

Effectiveness of Scratch-Assisted Problem-Based Learning for Mathematical Conceptual Understanding: A Quasi-Experimental Study

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ABSTRACT This study examined the effectiveness of Scratch-assisted problem-based learning (PBL) in improving eighth-grade students' mathematical conceptual understanding of systems of linear equations in two variables. The study employed a quantitative quasi-experimental approach with a pretest-posttest nonequivalent control group design. Two intact classes were selected through cluster random sampling, comprising 32 students in the experimental group and 30 students in the control group at SMP Negeri 15 Bandung. The intervention was implemented over three sessions. Data were collected using a five-item essay test and analyzed using descriptive statistics, the Shapiro-Wilk test, Levene's test, the Mann-Whitney U test, independent-samples t-tests, normalized gain (N-Gain), and Cohen's d. The experimental group achieved a significantly higher posttest mean than the control group (80.00 vs. 67.50), with a large effect size, $t(60) = 4.883$, $p < 0.001$, $d = 1.241$. The experimental and control groups obtained mean N-Gain scores of 0.591 and 0.362, respectively. This difference was also significant, $t(60) = 4.235$, $p < 0.001$, with a large effect size ($d = 1.076$). These findings indicate that, within the context and duration of this study, Scratch-assisted PBL was more effective than conventional instruction in improving mathematical conceptual understanding.

Keywords: Scratch, problem-based learning, mathematical conceptual understanding, systems of linear equations, quasi-experimental study

ABSTRAK Penelitian ini mengkaji efektivitas Problem-Based Learning (PBL) berbantuan Scratch dalam meningkatkan pemahaman konsep matematis siswa kelas VIII pada materi sistem persamaan linear dua variabel. Penelitian menggunakan pendekatan kuantitatif dengan metode kuasi eksperimen dan desain pretest-posttest nonequivalent control group. Partisipan penelitian berjumlah 62 siswa SMP Negeri 15 Bandung yang terdiri atas 32 siswa pada kelompok eksperimen dan 30 siswa pada kelompok kontrol, yang dipilih melalui cluster random sampling pada tingkat kelas. Intervensi dilaksanakan selama tiga pertemuan. Data dikumpulkan menggunakan tes uraian lima butir dan dianalisis melalui statistik deskriptif, uji Shapiro-Wilk, uji Levene, uji Mann-Whitney U, independent-samples t-test, normalized gain (N-Gain), dan Cohen's d. Kelompok eksperimen memperoleh rata-rata posttest yang lebih tinggi daripada kelompok kontrol (80,00 berbanding 67,50), dengan perbedaan yang signifikan dan ukuran efek besar, $t(60) = 4,883$, $p < 0,001$, $d = 1,241$. Rata-rata N-Gain kelompok eksperimen dan kontrol masing-masing sebesar 0,591 dan 0,362. Perbedaan N-Gain juga

signifikan, $t(60) = 4,235$, $p < 0,001$, dengan ukuran efek besar ($d = 1,076$). Hasil ini menunjukkan bahwa PBL berbantuan Scratch lebih efektif daripada pembelajaran konvensional dalam meningkatkan pemahaman konsep matematis pada konteks dan durasi penelitian ini.

Kata-kata kunci: Scratch, problem-based learning, pemahaman konsep matematis, sistem persamaan linear, kuasi eksperimen

INTRODUCTION

Conceptual understanding is a fundamental component of mathematics learning because it enables students to explain concepts, articulate mathematical ideas, establish connections, use multiple representations, and apply knowledge flexibly when solving problems (Sugawara et al., 2026). Students with strong conceptual understanding not only perform procedures but also recognize the mathematical reasoning underlying each solution process (Payadnya et al., 2021). However, developing such understanding remains challenging in many educational contexts, including Indonesia. Studies involving PISA-type tasks indicate that Indonesian students continue to experience difficulty interpreting mathematical information, connecting concepts, and applying knowledge in problem-solving situations (Putra et al., 2025; N. D. Rahmawati et al., 2026). These challenges underscore the need for instructional innovations that promote deeper conceptual learning.

This issue is particularly evident in systems of linear equations in two variables. The topic requires more than algebraic manipulation through elimination, substitution, or graphing; students must also understand relationships between variables, the meaning of a system's solution, and connections between algebraic and graphical representations (Mustafa et al., 2026; L. Rahmawati et al., 2023). In practice, instruction often continues to emphasize teacher explanations and routine procedural exercises (Hadianto et al., 2021). Consequently, students may memorize solution steps without understanding the underlying concepts and may struggle when problems differ from familiar examples (Belue et al., 2017; Fatio et al., 2020; Raudiyah & Suryadi, 2023).

A preliminary study at SMP Negeri 15 Bandung revealed a comparable pattern. Most students could apply elimination or substitution procedures but could not explain why the intersection of two lines represents the solution of a system. They also experienced difficulty connecting algebraic equations with graphical representations and contextual problems. Interviews with mathematics teachers further indicated that students tended to reproduce demonstrated procedures and struggled when problems were modified or situated in real-life contexts. Collectively, these findings confirmed the need for an instructional approach that supports deeper conceptual construction.

Digital technology offers opportunities to create more interactive and meaningful mathematics learning experiences. By visualizing abstract relationships dynamically,

technology allows students to explore mathematical objects and receive immediate feedback. Scratch, a block-based visual programming environment, offers this potential (Calder & Taylor, 2010; Maqhfiroh, 2025; Iskandar et al., 2024; Sungur & Ozkan, 2026). In mathematics education, Scratch can support the construction of simulations and interactive representations, making abstract concepts more accessible while encouraging exploration, logical reasoning, and active engagement (Nurhasanah et al., 2025; Pérez-Jorge & Martínez-Murciano, 2022).

However, technology does not automatically improve learning quality; its effectiveness depends on the pedagogical model through which it is used. Problem-based learning (PBL) is relevant in this context because it uses contextual problems as the starting point for learning (Amri et al., 2025; Rahman & Nisa, 2020) and encourages students to construct knowledge through inquiry, collaboration, discussion, and reflection (Cai et al., 2026; Pérez-Jorge & Martínez-Murciano, 2022; N. D. Rahmawati et al., 2026). Integrating Scratch with PBL may therefore combine interactive visualization with a structured problem-solving process, thereby supporting deeper mathematical conceptual understanding (Funa & Prudente, 2021; Merritt et al., 2017; Musna et al., 2021; Smith et al., 2022; L. Zhang & Ma, 2023).

Previous research indicates that digital technology and problem-based or project-based learning can support engagement, higher-order thinking, problem-solving, and learning outcomes (Aminah et al., 2023; Mangiri, 2024; Saad & Zainudin, 2022; Sukkamart et al., 2025; Sungur & Ozkan, 2026; W. Zhang et al., 2024). Research related to Scratch and conceptual learning has also addressed programming, computational thinking, creativity, digital literacy, procedural and conceptual understanding, and science achievement (Addido et al., 2025; Adeniji & Baker, 2022; Edo & Tasik, 2022; Meiliati et al., 2026; Prayitno et al., 2026; Sercenia et al., 2023; Sugawara et al., 2026). These studies suggest that integrating digital tools with student-centered learning can contribute to meaningful twenty-first-century mathematics education (Ayeih, 2025; Lukman & Setiani, 2019; Sercenia et al., 2023).

Even so, much of the existing research has focused on motivation, creativity, computational thinking, programming, or digital literacy rather than mathematical conceptual understanding (Calder, 2018; Nurhasanah et al., 2025; Saad & Zainudin, 2022; Sercenia et al., 2023; Wen et al., 2023). Scratch has also frequently been treated primarily as a learning medium rather than being systematically integrated with a pedagogically grounded learning model (Pérez-Jorge & Martínez-Murciano, 2022; Sulaiman et al., 2021). Although Scratch and PBL have been studied separately, research combining them to strengthen conceptual understanding of systems of linear equations in two variables at the junior high school level remains limited (Aminah et al., 2023; Ayeih, 2025; Belessova et al., 2024; Fitrah et al., 2025; Funa & Prudente, 2021; Lukman & Setiani, 2019; Mediana et al., 2025).

To address this gap, the present study examined the effectiveness of Scratch-assisted PBL in improving junior high school students' mathematical conceptual understanding of systems of linear equations in two variables. Unlike studies that primarily emphasize computational thinking, programming, creativity, motivation, or general learning outcomes, this study treated mathematical conceptual understanding as its principal outcome (Muzana et al., 2021; Purwanto et al., 2022; Purwoko et al., 2023; Sacristán et al., 2024). The findings are expected to provide empirical evidence concerning the integration of Scratch and PBL and to inform the development of more meaningful technology-supported mathematics instruction.

METHOD

Research Design

This study employed a quantitative quasi-experimental approach with a pretest-posttest nonequivalent control group design. Because the school had established intact classes before the study, individual students could not be randomly assigned; consequently, sampling was conducted at the class level. This design enabled the researchers to compare changes in mathematical conceptual understanding over time and to evaluate Scratch-assisted PBL relative to conventional instruction.

Table 1. Pretest-posttest nonequivalent control group design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1	O_2
Control	O_1	X_2	O_2

O_1 : pretest; X_1 : Scratch-assisted PBL; X_2 : conventional instruction without Scratch; O_2 : posttest.

Research Participants

The study was conducted during the second semester of the 2025/2026 academic year at SMP Negeri 15 Bandung, West Java, Indonesia. The population comprised all eighth-grade students studying systems of linear equations in two variables. Cluster random sampling was used because school policy did not permit individual randomization. All eighth-grade classes followed the same curriculum, instructional time allocation, subject teacher, and teaching materials. The selected sample comprised one experimental class with 32 students and one control class with 30 students, yielding a total of 62 participants.

Research Procedures

The research procedure comprised preparation, implementation, and post-intervention stages. During preparation, the researchers developed teaching modules, student worksheets, Scratch activities, and a mathematical conceptual understanding test. Both groups completed the pretest before instruction. The experimental group subsequently received Scratch-assisted PBL, whereas the control group received conventional instruction without Scratch or the PBL framework.

The same teacher delivered the intervention over three sessions, each lasting 2×40 minutes. Both groups studied equivalent content and followed the same learning objectives and time allocation. Instruction in the experimental group followed five PBL phases: orienting students to the problem, organizing learning, guiding inquiry, developing and presenting results, and analyzing and evaluating the problem-solving process. Scratch was used to visualize systems of equations, manipulate relationships between variables, and connect algebraic, graphical, and contextual representations. By contrast, the control group received teacher explanations, worked examples, question-and-answer activities, and individual exercises. Both conditions followed prepared teaching modules, and implementation was monitored descriptively using an observation sheet during each session.

After the intervention, both groups completed a posttest based on the same assessment framework as the pretest. The resulting data were then analyzed in accordance with the study objectives.

Research Instruments

The research instrument was a five-item essay test designed to assess mathematical conceptual understanding. The indicators were informed by relational understanding and multiple-representation perspectives (Skemp, 2006). Table 2 presents the indicators and their operational descriptions.

Table 2. Indicators of mathematical conceptual understanding

No.	Indicator	Description
1	Restating a concept	Explaining systems of linear equations in two variables using the student's own words and appropriate mathematical symbols.
2	Classifying mathematical objects	Identifying whether an equation or pair of equations satisfies the defining characteristics of a system of linear equations in two variables.
3	Providing examples and non-examples	Constructing examples and distinguishing them from expressions that do not represent the target concept.
4	Representing concepts in multiple forms	Expressing the concept through equations, tables, graphs, and contextual situations.
5	Applying and connecting concepts	Applying and relating concepts to solve contextual mathematical problems accurately.

Instrument Validation

Two mathematics education faculty members evaluated the instrument in terms of content, construction, language, and alignment with the specified indicators. The mean Aiken's V coefficient was 0.90, indicating very high content validity. The instrument was subsequently piloted with 26 students whose characteristics were comparable to those of the research participants. Corrected item-total correlations ranged from 0.835 to 0.956, and Cronbach's alpha was 0.969. The items demonstrated moderate difficulty and very good discrimination, supporting the instrument's use in the study.

Data Analysis

Data were analyzed using IBM SPSS Statistics. Descriptive statistics were first calculated to summarize the data. Distributional assumptions were then examined using the Shapiro-Wilk test, while homogeneity of variance was assessed using Levene's test. Because one pretest distribution was nonnormal, initial group equivalence was evaluated using the Mann-Whitney U test. After the relevant assumptions had been satisfied, posttest and N-Gain differences were examined using independent-samples t-tests. Normalized gain was calculated as

$$g = \frac{\text{posttest} - \text{pretest}}{\text{maximum score} - \text{pretest}}.$$

Cohen's d was used to quantify the practical magnitude of group differences. Statistical significance was evaluated at $\alpha = 0.05$.

FINDINGS AND DISCUSSION

Descriptive Statistics of Conceptual Understanding. Table 3 summarizes pretest and posttest performance. Before the intervention, the experimental group obtained a mean score of 50.63 ($SD = 8.684$), whereas the control group obtained a mean score of 47.50 ($SD = 10.401$). This 3.13-point difference suggested broadly comparable initial performance, which was subsequently examined through inferential analysis.

Table 3. Descriptive statistics of mathematical conceptual understanding

Group	Test	N	Min.	Max.	Mean	Mdn.	SD	Var.
Experimental	Pretest	32	35	70	50.63	50.00	8.684	75.403
Experimental	Posttest	32	55	100	80.00	80.00	9.672	93.548
Control	Pretest	30	25	70	47.50	50.00	10.401	108.190
Control	Posttest	30	50	90	67.50	70.00	10.484	109.914

Following instruction, both groups demonstrated improvement. The experimental group's mean increased by 29.37 points to 80.00, whereas the control group's mean

increased by 20.00 points to 67.50. This larger descriptive gain provided initial evidence that Scratch-assisted PBL may have supported stronger conceptual development.

Normality Test. The Shapiro–Wilk results are presented in Table 4. The experimental pretest scores were nonnormal ($p = 0.005$), while the control pretest scores were normal ($p = 0.435$). Both posttest distributions and both N-Gain distributions satisfied the normality criterion.

Table 4. Shapiro–Wilk normality test

Variable	Group	W	p-value	Decision
Pretest	Experimental	0.895	0.005	Nonnormal
Pretest	Control	0.966	0.435	Normal
Posttest	Experimental	0.955	0.203	Normal
Posttest	Control	0.942	0.110	Normal
N-Gain	Experimental	0.936	0.058	Normal
N-Gain	Control	0.968	0.478	Normal

Equivalence of Initial Ability. Because the experimental pretest distribution was non-normal, initial group equivalence was evaluated using the Mann–Whitney U test. Table 5 shows no significant difference between the groups, $U = 421.500$, $Z = -0.840$, $p = 0.401$. The experimental and control mean ranks were 33.33 and 29.55, respectively. Thus, the groups had statistically comparable initial mathematical conceptual understanding.

Table 5. Mann–Whitney U test for pretest scores

Statistic	Value
Mann–Whitney U	421.500
Z	−0.840
p-value	0.401

Homogeneity Test. Levene’s test indicated that the posttest variances were homogeneous, $F = 0.622$, $p = 0.434$ (Table 6). The N-Gain variances were also homogeneous, $F = 0.267$, $p = 0.607$. Consequently, independent-samples t-tests were appropriate for comparing the posttest and N-Gain scores.

Table 6. Levene's homogeneity tests

Variable	F	p-value	Interpretation
Posttest	0.622	0.434	Homogeneous variances
N-Gain	0.267	0.607	Homogeneous variances

Comparison of Posttest Performance. The independent-samples t-test showed a significant posttest difference between the experimental and control groups, $t(60) = 4.883$, $p < 0.001$. The mean difference was 12.50 points, and the 95% confidence interval ranged from 7.38 to 17.62. Cohen's $d = 1.241$ indicated a large effect. Thus, students who received Scratch-assisted PBL demonstrated substantially higher post-intervention conceptual understanding than those who received conventional instruction.

Table 7. Independent-samples t-test for posttest scores

Experimental Mean	Control Mean	Mean Difference	$t(60)$	p	95% CI	Cohen's d
80.00	67.50	12.50	4.883	< 0.001	7.38--17.62	1.241

Normalized Gain Analysis. Table 8 shows that the experimental group obtained a mean N-Gain of 0.591, compared with 0.362 for the control group. Both means were in the moderate category, but improvement was greater in the experimental group.

Table 8. Improvement based on N-Gain scores

Group	N	Mean	SD	Category
Experimental	32	0.591	0.211	Moderate
Control	30	0.362	0.222	Moderate

The N-Gain difference was statistically significant, $t(60) = 4.235$, $p < 0.001$. The mean difference of 0.229 and Cohen's $d = 1.076$ indicated a large practical effect. Scratch-assisted PBL therefore produced greater normalized improvement than conventional instruction in this sample.

Table 9. Independent-samples t-test for N-Gain scores

Mean Difference	t	df	p	Cohen's d
0.229	4.235	60	< 0.001	1.076

Taken together, the findings indicate that Scratch-assisted PBL improved students' mathematical conceptual understanding more effectively than conventional instruction. The significant posttest difference, higher N-Gain, and large effect sizes demonstrate that the intervention produced both statistically significant and practically meaningful gains. This finding is consistent with research suggesting that Scratch can facilitate mathematical exploration and that PBL can promote active knowledge construction (Calder, 2018; Merritt et al., 2017; Smith et al., 2022).

The effectiveness of the intervention cannot be attributed to Scratch as a presentation medium alone. In the experimental class, Scratch enabled students to manipulate relationships between variables, observe corresponding changes in graphs, and compare multiple solution representations. Simultaneously, the PBL framework gave these activities a clear instructional purpose: students began with contextual problems, formulated strategies, discussed alternatives, and evaluated their solutions. Thus, the combination of dynamic representation and structured inquiry supported connections among symbolic, graphical, and contextual forms.

This combined mechanism is especially relevant to systems of linear equations in two variables. Students often learn elimination and substitution as isolated procedures and may not recognize that an algebraic solution corresponds to the intersection of two lines. Through Scratch-based visualizations, changes in coefficients and variables could be linked immediately to changes in graphical representations. As a result, the relationship between equations and their solutions became more concrete, reducing students' reliance on memorized procedures.

Nevertheless, the large effect sizes should be interpreted in relation to the study design. The intervention involved only two intact classes from one school and lasted three sessions. The findings establish a strong difference within this sample, but they do not demonstrate long-term retention or generalizability to other schools, teachers, topics, or student populations. Moreover, implementation fidelity was monitored descriptively but was not analyzed as a formal outcome. These limitations should therefore be considered before the intervention is adopted on a wider scale.

CONCLUSIONS AND RECOMMENDATIONS

Scratch-assisted PBL was more effective than conventional instruction in improving eighth-grade students' mathematical conceptual understanding of systems of linear equations in two variables. The experimental group achieved both a higher posttest mean and a higher mean N-Gain than the control group. The posttest comparison produced $t(60) = 4.883$, $p < 0.001$, and $d = 1.241$, whereas the N-Gain comparison produced $t(60) = 4.235$, $p < 0.001$, and $d = 1.076$. These results suggest that integrating dynamic Scratch visualizations with problem-based inquiry can support conceptual connections, mathematical exploration, and collaborative problem-solving.

The conclusions are limited to two classes at one school and a three-session intervention. Future studies should involve more schools, longer interventions, and delayed posttests to evaluate retention. Researchers should also analyze implementation fidelity systematically and examine whether the approach supports other outcomes, including mathematical reasoning, problem-solving, critical thinking, and transfer to other topics. Classroom implementation should ensure that Scratch activities remain focused on mathematical meaning rather than programming complexity.

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