

Effect of experiential learning on students' conceptual understanding and collaborative skills in linear equation systems

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Received: Apr 1, 2026 | Revised: Aug 31, 2026 | Accepted: Sept 7, 2026 | Published Online:
Sept 28, 2026

Abstract

This study addresses the need for instructional approaches that integrate conceptual understanding with collaborative competencies in 21st-century education. Specifically, it examines the effects of experiential learning on students' conceptual understanding and collaborative skills concerning Systems of Linear Equations in Two Variables (SLETV). A quasi-experimental nonequivalent control group design was employed, involving 64 ninth-grade students divided equally into a control group ($n = 32$) and an experimental group ($n = 32$). Data were collected using a conceptual understanding test and a collaborative skills questionnaire, both of which demonstrated acceptable validity and reliability. Data analysis included independent-samples t-tests, paired-samples t-tests, and multivariate analysis of variance (MANOVA). The results indicated significant differences between the groups, with the experimental group exhibiting higher posttest scores in both conceptual understanding and collaborative skills. Furthermore, MANOVA confirmed a significant multivariate effect (Wilks' Lambda = 0.751, $F = 10.090$, $p < 0.001$), showing substantial improvements in both conceptual understanding ($F = 19.766$, $p < 0.001$) and collaborative skills ($F = 4.408$, $p = 0.040$). Ultimately, students who engaged in experiential learning outperformed their peers receiving conventional instruction. These findings highlight the efficacy of experiential learning in simultaneously fostering mathematical comprehension and collaborative competencies in junior high school mathematics.

Keywords: experiential learning; conceptual understanding; collaborative; SLETV

How to Cite: Rizbudiani, A.D., Wardhani, N.K., & Wulandari, A.T. (2026). Effect of experiential learning on students' conceptual understanding and collaborative skills in linear equation systems. *Aksioma: Jurnal Matematika dan Pendidikan Matematika*, 17 (2), 187-202. <https://doi.org/10.26877/2djdzk74>

INTRODUCTION

Twenty-first-century education demands learning models that not only emphasize the mastery of subject matter (Avdiu et al., 2025; Permatasari et al., 2025), but also foster the development of critical thinking, collaboration, and creativity (Thornhill-Miller et al., 2023). Mathematics plays a crucial role in this context, requiring a conceptual understanding that goes beyond rote memorization. Students must grasp underlying principles, recognize relationships between concepts, and apply them to novel situations (Moghees and Dogar, 2022). Conceptual understanding refers to the ability to comprehend and apply fundamental principles in depth rather than merely memorizing formulas (Anderson and Krathwohl, 2001). To achieve these cognitive outcomes and

apply their knowledge in real-world contexts (Rogers, 2021), students are also expected to develop strong collaborative skills, allowing them to work effectively with both peers and teachers (Alzubi et al., 2024). Collaborative learning facilitates this by having two or more students work together, exchange ideas, and solve problems collectively (Ansari and Naseer, 2024; Greenstein, 2012; Lu and Smiles, 2022).

Systems of Linear Equations in Two Variables (SLETV) represent a fundamental mathematical topic with direct relevance to everyday life, such as calculating prices, determining profits, or comparing costs (Cahyana et al., 2024; Rahim et al., 2025). Mastering this topic requires connecting ideas and utilizing logical reasoning to solve a wide range of contextual problems (Moghees and Dogar, 2022). However, many students encounter difficulties when solving SLETV problems due to limited conceptual understanding, low accuracy, and challenges in translating word problems into mathematical expressions (Masiani et al., 2024; Sundary et al., 2022). Students often struggle to understand the problem context, identify relevant information, construct mathematical models, and apply appropriate solution procedures. Because mathematics requires a logical and systematic sequence of reasoning, errors occurring at a single step can significantly compromise the final result (Gumelar and Afrilianto, 2021). Consequently, insufficient mastery of SLETV can lead to recurring errors and hinder students' ability to comprehend more advanced mathematical topics (Rahim et al., 2025).

These literature-based assertions are corroborated by preliminary observations and interviews conducted at a junior high school in Central Java, Indonesia. An interview with a mathematics teacher indicated that students' communication and collaborative skills remained limited, partly due to the predominance of conventional instructional practices and the underutilization of interactive learning media. The teacher also reported that students tended to participate passively during learning activities, particularly when tasks required discussion and peer cooperation. These preliminary findings suggest a critical need for instructional practices that provide greater opportunities for active participation, interaction, and collaborative problem-solving.

This condition highlights the necessity for learning approaches that transcend procedural mastery to emphasize the co-development of collaborative skills and contextual understanding. Traditional approaches that prioritize memorization often prevent students from connecting mathematical concepts to real-life contexts (Alam,

2024). In this regard, experiential learning offers a promising solution through a learning cycle based on direct experience. The experiential learning theory developed by Kolb (2015) emphasizes learning through four cyclical stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Through this process, students engage in concrete experiences, reflect on them, construct abstract concepts, and apply them to new situations (Hakima and Hidayati, 2020). This cycle not only helps students solve SLETV problems but also cultivates their ability to discuss, collaborate, and appreciate diverse problem-solving strategies within group settings.

Recent curriculum policy changes in Indonesia further reinforce the importance of such integrative approaches. Starting from the 2025/2026 academic year, the curriculum framework shifts towards the *Profil Lulusan 8 Dimensi* (8-Dimensional Graduate Profile), replacing the previous iteration to more strongly emphasize the holistic development of both academic competencies and student character (Adha and Marmoah, 2025). This policy direction underscores the importance of learning experiences that simultaneously develop cognitive knowledge and interpersonal collaboration. Experiential learning is highly relevant to SLETV instruction in this context, as its cyclical nature enables the development of conceptual mathematical understanding and collaborative competencies within the same instructional process.

The concept of experiential learning has been widely explored across various educational contexts. Previous studies have demonstrated its effectiveness in enhancing communication skills among elementary school students (Nurchayaningsih et al., 2024; Suleman, 2024), improving mathematical communication through ELT-based worksheets (Hayati et al., 2025), increasing academic achievement in primary education (Umkabu and Lestari, 2023), fostering interest in biology (Nuraeni and Karmana, 2025), strengthening critical thinking (Simbolon et al., 2025), and improving conceptual understanding of global warming topics (Mufida and Qosyim, 2020). Taken together, these studies suggest that experiential learning effectively supports both cognitive and non-cognitive outcomes. However, previous research has predominantly examined these outcomes separately and focused largely on elementary education or subjects outside of junior high school mathematics. Thus, the extent to which experiential learning can simultaneously enhance conceptual understanding and collaborative skills in junior high school mathematics remains insufficiently established.

This research gap is particularly relevant to SLETV, which demands that students understand abstract concepts, translate contextual situations into mathematical representations, communicate reasoning, and compare solution strategies. Examining conceptual understanding and collaborative skills simultaneously is crucial because successful SLETV mastery involves both the internal construction of mathematical knowledge and external interaction with others. The present study addresses this gap by investigating the effects of experiential learning on both outcomes within the same instructional context among junior high school students.

The potential of experiential learning to achieve these dual outcomes can be explained through Kolb's (2015) framework. In the *concrete experience* stage, students engage directly with contextual problems, providing opportunities to connect mathematical ideas with meaningful experiences while interacting with peers (Rahmi, 2024). During *reflective observation*, students evaluate and discuss their experiences, deepening their conceptual understanding while strengthening collaborative skills through the exchange of diverse perspectives (Morris, 2019; Rahmi, 2024). In the *abstract conceptualization* stage, students formulate general mathematical principles from their reflections, a process that supports structured understanding while allowing them to refine ideas through group interaction (Jäder and Johansson, 2025). Finally, *active experimentation* enables students to apply constructed concepts to new contextual problems, test strategies, and revise solutions collaboratively (Lin et al., 2025). Through this cycle, experiential learning provides a robust theoretical basis for integrating cognitive development with collaborative engagement.

Accordingly, this study aims to examine the effects of experiential learning on students' conceptual understanding and collaborative skills in Systems of Linear Equations in Two Variables at the junior high school level. Specifically, this study addresses the following research questions: (1) Does experiential learning significantly affect students' conceptual understanding of SLETV? (2) Does experiential learning significantly affect students' collaborative skills? and (3) Does experiential learning produce a significant multivariate effect on students' conceptual understanding and collaborative skills simultaneously?

Based on the theoretical framework and previous findings, the hypotheses are formulated as follows: H1: Experiential learning has a significant effect on students'

conceptual understanding, H2: Experiential learning has a significant effect on students' collaborative skills, H3: Experiential learning has a significant multivariate effect on students' conceptual understanding and collaborative skills simultaneously.

METHODS

This study employed a quasi-experimental design to examine the effect of an experiential learning approach on students' conceptual understanding and collaborative skills in Systems of Linear Equations in Two Variables (SLETV). A pretest-posttest nonequivalent control group design (Nahar et al., 2022) was adopted, as illustrated in Table 1.

Table 1. Research Design

Groups	Initial	Treatment	Final
Control (n=32)	O ₁	-	O ₂
Experimental (n=32)	O ₃	X	O ₄

Note: O₁ and O₃ represent pretest; O₂ and O₄ represent posttest; X denotes the implementation of experiential learning

Both groups were administered a pretest to assess students' baseline conceptual understanding. Subsequently, the control group received conventional instruction, whereas the experimental group was taught using the experiential learning approach. The intervention spanned two instructional meetings. Upon completion, both groups took the same conceptual understanding test as a posttest, alongside a collaborative skills questionnaire.

The study was conducted at a junior high school in Central Java, Indonesia. Using purposive sampling, 64 ninth-grade students from two intact classes were selected, with 32 students assigned to the control group and 32 to the experimental group. The research instruments comprised a conceptual understanding test and a collaborative skills questionnaire. The conceptual understanding test consisted of 25 items developed based on seven indicators: (1) restating a concept; (2) identifying necessary or sufficient conditions of a concept; (3) selecting and applying appropriate procedures or operations; (4) applying concepts or algorithms to solve problems; (5) representing concepts in

various forms; (6) providing examples and non-examples of a concept; and (7) classifying objects according to specific characteristics (Mahendra & Rini Purwati, 2019).

The collaborative skills instrument consisted of 28 items measured on a four-point Likert scale. It covered five indicators adapted from Greenstein (2012): (1) *working productively* (collaborating toward goals, contributing equitably, maintaining focus); (2) *demonstrating respect* (appreciating opinions, active listening, respectful interactions); (3) *compromising* (flexibility, reaching consensus, resolving differences positively); (4) *shared responsibility* (fulfilling roles, dependability); and (5) *contributing* (providing ideas, participating in decisions, supporting optimal outcomes). Instrument validity was assessed using Pearson correlation, while reliability was examined using Cronbach's Alpha. Data analysis included descriptive statistics, prerequisite tests (normality and homogeneity), independent-samples t-tests, paired-samples t-tests, and Multivariate Analysis of Variance (MANOVA).

RESULTS AND DISCUSSION

Based on data collected from 64 participants, a series of analyses was conducted, including validity and reliability assessments, prerequisite tests, and hypothesis testing.

The validity analysis revealed that all indicators of conceptual understanding and collaborative skills showed Pearson correlation coefficients exceeding the critical value ($r > .244$), with significance levels below .05. Regarding reliability, both instruments exceeded the acceptable threshold of .70, indicating strong internal consistency (Maulana, 2022). The reliability results are presented in Table 2.

Table 2. Reliability Test Results

Variable	Reliability Value
Conceptual understanding	0.842
Collaborative skills	0.869

Descriptive Analysis

The descriptive statistics demonstrate an improvement in conceptual understanding scores for both groups (Table 3). The control group's mean score increased from 59.86 at pretest to 74.12 at posttest. Meanwhile, the experimental group exhibited a substantially higher increase, progressing from a pretest mean of 66.38 to a posttest mean of 87.00.

Table 3. Descriptive Analysis of Conceptual Understanding

Groups	Mean	Median	Maximum	Minimum
Control Pretest	59.86	60	84	20
Control Posttest	74.12	74	100	48
Experimental Pretest	66.38	66	84	48
Experimental Posttest	87.00	88	100	68

Regarding collaborative skills (measured post-intervention), the experimental group achieved a higher mean score (3.02) compared to the control group (2.87), as shown in Table 4. These findings descriptively suggest that the experiential learning approach fostered stronger interaction and cooperation.

Table 4. Descriptive Analysis of Collaborative Skills

Groups	Mean	Median
Control	2.87	2.96
Experimental	3.02	3.00

Prerequisite Tests

The fulfillment of statistical assumptions was verified using the Kolmogorov-Smirnov test for normality and Levene's test for homogeneity (Widyasari et al., 2024). The data were considered normally distributed and homogeneous if the significance values (p) were .05. The results indicated that the data for all groups were normally distributed ($p > .05$) and that the variances across groups were homogeneous ($p > .05$), satisfying the assumptions for parametric testing.

Hypothesis Testing

Hypothesis testing involved independent-samples t -tests, paired-samples t -tests, and MANOVA. A significance level of $\alpha = .05$ was utilized.

Independent Samples t-Test

An independent-samples t -test was conducted to examine group differences, as shown in Table 5.

Table 5. Independent t -Test Results

Group Comparison	Sig.	Alpha
<i>Pretest</i> (Control vs. Experimental)	0.040	0.05
<i>Posttest</i> (Control vs. Experimental)	0.000	0.05

The results revealed a statistically significant difference between the control and experimental groups at the pretest stage ($p = .040$), indicating that the groups were not

equivalent at baseline. Consequently, the significant posttest difference ($p < .001$) cannot be interpreted in isolation as definitive evidence of the intervention's effect, as initial disparities may have contributed to the outcomes.

Paired Samples t-Test

A paired samples t-test examined the internal changes within each group. The results indicated statistically significant improvements in conceptual understanding from pretest to posttest in both the control and experimental groups ($p < .001$). Although both groups improved significantly, the experimental group achieved a notably higher posttest mean.

MANOVA Test

To examine the simultaneous effect of the instructional method (Group) on both dependent variables (conceptual understanding and collaborative skills), a MANOVA was conducted. The assumption of homogeneous covariance matrices was satisfied based on Box's M test ($F = 1.535$, $p = .203$) as shown in Table 6.

Table 6. Box's Test Results

Box's M	F	df1	df2	Sig.
4.771	1.535	3	691920	0.203

Multivariate Test and Test of Between-Subject Effect

A multivariate analysis was conducted to examine the effect of test category on the two dependent variables simultaneously, namely conceptual understanding and collaborative skills. The assumption of equality of covariance matrices was satisfied based on Box's M test ($p = 0.203 > 0.05$). The multivariate test using Wilks' Lambda yielded a value of 0.751, with $F(2, 61) = 10.090$, $p < 0.001$, and partial $\eta^2 = 0.249$. This result indicates a statistically significant multivariate effect of test category on the combined dependent variables.

Table 7. Wilk's Lambda Results

Effect	Wilks' Lambda	F	Hypothesis df	Error df	Sig.	Partial η^2
Group	0.751	10.090	2	61	< 0.001	0.249

The univariate tests further indicated statistically significant effects on both dependent variables. Conceptual understanding yielded $F(1, 62) = 19.766$, $p < 0.001$, whereas collaborative skills yielded $F(1, 62) = 4.408$, $p = 0.040$. These findings indicate

that the test category was significantly associated with changes in both conceptual understanding and collaborative skills.

The effect was more pronounced for conceptual understanding than for collaborative skills, as reflected in the larger F statistic and partial eta squared. The partial η^2 values were approximately 0.242 for conceptual understanding and 0.066 for collaborative skills, indicating a substantially stronger effect on students' conceptual understanding. This difference may be related to the nature of the experiential learning intervention, which directly engaged students in contextual mathematical problems, reflection, conceptual construction, and application, thereby providing stronger opportunities to develop mathematical understanding. In contrast, collaborative skills involve interpersonal behaviors that may require more sustained interaction and repeated practice to develop.

Table 8. Test of Between-Subject Effect

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Posttest (Control-experimental)	2652.25	1	2652.250	19.766	0.000
	Collaborative Skills (CS)	306.25	1	306.250	4.408	0.040
Intercept	Posttest (Control-experimental)	415380.250	1	415380.250	3095.568	0.000
	Collaborative Skills (CS)	435270.063	1	435270.063	6264.787	0.000
Test Category	Posttest (Control-experimental)	2652.250	1	2652.250	19.766	0.000
	Collaborative Skills (CS)	306.250	1	306.250	4.408	0.040
Error	Posttest (Control-experimental)	8319.500	62	134.185		
	Collaborative Skills (CS)	4307.688	62	69.479		
Total	Posttest (Control-experimental)	426352.000	64			
	Collaborative Skills (CS)	439884.000	64			
Corrected Total	Posttest (Control-experimental)	10971.750	63			
	Collaborative Skills (CS)	4613.938	63			

The findings suggest that experiential learning supports both students' conceptual understanding and collaborative skills in learning SLETV. Although both groups demonstrated improvement, the experimental group exhibited a greater increase in conceptual understanding (from 66.38 to 87.00) and achieved higher collaborative skill scores (3.02 vs. 2.87). However, given the significant baseline differences, these disparities should be interpreted cautiously.

The stronger pattern observed for conceptual understanding is theoretically robust. The experiential learning cycle affords students repeated opportunities to encounter mathematical problems, reflect on their experiences, formulate concepts, and apply them to novel situations (Kolb, 2015). In the *concrete experience* stage, direct engagement with contextual SLETV problems helps students move beyond procedural memorization and aligns with constructivist principles (Wijnen-Meijer et al., 2022). Furthermore, *reflective observation* allows students to identify errors and compare approaches, strengthening conceptual connections and systematic reasoning (Morris, 2019; Rahmi, 2024). *Abstract conceptualization* and *active experimentation* subsequently enable students to generalize these relationships and test their understanding through practical applications (Lin et al., 2025).

This same cyclical framework explains the development of collaborative skills. Experiential learning embeds interaction into the knowledge construction process itself. Exploring problems collectively during concrete experience, negotiating shared interpretations during abstract conceptualization, and collaboratively testing solutions during active experimentation ensure that collaboration is an integral mechanism of learning, not merely an ancillary activity (Coleman et al., 2024; Pinasti, 2023).

The difference in effect sizes between the two outcomes ($\eta_p^2 = .242$ for conceptual understanding vs. $\eta_p^2 = .066$ for collaborative skills) is noteworthy. Experiential learning directly targets the construction of cognitive concepts, which closely align with the measured conceptual understanding outcomes. Conversely, collaborative skills involve complex interpersonal behaviors, such as sharing responsibility and negotiating differences, which typically require more sustained social interaction to develop substantially. Thus, the cognitive outcomes of a relatively short intervention may simply be more immediately observable than behavioral changes in interpersonal competencies (U-senyang, 2024).

Overall, the present study extends previous literature by simultaneously examining these two outcomes in junior high school mathematics. The findings confirm that experiential learning holds significant potential as an instructional approach for integrating mathematical comprehension with the development of collaborative competencies in 21st-century education.

CONCLUSION

This study highlights the potential of experiential learning to simultaneously enhance students' conceptual understanding and collaborative skills in Systems of Linear Equations in Two Variables. Students in the experimental group achieved higher posttest scores in conceptual understanding and exhibited better collaborative skills than their counterparts in the control group. The experiential learning cycle provides a meaningful framework for students to engage with contextual problems, reflect on mathematical concepts, and apply their understanding collaboratively.

In practice, these findings encourage mathematics teachers to adopt experiential learning as a viable strategy for integrating cognitive development with interpersonal competencies, particularly for topics requiring contextual reasoning. However, this study is subject to several limitations. First, the small sample size ($n = 64$) from a single school limits generalizability. Second, the purposive sampling resulted in significant baseline differences between groups, necessitating cautious interpretation of the posttest gains. Third, collaborative skills were measured using a self-report questionnaire, which is prone to response bias, and the use of the same test items for pre- and post-assessments may have introduced a testing effect. Future research should employ larger, randomized samples, incorporate behavioral observations for assessing collaboration, and use alternative test forms to substantiate the efficacy of experiential learning.

ACKNOWLEDGMENTS

The researcher thanked the mathematics teacher and all the student participants involved in this research.

DECLARATIONS

Author Contribution : ADR: conceptualization, writing-original draft, visualization; NKW: writing-review & editing, and methodology; ATW: validation, formal analysis, and resources.

Funding Statement : this research was conducted with the researcher's own funds.

Conflict of Interest : The authors declare no conflict of interest.

Additional Information : Additional information is available for this paper.

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