

THE EFFECT OF ALGORITHMIC GAUSS–JORDAN METHOD ON MATHEMATICAL REASONING AND LEARNING OUTCOMES IN DYNAMIC ELECTRICITY

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Article Info

Received: Dec 27, 2025

Revised: Jan 09, 2026

Accepted: Feb 12, 2026

OnlineVersion: Feb 19, 2026

Abstract

This study was motivated by the limited empirical evidence on the application of systematic methods in solving linear equation systems in physics education, particularly in dynamic electricity, to support students' mathematical reasoning abilities and learning outcomes. Previous studies have mostly emphasized conceptual understanding, while the use of the Gauss–Jordan method as a structured problem-solving approach has received limited attention. Therefore, this study aims to analyze the impact of applying the Gauss–Jordan method on students' mathematical reasoning abilities and learning outcomes. This study used a quasi-experimental design with a posttest-only control group. Participants consisted of 67 high school students and 65 physics education students selected through purposive sampling. Data were collected using essay tests based on four indicators of mathematical reasoning and student response questionnaires. Data were analyzed using the Shapiro–Wilk test, independent samples t-test, and Mann–Whitney U test. The results showed that students in the experimental group obtained significantly higher scores in mathematical reasoning and learning outcomes compared to students in the control group ($p < 0.05$). The novelty of this study lies in the integration of algorithm-based and matrix-oriented problem solving in dynamic electricity learning. These findings indicate that systematic mathematical modeling strengthens students' reasoning and conceptual understanding in physics. However, the limited sample size restricts generalization, and further research is recommended.

Keywords: Dynamic Electricity, Gauss-Jordan Elimination, Mathematical Reasoning.



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INTRODUCTION

Technological developments and global needs are driving changes in the world of education (Vyshnevskaya, 2022). Modern education requires the adaptation of learning approaches in line with the times (Dewra, 2025). 21st-century learning requires students to have competencies such as collaboration skills, problem-solving skills, self-control skills, critical thinking skills, communication skills, and

information and communication technology (ICT) skills to develop knowledge and skills in a meaningful and sustainable manner (González-Salamanca et al., 2020; Peña-Ayala, 2021). In line with the opinion of Mukarramah et al. (2021), 21st-century learning needs to integrate character education strengthening (PPK), communication, collaboration, creativity, critical thinking (4C) skills, literacy strengthening, and high-order thinking skills (HOTS) strengthening in the learning process. One of the abilities to support the achievement of educational demands in the modern era, especially in the aspect of critical thinking, is through mathematical reasoning skills (Abayeva et al., 2024; Mukuka et al., 2023). For this reason, learning activities are needed that can accommodate students' thinking abilities in accordance with the indicators of mathematical reasoning skills.

In the learning process, mathematical reasoning is a cognitive ability that can support the achievement of modern era demands (Marasabessy, 2021). Mathematical reasoning refers to the ability to think logically, which plays an important role in building and developing basic structures and principles in mathematics (Kotsis, 2025; Yenmez & Gökçe, 2025). Mathematical reasoning ability is one of the higher-order thinking skills that consists of the ability to analyze, evaluate, and create, which are needed to solve problems logically (Mafada et al., 2020). However, students' mathematical reasoning skills are currently still low. This is in line with the results of a study by Tanudjaya & Doorman (2020), which stated that only 1% of 375 students were able to provide arguments accompanied by complete mathematical procedures, and only 14% of students were able to provide arguments accompanied by simple mathematical procedures. Mokoginta et al. (2025) concluded that only 2 out of 32 students had excellent mathematical reasoning skills. Research by Handayani & Setiawati (2024) concluded that 21.05% of students had high mathematical reasoning skills, 42.10% had moderate skills, and 36.85% had low skills. The students' low level of mathematical reasoning skill is due to their difficulty in solving physics problems because they are not yet able to identify important information, predict solutions, perform mathematical manipulations, and conclude the final results accurately (Hamdi et al., 2024; Qotrunnada, 2022). These findings indicate that students' mathematical reasoning abilities are generally still low.

Mathematical reasoning skills are essential in physics learning because, in practice, physics learning is not only about memorizing formulas but also understanding the interrelationships between concepts so that students are able to analyze and interpret scientific concepts (Palmgren & Rasa, 2024; Tong et al., 2025). One physics subject that requires a high level of understanding is Dynamic Electricity (Azizahwati et al., 2024). A dynamic electrical circuit is a closed circuit through which electric current flows. Analyzing electrical circuits requires good mathematical reasoning skills, especially in solving linear equation systems, which are generally based on the application of Kirchhoff's laws. According to Hasan et al. (2020), Kirchhoff's first law states that the total current flowing into a junction is equal to the total current flowing out of it,

$$\sum I_{in} = \sum I_{out} \quad \dots (1)$$

Meanwhile, Kirchhoff's Second Law states that the algebraic sum of voltages around a closed loop is equal to zero, which is mathematically formulated as follows:

$$\sum \varepsilon + \sum I.R = 0 \quad \dots (2)$$

Student learning outcomes in dynamic electricity are generally still below the established standard of mastery. This condition is demonstrated by various findings from previous studies. The results of a study (Utusan et al., 2023) show that the average score of students was only 51.33. In line with these findings, the results of a study by Yadiannur & Supahar (2017) show that the average score of students was 47.56 (experimental class) and 45.35 (control class). Similar findings were also obtained in the research results of Rambe et al. (2025), which concluded that 43% of students' learning outcomes were still below the established mastery criteria. In addition, the research by Maries et al. (2022) states that the average learning outcomes of students in dynamic electricity material are still far below the established mastery standards. The low learning outcomes of students in dynamic electricity material are due to students still having difficulty in solving linear equation systems (LES) (Fatio et al., 2020). This is in line with the opinion of Antoro et al. (2020), who stated that students still have difficulty solving LES using the substitution-elimination method because it is multi-level and multi-stage. According to Hasanudin et al. (2019), the form of LES can be seen in equation (1) as follows.

$$\begin{aligned} p_1x + q_1y + r_1z &= s_1 \\ p_2x + q_2y + r_2z &= s_2 \\ p_3x + q_3y + r_3z &= s_3 \end{aligned} \quad (3)$$

Methods for solving linear equation systems not only use substitution and elimination methods, but can also be done through a matrix algebra approach. (Figotin, 2020) reveals that dynamic electrical circuits can be solved using Hamiltonian matrices and Jordan analysis. According to Supriadi et al. (2024), the Cayley-Hamilton theorem is one of the matrix algebra methods that can be used to solve two-to-three-loop electrical circuits. In addition, Cramer's rule can also be used to solve 2-loop electrical circuit problems (Rahayu et al., 2023; Supriadi, Arsita, Ni'mah, & Afidah, 2025). The research by Batarius et al. (2021) shows that five-loop electrical circuit problems can be solved using the Gauss–Jordan method to determine the magnitude of the electric current in each loop. This method works by simplifying the system of linear equations formed from the application of Kirchoff's law into a matrix form. In addition, Gauss–Jordan elimination has a relatively small error rate because the row operation calculation steps are carried out systematically in solving the linear equation system (Tran et al., 2020). According to Narhari et al. (2025), the Gauss–Jordan elimination method serves as a mathematical and algorithmic approach in matrix manipulation, especially through the use of elementary row operations. These operations are carried out in several steps: (1) interchanging two rows, (2) multiplying a row by a nonzero constant, and (3) adding to or subtracting from a row another row or its multiples (Supriadi et al., 2025). The steps of the Gauss-Jordan Elimination method according to Jang et al. (2024) are as follows

- a. Express the system of linear equations in equation (3) in matrix multiplication form $A\psi = B$

$$\begin{bmatrix} t_1 & u_1 & v_1 \\ t_2 & u_2 & v_2 \\ t_3 & u_3 & v_3 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix} \quad \dots (4)$$

with $A = \begin{bmatrix} t_1 & u_1 & v_1 \\ t_2 & u_2 & v_2 \\ t_3 & u_3 & v_3 \end{bmatrix}$; $\psi = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$ and $B = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix}$

- b. Converting matrix multiplication (4) into augmented matrices $(A|B)$

$$\begin{bmatrix} t_1 & u_1 & v_1 & | & s_1 \\ t_2 & u_2 & v_2 & | & s_2 \\ t_3 & u_3 & v_3 & | & s_3 \end{bmatrix} \quad \dots (5)$$

- c. Using Elementary Row Operations (ERO), transform the augmented matrix in Equation (5) into an augmented matrix whose main matrix is the identity matrix.

$$\begin{bmatrix} t_1 & u_1 & v_1 & | & s_1 \\ t_2 & u_2 & v_2 & | & s_2 \\ t_3 & u_3 & v_3 & | & s_3 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 0 & 0 & | & a_1 \\ 0 & 1 & 0 & | & a_2 \\ 0 & 0 & 1 & | & a_3 \end{bmatrix} \quad \dots (6)$$

- d. Menentukan Determine variables x , y , and z based on equation (6)

$$x = a_1, y = a_2, \text{ dan } z = a_3. \quad \dots (7)$$

Learning physics in the subject of dynamic electricity requires students to be able to analyze circuits and construct linear equation systems in a logical manner based on the interrelationships between physical quantities (Anisa & Astriani, 2022). However, the learning methods that have been applied so far generally still emphasize the achievement of final results through the substitution-elimination method without building a structural understanding of the resulting equation system. As a result, students have difficulty understanding the relationships between variables, performing mathematical manipulations, and drawing conclusions systematically, so that their mathematical reasoning skills and learning outcomes are still relatively low. Although several studies have examined the matrix algebra approach in solving electrical circuits, the use of the Gauss–Jordan elimination method as a physics learning strategy is still limited (Afriza et al., 2018; Mazur et al., 2023; Wakhid, 2025).

This low ability has an impact on students' weak understanding of physics concepts and problem-solving skills, and is not in line with the demands of 21st-century learning, which emphasizes critical, logical, and systematic thinking skills (Musengimana et al., 2025; Ningsih, 2022). However, most previous studies have focused on computational aspects and have not empirically examined the use of the Gauss–Jordan elimination method as a learning strategy to develop mathematical reasoning skills and learning outcomes in the context of dynamic electricity. In addition, studies integrating this approach at the secondary and higher education levels are still limited. This condition indicates a research gap that needs to be further explored.

Therefore, this study applies the Gauss–Jordan elimination method, which emphasizes the algorithmic process through elementary row operations in solving linear equation systems. Problem solving is carried out through the stages of circuit analysis, equation system formulation, transformation into matrix form, row operations, and interpretation of calculation results. The novelty of this study lies

in the use of the Gauss–Jordan elimination method as an approach to physics learning to develop mathematical reasoning skills and learning outcomes of students and university students in dynamic electricity material. Based on this, this study aims to empirically analyze the effect of applying this method on mathematical reasoning skills and learning outcomes of students and university students by comparing learning achievements between the experimental class and the control class.

RESEARCH METHOD

This research adopted a quantitative approach with a quasi-experimental design employing a posttest-only control group model. The study was carried out at a senior high school and a university in Jember Regency during the odd semester of the 2025/2026 academic year. The participants consisted of 32 students in the control class and 35 students in the experimental class at the senior high school level, as well as 30 college students in the control group and 35 college students in the experimental group. Samples were determined through purposive sampling based on students’ initial abilities and class characteristics. Group assignment was not completely randomized due to constraints in the learning environment. The research design is presented in Figure 1.

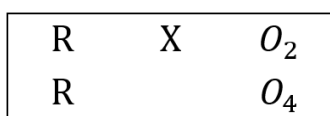


Figure 1 Research Design Source: (Sugiyono, 2018)

Description :

- R : Two randomly selected groups O_2 : Posttest in the experimental class
- X : Treatment O_4 : Posttest in the control class

The research design included two groups, namely the experimental group, which was given treatment using the Gauss–Jordan elimination method, and the control group, which was given learning using the substitution–elimination method. The experimental group received treatment (X) and was given a posttest (O_2), while the control group was given a posttest (O_4). The research instrument used consisted of five essay questions to measure learning outcomes and mathematical reasoning abilities (Sriamanda et al., 2025). Learning outcomes were assessed based on the overall scores obtained by students, while students’ mathematical reasoning abilities in this study were evaluated using four indicators: (1) formulating conjectures; (2) predicting solutions and problem-solving procedures; (3) performing mathematical manipulations; and (4) making conclusions (Gultom et al., 2022). The test instruments were developed based on these indicators and dynamic electricity material, then consulted with two physics education lecturers and one physics teacher to obtain input regarding the suitability of the content, language, and level of difficulty of the questions.

The learning process was carried out over three meetings, each lasting 150 minutes, which were held in November 2025. In the experimental class, teachers and lecturers delivered dynamic electricity material by applying the Gauss–Jordan elimination method in solving linear equation systems. Meanwhile, the control class received learning using the substitution–elimination method. After all treatments were completed, a posttest was given to all students to measure their mathematical reasoning abilities and learning outcomes. The obtained data were then processed using descriptive and inferential statistical analyses with the assistance of SPSS version 25. The Shapiro–Wilk test was applied to assess data normality as a reference for selecting appropriate statistical analysis methods. When the data were normally distributed, the Independent Samples t-test was applied, whereas when the data were not normally distributed, the Mann–Whitney U test was employed with a significance level of 0.05. Both tests were used to examine the effects of mathematical reasoning and learning outcomes (Sugiyono, 2018).

In addition to the tests, a student response questionnaire was used, which was compiled based on five indicators, namely interest, motivation, readability, satisfaction, and response, using a five-point Likert scale, as shown in Table 1.

Table 1 Criteria for Response Score

Criteria	Score
Strongly agree	5
Agree	4
Undecided	3
Disagree	2
Strongly disagree	1

(Source: Mawaddah & Anisah (2015))

Data from the student response questionnaire will be converted into percentages as shown in the following equation with the categories in Table 2.

$$Percentage = \frac{Total\ score\ obtained}{Highest\ score} \times 100\% \quad \dots (8)$$

Table 2 Category of Response Result Percentage

Percentage (%)	Category
$80\% < P \leq 100\%$	Very positive
$60\% < P \leq 80\%$	Positive
$40\% < P \leq 60\%$	Fairly positive
$20\% < P \leq 40\%$	Less positive
$0\% < P \leq 20\%$	Not very positive

(Source: Supriadi, et al. (2025))

The strength of this study is supported by a relatively adequate sample size in each group and values that indicate a moderate to high effect of the treatment, giving the results a sufficient level of confidence.

RESULTS AND DISCUSSION

The application of the Gauss-Jordan elimination method in solving dynamic electrical circuit problems is demonstrated in solving the 2-loop electrical circuit problem in Figure 2. Figure 2 shows a 2-loop electrical circuit consisting of 2 voltage sources ($E_1 = 24\text{ V}$ dan $E_2 = 10\text{ V}$) dan 3 resistors ($R_1 = 4\ \Omega$, $R_2 = 2\ \Omega$, dan $R_3 = 6\ \Omega$).

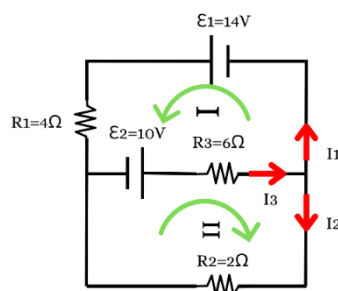


Figure 2 Two-Loop Electrical Circuit

The magnitude of the electric currents (i_1, i_2 dan i_3) flowing in the circuit can be determined based on the application of Kirchoff's 1st and 2nd laws. Based on Kirchoff's laws and the loop rule, the LES is obtained as follows

$$\begin{aligned} I_1 + I_2 - I_3 &= 0 \\ 4I_1 + 6I_3 &= 24V \\ 2I_2 + 6I_3 &= 10V \end{aligned} \quad \dots (9)$$

The steps of the Gauss-Jordan elimination method in solving equation (9) are as follows:

a. Write the SPL in the matrix multiplication equation $A\psi = B$

$$\begin{bmatrix} 1 & 1 & -1 \\ 4 & 0 & 6 \\ 0 & 2 & 6 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 24 \\ 10 \end{bmatrix} \quad \dots (10)$$

$$\text{with } A = \begin{bmatrix} 1 & 1 & -1 \\ 4 & 0 & 6 \\ 0 & 2 & 6 \end{bmatrix}; \psi = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} \text{ and } B = \begin{bmatrix} 0 \\ 24 \\ 10 \end{bmatrix}$$

b. Transforming equation (10) into an augmented matrix

$$\left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 4 & 0 & 6 & 24 \\ 0 & 2 & 6 & 10 \end{array} \right] \dots (11)$$

c. Through elementary row operations (ERO), transform the augmented matrix into a reduced row echelon matrix

$$\begin{aligned} & \left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 4 & 0 & 6 & 24 \\ 0 & 2 & 6 & 10 \end{array} \right] \xrightarrow{B_2-4B_1} \left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 0 & -4 & 10 & 24 \\ 0 & 2 & 6 & 10 \end{array} \right] \xrightarrow{\frac{1}{4}B_2} \left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 0 & 1 & -2,5 & -6 \\ 0 & 2 & 6 & 10 \end{array} \right] \xrightarrow{B_3-2B_1} \left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 0 & 1 & -2,5 & -6 \\ 0 & 0 & 11 & 22 \end{array} \right] \\ & \xrightarrow{B_1+B_3} \left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 0 & 1 & -2,5 & -6 \\ 0 & 0 & 11 & 22 \end{array} \right] \xrightarrow{\frac{1}{11}B_3} \left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 0 & 1 & -2,5 & -6 \\ 0 & 0 & 1 & 2 \end{array} \right] \xrightarrow{B_2+2,5B_3} \left[\begin{array}{ccc|c} 1 & 1 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 2 \end{array} \right] \\ & \xrightarrow{B_1+B_3} \left[\begin{array}{ccc|c} 1 & 1 & 0 & 2 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 2 \end{array} \right] \xrightarrow{B_1-B_2} \left[\begin{array}{ccc|c} 1 & 0 & 0 & 3 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 2 \end{array} \right] \end{aligned}$$

a. Using the definition from equation (7), we obtain $I_1 = 3A, I_2 = -1A, \text{ dan } I_3 = 2A$... (12)

Mathematical reasoning skills

In this study, mathematical reasoning ability was assessed through four indicators, namely: (1) formulating conjectures; (2) predicting solutions and problem-solving procedures; (3) performing mathematical manipulations; and (4) making conclusions (Gultom et al., 2022). The scores for mathematical reasoning ability and student and university student learning outcomes were obtained through tests. Table 3 is a recapitulation of the mathematical reasoning abilities of the control and experimental classes for both students and university students.

Table 3 Mathematical Reasoning Ability Score Data

Indicator	Students				College Students			
	Control Group		Experiment Group		Control Group		Experiment Group	
	Score	Average	Score	Average	Score	Average	Score	Average
1	1204	37.6	2788	79.6	634.5	19.8	1445.5	45.2
2	1376	43	2648	75.6	535.5	16.7	1544.5	48.3
3	1048	32.7	2408	68.8	528	16.5	1552	48.5
4	732	22.9	1616	46.2	528	16.5	1552	48.5

Based on the information in Table 4, the results show that students in the experimental group had better mathematical reasoning skills than those in the control group on all indicators measured. The scores in the experimental group ranged from 46.2 to 79.6, while those in the control group only reached 22.9 to 43. The normality test showed that the student data was normally distributed, so it was analyzed using the Independent Samples t-test, while the university student data was analyzed using the Mann–Whitney U test. The t-test results showed significant differences in all indicators with a p-value < 0.05. Similarly, the Mann–Whitney test produced a significance value (2-tailed) of 0.000, indicating a statistically significant difference between the two groups.

Table 4 Results of T-tests for Each Indicator of Students' Mathematical Reasoning

No	Variance	Levene's Test for Equality of Variance		Independent Samples Test t-test for Equality of Means						
		F	Sig	t	df	Sig (2-tailed)	Mean Diff	Std Error	95% Confidence interval of the Difference	
									Lower	Upper
1	Equal assumed	.074	.787	-	65	.000	-	5.240	-	-
	Not assumed			9.095	64.907	.000	47.657	5.227	58.122	37.192
2	Equal assumed	24.716	.000	-	65	.000	-	3.869	-	-
	Not assumed			8.440	51.807	.000	32.657	3.769	40.385	24.930
3	Equal assumed	7.316	.009	-	65	.000	-	4.250	-	-
	Not assumed			8.483	58.138	.000	36.050	4.168	44.537	27.563
4	Equal assumed	19.311	.000	-	65	.000	-	5.431	-	-
	Not assumed			4.289	48.532	.000	23.296	5.272	34.143	12.450

Table 5 shows that all the indicators checked, such as namely formulating conjectures, predicting solutions and problem-solving procedures, performing mathematical manipulations, and making conclusions in the student category, had a significant value (two-tailed) less than 0.05. These results show that there are big differences between the experimental group and the control group in every existing measure. So, these results show that using the Gauss–Jordan method in the experimental class makes a noticeable difference in students' math reasoning skills compared to the substitution–elimination method used in the control class, across all four measures.

Table 5 Mann-Whitney Test Results for Each Indicator of Students' Mathematical Reasoning Ability

	Proposing conjectures	Predicting answers and the solution process	Mathematical manipulation	Making Conclusions
Mann-Whitney U	106.500	7.500	.000	.000
Wilcoxon W	634.500	535.500	528.000	528.000
Z	-6.067	-7.200	-6.899	-6.909
Asymp. Sig. (2-tailed)	.000	.000	.000	.000

Based on the Mann–Whitney test results in Table 5, the Asymp. Sig. (2-tailed) value was 0.000 (< 0.05) for all indicators, namely proposing conjectures, predicting answers and solution processes, mathematical manipulation, and drawing conclusions. These results indicate that there are differences between the control class and the experimental class in each indicator of students' mathematical reasoning abilities. Thus, the treatment given to the experimental class using the Gauss-Jordan method to solve dynamic electricity problems had an effect on students' mathematical reasoning abilities compared to the control class, which used the substitution-elimination method to solve dynamic electricity problems.

Proposing conjectures

Making conjectures is the ability of students to write down known mathematical symbols and their units and to rewrite the questions asked in the problems. Gultom et al. (2022) stated that the indicator

of making conjectures is the ability of students to write down what is known and what is asked according to the information provided in the problems. Students who consistently write down the facts from the question are better able to proceed to the next stage (Warae et al., 2023). The results of the students' work are presented in Figure 3 as follows:

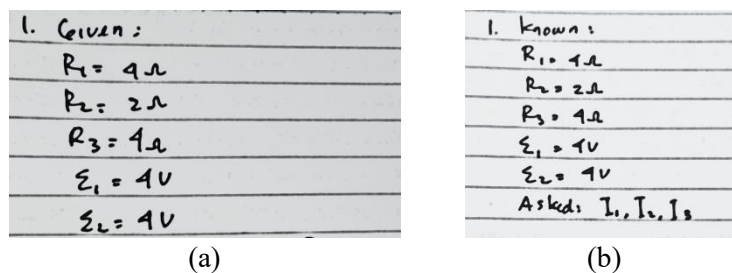


Figure 3 (a) Control Class by AD, (b) Experimental Class by MMF

In part (a), students in the control class only wrote down known information, while others did not write down any information or answer the questions asked. This was because students in the control class were not accustomed to writing down known information or answering questions. Meanwhile, in section (b), students wrote down the information completely. Although the indicator of proposing a conjecture using the Gauss-Jordan elimination method did not have a direct effect, the students in the experimental class were aware of the need to write down what was known and asked because it greatly affected the ease of completing the next stage. This is in line with the results of research by Bayat & Tarmizi (2010), which concluded that a learning approach that emphasizes awareness of one's own thinking process (metacognitive awareness) can help students be more effective in identifying initial information and planning steps for completion. The research by Kabael & Akin (2016) states that the Gauss–Jordan elimination method has the advantages of being algorithmic, systematic, and transparent in each stage of the solution, thus helping students build a coherent line of thinking from the initial stage to the final solution. By transforming the system of linear equations into reduced echelon matrix form, students can see the relationship between variables more clearly without having to perform repeated substitutions, which are often a source of algebraic errors (Lay et al., 2016). This approach encourages accuracy, procedural consistency, and awareness of the importance of writing down complete initial information as a basis for mathematical decision-making in the next stage. Gauss–Jordan elimination not only improves the accuracy of solving linear equation systems, but also contributes positively to mathematical reasoning and conjecture-making abilities because students become accustomed to following logical and structured solution patterns (Mufid, 2023). These findings reinforce the results of the Mann–Whitney test and the independent sample t-test, which show that there is a significant difference between the two classes in terms of the indicator of proposing conjectures.

Predicting answers and the solution process

Predicting answers and the solution process is the ability of students to describe the electrical circuit asked in the question by assuming the direction of the electric current and being able to arrange the resulting linear equations. According to (Gultom et al., 2022) students are considered to have fulfilled the indicator of predicting answers and solution processes well when they are able to correctly sketch and label the symbols in the question. In line with the opinion of Nuraini et al. (2024) students are considered to have fulfilled the indicator when they are able to present information in the form of accurate drawings. The results of the students' work are presented in Figure 4 as follows:

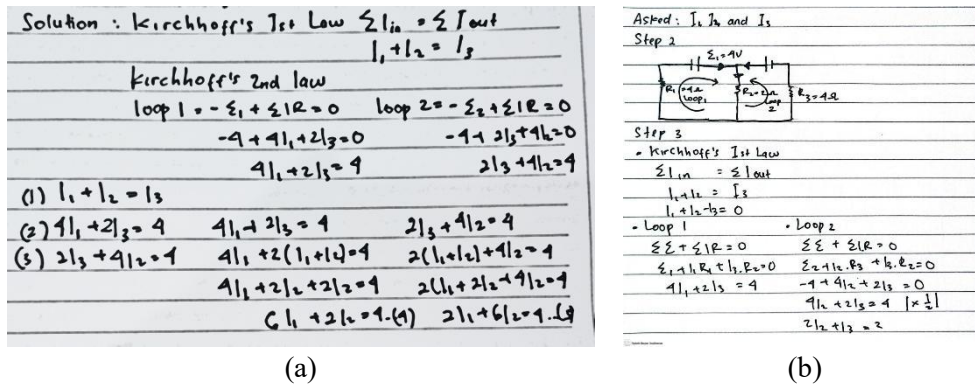


Figure 4 (a) Control Class by DSM, (b) Experimental Class by DHP

Figure 4 shows that students in the control class in part (a) only analyzed linear equations and some of them did not complete their flow analysis. This is because in the control class, using the elimination substitution method, students were not required to draw or analyze completely, as the elimination substitution method only required them to be able to operate rows. Research by Febrianty et al. (2024) shows that the procedural approach in solving LES tends to focus on algebraic manipulation skills rather than problem modeling. Meanwhile, in part (b) of the experimental class, students must find and analyze the flow sequentially and then write the results in LES and convert them into matrix multiplication equations. The advantage of the Gauss–Jordan elimination method is evident in its ability to accustom students to conducting a sequential initial analysis before entering the mathematical manipulation stage (Ilmi et al., 2023). In solving dynamic electrical problems, this method requires students to draw circuits, analyze the current in each branch, and systematically compile LES before representing it in matrix form (De Cock, 2012). This procedure encourages students to predict answers and plan their solution steps in a more focused manner, as each stage is interrelated and cannot be skipped (Simamora, 2021). Overall, these findings reinforce the results of the Mann–Whitney test and the independent samples t-test, which show significant differences between the two classes in terms of indicators predicting answers and the completion process.

Mathematical manipulation

Mathematical manipulation in this study refers to students' ability to solve linear problem systems from the results of flow analysis. In line with the opinion of Warae et al. (2023), mathematical manipulation ability is the ability of students to answer questions according to the specified steps correctly. The results of the students' work are presented as follows.

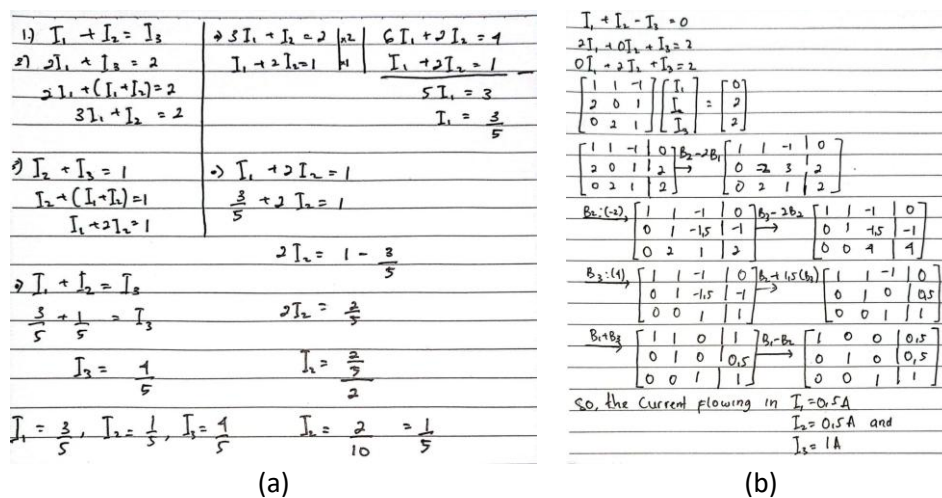


Figure 5 (a) Control Class by SL, (b) Experimental Class by GNR

Figure 5 shows that the control class students in part (a) still made mistakes in calculating between variables. The elimination substitution method requires a thorough understanding of the relationship

between variables. When students made mistakes in their calculations, the results obtained were inaccurate. Meanwhile, the experimental class students in part (b) completed most of the steps correctly. It can be seen that students perform calculations in a structured manner. In the Gauss-Jordan elimination method, students only perform row operations using basic mathematical skills to complete the pattern that has been set. In this method, students are not required to understand the relationships between variables as in the substitution-elimination method, but rather to consistently apply basic mathematical operations according to the matrix solution pattern. In line with Duval (2006) opinion, the Gauss-Jordan method minimizes calculation errors and improves procedural accuracy, as reflected in the more structured and systematic quality of the experimental class students' answers. The procedural nature of the Gauss-Jordan elimination method is in line with Santia et al. (2019) view of algorithmic-oriented mathematics learning, in which students can solve problems by applying procedural steps without first having to build a relational understanding between mathematical objects. A number of studies show that Gauss-Jordan elimination effectively improves the accuracy of calculations and the quality of the process of solving linear equation systems because it provides a clear and easy-to-follow solution flow, both in the context of mathematics learning and its application to physics problems (Bollen et al., 2017; Simamora, 2021). In line with the opinion of Siahaan et al. (2023), the Gauss-Jordan method minimizes calculation errors and improves procedural accuracy, as reflected in the more structured and systematic answers given by students in the experimental class. The procedural nature of the Gauss-Jordan elimination method is in line with the view (Smith & Powell, 2015) of algorithmic-oriented mathematics learning, where students can solve problems by applying procedural steps without having to first. From the two answers, the quality of the experimental class's work was better, so that both classes had a significant effect, in line with the Mann-Whitney test results.

Making Conclusions

Drawing conclusions in this study is the ability of students to rewrite the results obtained in a series of electrical currents. Students are considered capable of drawing conclusions when they are able to correctly rewrite the results of their answers (Gultom et al., 2022). In line with the opinion of Warae et al. (2023) mastery of this indicator is important because drawing conclusions is a form of students' final understanding of the problems solved. The results of the mathematical manipulation indicator by the control class and experimental class students are shown in Figure 6.

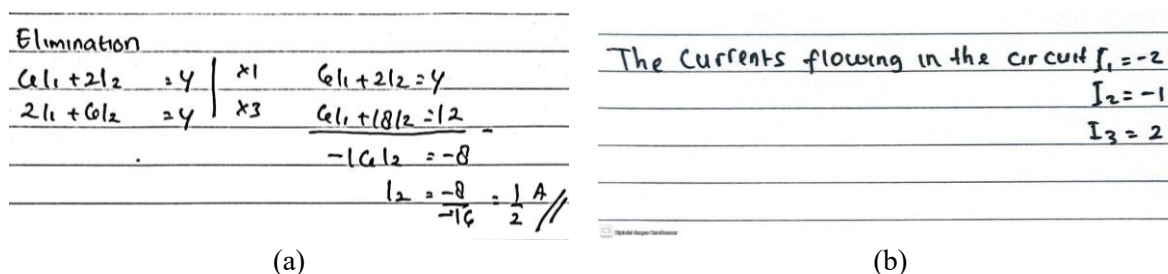


Figure 6 (a) Control Class by KHG, (b) Experimental Class by DK

Figure 6 shows that students in the control class (a) tended to simply draw lines on the calculations obtained, meaning that they were not aware of the need to write down the results. Meanwhile, students in the experimental class (b) were able to repeat the calculation results obtained completely and correctly. This is because the calculation results obtained are still presented in matrix form so that students are aware of rewriting the calculation results by writing conclusions to reaffirm the calculation results obtained. In addition, the experimental class students obtained structured calculation results so that it was easier for them to see the magnitude of the values between the results obtained. This finding is in line with Duval's (2006) opinion, which states that structured mathematical representations, such as matrices, help students reinterpret calculation results and express them in meaningful conclusions. A similar point was also made by Simamora (2021), who emphasized that presenting solutions systematically can improve students' accuracy in writing down the final results of their work. However, the comparison between the two classes was still very low, because students were not accustomed to restating the results they had obtained. According to research by (Jufri et al., 2021), students still rarely write conclusions because they are not

accustomed to drawing conclusions after completing calculations. Therefore, the ability to write conclusions still needs to be improved in both the control and experimental classes.

Learning Outcomes

In addition to examining mathematical reasoning skills in solving dynamic electrical circuit problems, this study also analyzes the differences in learning outcomes between high school students and university students. A summary of the learning outcomes of high school students and university students is presented in the following table 6.

Table 6 Learning Outcome Data

Group	Class	Number of Samples	Maximum Score	Total Score	Average
Student	Control	32	3200	936	29.25
	Experimen	35	3500	2197.6	62.8
College Student	Kontrol	30	3000	1301	43.38
	Experimen	35	3500	3119.5	89

Student and college student learning outcome data are summarized in Table 6. The mean score of students in the experimental class reached 62.8, which was higher than that of the control class at 29.25. Meanwhile, among college students, the experimental group obtained an average score of 89, compared to 43.38 in the control group. The results of the Independent Samples t-test for the student group produced a significance value of 0.000 (< 0.05), indicating a statistically significant difference in learning outcomes between the two groups. In addition, the Mann–Whitney test for the student group also yielded an Asymp. Sig. value of 0.000 (< 0.05). These findings demonstrate that the implementation of the Gauss–Jordan elimination method had a significant impact on students’ learning outcomes.

Table 7 Independent Sample t-Test Results of Student Learning Outcomes

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Student Learning Outcomes	Equal variances assumed	16.036	.000	-9.883	65	.000	-33.5386	3.4916	-40.5118	-26.5653
	Equal variances not assumed			-9.883	49.727	.000	-33.5386	3.3934	-40.3553	-26.7218

Based on the results of the Independent Samples t-test on student learning outcome data, a significance value (Sig. 2-tailed) of 0.000 < 0.05 was obtained, indicating a statistically significant difference between the experimental and control classes. The Levene test yielded a Sig. value of 0.000, showing that the variances between the two groups were not homogeneous; therefore, the interpretation of the mean difference was based on the “equal variances not assumed” row. In this row, a t value of -9.883 with $df = 49.727$ and a mean difference of -33.54 was obtained, demonstrating that the experimental class achieved higher average learning outcomes than the control class. These findings confirm that the learning treatment applied to the experimental class had a significant effect on enhancing learning outcomes in dynamic electricity material involving two-loop circuits.

Table 8 Mann-Whitney Test Results College Students' Learning Outcomes

Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
.000	528.000	-6.915	.000

The Mann–Whitney test results for the student group produced an Asymp. Sig. (2-tailed) value of $0.000 < 0.05$, indicating a statistically significant difference in learning outcomes between the experimental and control classes. Furthermore, the analysis revealed that learning outcomes differed significantly between the experimental and control groups in both the student and undergraduate categories. The difference in mean scores indicates that students in the experimental class have better abilities in solving dynamic electrical problems through more accurate, consistent, and systematic solution procedures. Dynamic electrical problems require skills in representing circuits visually, analyzing the direction and magnitude of electric current, and modeling the analysis results into a system of linear equations (Tuveri et al., 2026). Therefore, a mathematically structured solution approach is needed so that the problem-solving process can be carried out effectively (Docktor & Mestre, 2014; Nirmala & Ganesan, 2021).

Learning in experimental classes that apply the Gauss–Jordan elimination method provides a clear and systematic solution framework (Venkatesham, 2025). This method allows students to arrange problems into matrix form and obtain the final solution directly without going through a process of repeated substitution. The explicit solution flow helps students reduce procedural errors and increase efficiency in solving linear equation systems (Gilmore, 2023). These findings are in line with the research by Lay et al. (2016), which states that matrix methods, including Gauss–Jordan elimination, are effective in solving complex linear equation systems because they are algorithmic and consistent. In addition, a matrix-based mathematical approach in science learning has been proven to improve students' ability to organize numerical information and increase calculation accuracy (Bollen et al., 2017). In contrast, the control class that used the substitution and elimination methods tended to encounter errors, especially when the problems involved more than two variables. This is in line with the results of a study (Kabael & Akin, 2017) which states that the substitution-elimination method is less efficient because it is prone to algebraic errors.

Higher learning outcomes in the experimental class reflect the success of students in applying systematic solution procedures, thereby maintaining an optimal understanding of physics concepts, including dynamic electrical circuits (Burde & Wilhelm, 2020). In this context, students are required to be able to relate physical quantities to mathematical models in the form of linear equation systems. When the solution method used has a clear and consistent structure, such as Gauss–Jordan elimination, the mathematical representation process becomes easier to understand and contributes directly to strengthening the understanding of physics concepts. These findings are consistent with research confirming that mastery of basic mathematics plays an important role in improving conceptual understanding and learning outcomes in physics (Baily et al., 2015). The findings of this study confirm the novelty of the study by positioning the Gauss–Jordan elimination method not only as a mathematical computational tool, but as an integrated pedagogical approach in physics learning to develop mathematical reasoning skills and improve student learning outcomes.

Response

Student responses were obtained through questionnaires after students learned about solving Dynamic Electricity problems using the Gauss–Jordan method in the context of Linear Equation Systems. Based on the analysis of response data for five indicators in Table 9.

Table 9 Average Response Percentage for Each Indicator

No	Indicator	Average Response Percentage	Response Criteria	Average Category
1	Interest	77.5%	Positif	
2	Motivation	73.1%	Positif	
3	Satisfaction	74.4%	Positif	75.88%
4	Awareness	76.3%	Positif	
5	Response	73.1%	Positif	

The results of the student response questionnaire analysis show that the average response percentage for the five indicators is in the positive category, with a value of 75.88%. The interest indicator received the highest percentage of 77.5%, while the motivation and response indicators received a percentage of 73.1%. These results indicate that students responded positively to the application of the Gauss–Jordan elimination method in dynamic electricity learning. The detailed explanation is as follows.

Indicator of Interest

The interest indicator received a positive response from students with an average percentage of 77%. This shows that participants were interested, enthusiastic about learning, and enjoyed solving dynamic electricity problems using the Gauss–Jordan method. The structured and systematic nature of instructional methods that guide students through clear and sequential steps has been shown to reduce extraneous cognitive load and support meaningful learning, which in turn can improve engagement and motivation in problem-solving tasks (Evans et al., 2024). The average student response based on the five answer categories on the interest indicator is distributed in the following diagram figure 7.

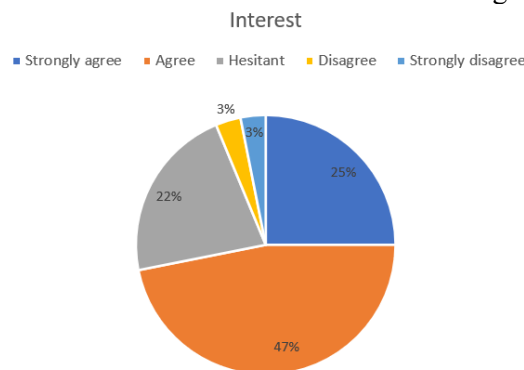


Figure 7 Percentage Diagram of Interest Indicators

Motivation Indicator

In Figure 8, the dominance of the agree and strongly agree categories (69%) shows that students feel motivated, more enthusiastic, and internally driven to work on Dynamic Electricity problems using the Gauss–Jordan method. Meanwhile, the relatively small percentage of “unsure,” “disagree,” and “strongly disagree”. Recent research emphasizes that instructional approaches designed to provide clear, structured guidance and feedback enhance students’ motivation and engagement, particularly in complex problem-solving tasks (Hariri et al., 2021). The interest indicator received a positive response from students, with the following percentage distribution:

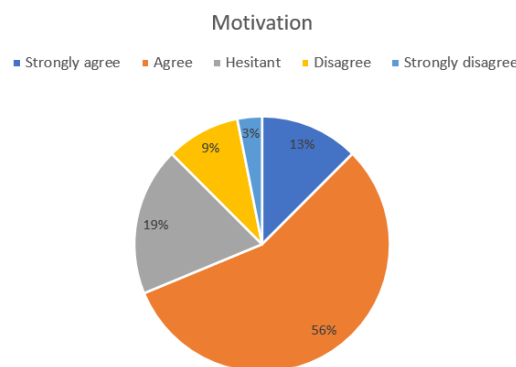


Figure 8 Percentage Diagram of Motivation Indicators

Satisfaction Indicators

In Figure 9, the dominance of the agree and strongly agree categories (75%) shows that students have a high interest in using the Gauss–Jordan method to solve Dynamic Electricity and LES problems in other physics subjects. Meanwhile, the relatively small percentage of “unsure,” “disagree,” and “strongly disagree” responses indicates that only a small number of students are not yet fully confident or accustomed to applying this method, and therefore still require additional explanation and practice.

Studies in science education highlight that students' satisfaction with instructional methods is strongly connected to clarity of presentation, relevance of activities, and perceived usefulness in solving problems, which in turn contribute to lasting engagement and academic confidence (Teig, et al., 2022). Students responded positively to the satisfaction indicator, as indicated by the percentage below:

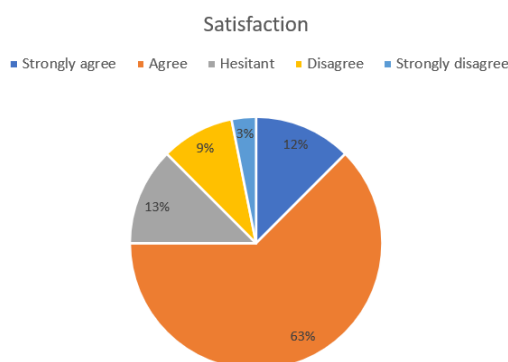


Figure 9 Percentage Diagram of Satisfaction Indicators

Awareness Indicator

The Awareness indicator shows a positive response to the use of the Gauss–Jordan method in solving Dynamic Electricity problems. Students feel that this method suits their needs and helps them solve problems more freely, while a small number of students still require further assistance. Recent studies in physics education highlight that students' positive perceptions of instructional methods, including their relevance and clarity, are closely associated with meaningful engagement and learning responses (Jeong et al., 2025). Research also suggests that when instructional approaches reduce unnecessary cognitive burden and support structured learning, students are more likely to accept and respond favorably to those methods, contributing to higher satisfaction and positive learning attitudes (Cairns, 2025). Therefore, the positive awareness and response shown in this study align with trends in current educational research. Indicators of response show positive reactions from students, as reflected in the following percentage distribution:

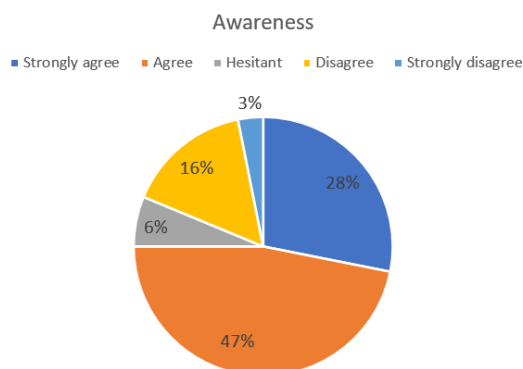


Figure 10 Diagram of Awareness Indicator Percentage

Response Indicator

The response indicator shows positive results, which means that most students responded well to the use of the Gauss–Jordan method in Dynamic Electricity material. This can be seen in the dominance of the agree and strongly agree categories in Figure 11, which illustrates the distribution of students' responses to the response indicator.

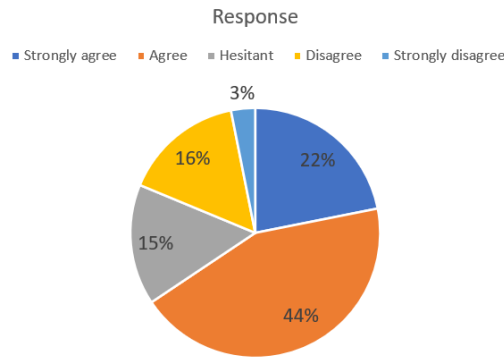


Figure 11 Response Indicator Percentage Diagram

According to the results of students’ response analysis after learning Dynamic Electricity problem solving using the Gauss–Jordan method in the context of Linear Equation Systems, it can be concluded that this method received positive responses from students on all indicators assessed, namely interest, motivation, satisfaction, enthusiasm, and response. This indicating that the structured and algorithmic nature of the method supports students’ understanding of physics concepts involving linear equation systems. Contemporary research suggests that satisfaction with well-structured learning approaches correlates with positive attitudes toward future learning and increased willingness to apply the method in broader contexts (Berger et al., 2020). These findings support the positive satisfaction responses demonstrated in this study.

These findings are consistent with previous studies reporting that instructional strategies integrating mathematical structure and guided problem solving. Additionally, recent studies in educational sciences underscore the evolving role of cognitive load theory in optimizing instructional materials and sequencing to enhance learning efficiency, engagement, and overall task interest (Ouwehand et al., 2025). These findings support the view that the structured application of the Gauss–Jordan method can effectively foster students’ interest and engagement in physics problem-solving activities. Similar research has emphasized the importance of reducing extraneous cognitive load through clear procedural guidance to support conceptual understanding and positive learning experiences. The novelty of this study lies in the integration of the Gauss–Jordan elimination method as a pedagogical approach in Dynamic Electricity learning, not merely as a mathematical computation technique. By explicitly connecting linear equation systems with physics problem-solving processes, this study demonstrates how mathematical algorithms can be transformed into effective instructional strategies that strengthen the relationship between mathematical representations and physics concepts.

CONCLUSION

Based on the results of the research and discussion, it can be concluded that the application of the Gauss–Jordan elimination method has a significant effect on the mathematical reasoning abilities and learning outcomes of students and university students in dynamic electricity material. The experimental class showed higher achievements than the control class in all mathematical reasoning indicators, as well as better learning outcomes than the substitution-elimination method. These findings indicate that the algorithmic and structured approach through the Gauss–Jordan elimination method can strengthen the connection between understanding physics concepts and mathematical representations, and confirms its role as an effective pedagogical approach, not merely a computational tool. This study provides empirical contributions to the development of physics learning strategies based on the systematic solution of linear equation systems. Therefore, teachers and lecturers are advised to integrate this method into the learning of dynamic electricity and other relevant physics materials, and further research needs to examine its application in a broader context and sample.

ACKNOWLEDGMENTS

The authors would like to thank everyone who has contributed to the completion of this research. This research was funded by the Thesis Reworking Grant, Institute for Research and Community Service, University of Jember.

AUTHOR CONTRIBUTIONS

Conceptualization, Author 1 and Author 2; methodology, Author 1, Author 3, and Author 4; formal analysis, Author 1, Author 4, and Author 5; investigation, Author 2, Author 3, and Author 6; data curation, Author 3, Author 4, and Author 7; writing—original draft preparation, Author 1, Author 5, and Author 6; writing—review and editing, Author 2, Author 5, and Author 7; visualization, Author 6 and Author 7; supervision, Author 1 and Author 2; project administration, Author 2. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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