform them into appropriate mathematical equations (Shidqiya & Sukestiyarno, 2022). The experimental classes obtained a mean score of 15.3, which was lower compared to the control classes that achieved an average score of 17.2.

Figure 4 illustrates the comparison of students' responses, where part (a) represents the experimental class's work and part (b) represents the control class's work. Based on the results of the students' work, the majority of students in the experimental class only answered questions 1 to 3 correctly and accurately because they were more focused on solving the problems in each question. Meanwhile, the control class students worked on all questions correctly and accurately. As a result, the recapitulation of the results in the experimental classes was lower than that of the control classes. Investigation by Rahmawati et al. (2025) shows that critical thinking skills in solving three-variable linear equation systems are important skills that support students in developing problem-solving strategies and thinking mathematically. This finding suggests that the matrix inverse method may reduce students' engagement in the modeling process. Since the method provides a direct pathway to the solution, students may rely more on procedural execution rather than critically constructing the mathematical model from physical representations. As a result, students' critical thinking skills in formulating equations may not develop optimally. This condition may indicate a shift from conceptual reasoning to procedural dependence, where students prioritize following steps rather than evaluating the validity of the model they construct.



(a) (b)

Figure 4. (a) Critical thinking indicators of AKI students; (b) Critical thinking indicators of AHBA students

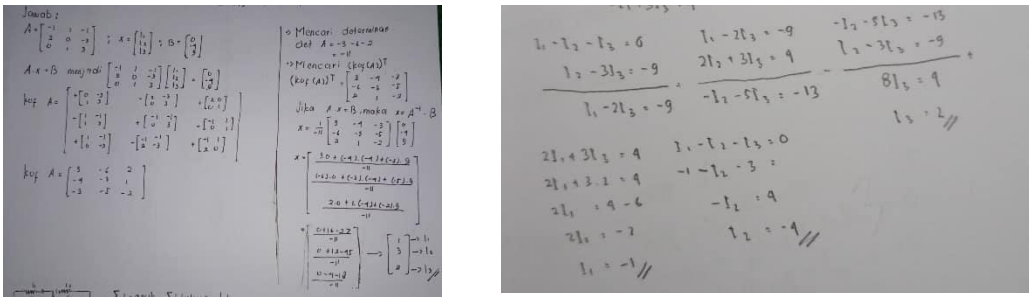
Problem Solving

Problem solving is the fourth indicator of mathematical thinking skills, which requires students to develop problem-solving strategies (Shidqiya & Sukestiyarno, 2022). The mean scores were 13.9 and 11.5, respectively. Students in the control classes attempted to complete the entire set of problems but still encountered errors when applying the substitution-elimination method, whereas students in the experimental classes answered only several problems but applied the matrix inverse method accurately and appropriately.

Figure 5 shows the results of student problem-solving indicators. Part (b) shows that the experimental class students used the inverse matrix method in a structured and systematic manner, resulting in more consistent results. The matrix inverse method provides a more systematic and structured approach compared to the substitution-elimination method. This allows students to follow clear steps in solving problems, reducing errors in calculation. The results obtained in this study support the findings reported by Purwanti et al. (2025), who stated that matrix representation simplifies complex calculations and improves accuracy. Furthermore, based on student responses, the method helps them maintain consistency in solving multi-variable problems. In contrast, part (a) shows control class students who used the substitution-elimination method but made substitution errors that affected the

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final results. This finding is supported by interviews with students in the experimental classes who stated that the matrix inverse method was more focused in solving problems. These results imply that applying systematic procedures helps students manage cognitive demands more effectively, so they can emphasize understanding concepts rather than spending effort on repeated calculation attempts.

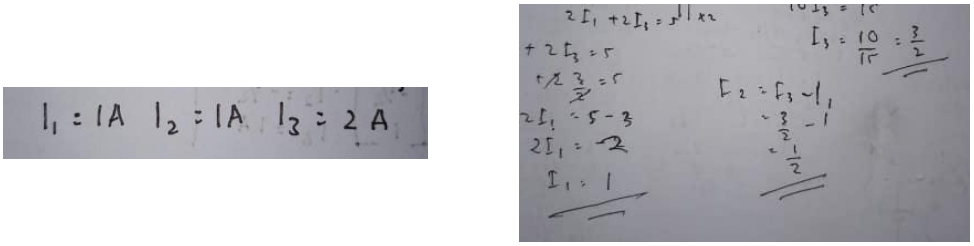


(a) (b)

Figure 5. (a) Problem-solving indicators for ZRR students; (b) Problem-solving indicators for NF students

Communicating

Communication is the fifth indicator of mathematical thinking skills, which requires students to express the results of problem solving (Shidqiya & Sukestiyarno, 2022). A complete mathematical communication response in this study included writing the final conclusions systematically, presenting appropriate units, and clearly explaining the obtained results. Table 2 shows that the mean scores differed between the experimental and control classes, with respective values of 13.1 and 8.5. Only a small number of students in the control class wrote conclusions, while in the experimental class, the majority of students wrote complete conclusions with units. Samples of students' work are illustrated in Figure 6.



(a) (b)

Figure 6. (a) Indicators of student communication in RPS students; (b) Indicators of student communication in NHM students

Figure 6 illustrates that students from the experimental class were capable of providing final answers accompanied by complete conclusions and appropriate electrical current units (Amperes). In contrast, students in the control class only reported the final numerical results without including clear units. Research by Samawati & Kurniasari (2021), mathematical communication ability refers to students' competence in expressing solution strategies and presenting problem-solving outcomes through written representations. Based on the above explanation, the difference between the two classes demonstrates that students in the experimental class were more thorough in presenting their work results. This indicates that structured solution methods not only affect problem solving but also influence how students organize and present their answers. The step-by-step nature of the matrix inverse method encourages students to produce more complete and systematic written explanations. This supports the idea that procedural clarity contributes to better mathematical communication.

The normality test results for the overall mathematical thinking ability scores obtained a sig value > 0.05, indicating that the mathematical thinking ability scores are normally distributed. Therefore, the testing of mathematical thinking ability scores was continued with a parametric Independent Samples t-test, which can be seen in Table 3.

Table 3. Independent Samples t-test of mathematical thinking ability

Variable	Levene Sig.	t	df	Sig. (2-tailed)	Interpretation
Mathematical Thinking Ability	0.873	-2.429	62	0.018	Significant Difference

The homogeneity test results presented in Table 3 indicate that Levene's Test obtained a sig.value of 0.873 (> 0.05). The results of the homogeneity test confirmed that both classes had comparable variances. Thus, hypothesis testing proceeded with the Independent Samples t-test as a parametric test. The t-test analysis produced a sig.value of 0.018 < 0.05, demonstrating that students' mathematical thinking abilities differed significantly between the two classes. This finding demonstrates that students who learned through the matrix inverse method showed different mathematical thinking abilities compared to those who were taught using the substitution-elimination method.

This difference is thought to be because the representation of Linear Equation System (LES) in matrix form provides a more organized calculation structure. This finding is supported by interviews with students in the experimental classes who stated that the matrix inverse method is more systematic and focused, thereby minimizing errors. In line with this, Ilmi et al. (2023) stated that the matrix inverse method is simple and can be used directly to obtain solutions to problems. This indicates that structured mathematical representations help reduce cognitive complexity when dealing with multiple variables. By organizing equations into matrix form, students can process information more efficiently, which enhances their overall mathematical thinking performance. Although not all indicators of mathematical thinking ability showed significant differences individually, the overall mathematical thinking ability demonstrated a significant difference between the experimental and control classes, as indicated by the Independent Samples t-test results in Table 3.

Learning Outcomes

In addition to measuring mathematical thinking skills, this study measured student learning outcomes. The following are the learning outcome scores of students in both classes. In addition to the average scores, the distribution of students' learning outcomes was also analyzed using standard deviation, minimum score, and maximum score to provide a clearer description of students' performance in both classes. Higher learning outcomes were obtained by students in the experimental class than by those in the control class, as shown in Table 4. Before the hypothesis test was conducted, the normality of the data was examined. The analysis indicated that the data from both classes were normally distributed, with sig. values of 0.643 for the experimental class and 0.183 for the control class. As both significance values exceeded 0.05, the data met the normality assumption. Thus, the data were further analyzed using the Independent Samples t-test as a parametric test.

Table 4. Student learning outcomes

Class	Scores Obtained	Average Score	Standard Deviation	Min Score	Max Score
Control Class (33 Students)	1862	56,42	14.645	28	100
Experimental Class (31 Students)	2121	68,42	16.402	39	100

As shown in Table 5, Levene's test yielded a significance value of 0.954 (> 0.05), indicating homogeneous data variance. Thus, the variances of the two classes can be considered homogeneous. Based on this result, hypothesis testing was conducted using the Independent Samples t-test. The analysis resulted in a significance value of 0.005 < 0.05, demonstrating a significant difference in learning outcomes between students in the experimental and control classes.

Table 5. Independent samples t-test of student learning outcomes

Variable	Levene Sig.	t	df	Sig. (2-tailed)	Interpretation
Student Learning Outcomes	0.954	-2.946	62	0.005	Significant Difference

The variation in learning outcomes can be attributed to the instructional process applied in each

class. In the control class, students encountered greater difficulties in solving systems of linear equations using substitution and elimination procedures. Meanwhile, students in the experimental class showed greater accuracy and more systematic solution steps. This result is consistent with the findings of Indriyani et al. (2025), who explained that students often encounter difficulties in determining appropriate procedures when solving linear equations using the substitution-elimination method. Meanwhile, the matrix inverse method enables students to solve problems simultaneously through matrix representation (Purwanti et al., 2025). These findings indicate that the matrix inverse method can assist students in solving dynamic electricity problems more effectively and improve their learning outcomes.

CONCLUSION

This study produced several conclusions. First, students' mathematical thinking abilities differed significantly between the experimental and control classes in dynamic electricity learning. Second, the students' learning outcomes also showed a significant difference between the two groups. Third, the implementation of the matrix inverse method demonstrated its potential in enhancing students' reasoning, problem-solving, and communication abilities through systematic solution procedures. However, students still require further guidance to develop generalization and mathematical model construction skills from various representations. Future research is suggested to involve broader samples and different educational settings to gain deeper insights into the implementation of the matrix inverse method in physics learning.

Acknowledgements

This study was conducted as a requirement for completing an undergraduate degree in Physics Education. The author would like to convey sincere appreciation to the supervisors for their guidance, constructive feedback, and ongoing support throughout the research. Gratitude is also extended to the school principal, physics teachers, and students involved in this study for their cooperation and assistance. The author further acknowledges everyone who contributed, either directly or indirectly, to the completion of this research.

Conflict of Interest

The authors declare that they have no conflict of interest related to this study.

Funding

This research received no external funding.

Author Contributions

R.F.Z., B.S., S.R., and T.N.F. contributed to the conceptualization, methodology, investigation, data analysis, and preparation of the manuscript. All authors participated in reviewing and editing the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

Formal ethics approval was not sought for this study. However, permission to conduct the research was obtained from the school administration. Participation was voluntary, and informed consent was obtained from the participants and/or their legal guardians, as applicable.

Generative AI Declaration

The authors declare that no generative artificial intelligence tools were used in the preparation, writing, or revision of this manuscript.

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