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Developing a scaffolding chatbot to enhance mathematical problem-solving skills in three-variable linear equation systems

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Abstract

Background: Although chatbots are increasingly used in mathematics education, many primarily deliver direct answers or explanations, offering limited scaffolding to guide students systematically through mathematical problem solving.
Aims: This study aimed to develop and evaluate a scaffolding chatbot designed to enhance students' mathematical problem-solving skills in Three-Variable Linear Equation Systems.
Method: A research and development approach employing the ADDIE model was conducted with 23 eleventh-grade students. Data were collected through expert validation, teacher and student practicality questionnaires, and pretest–posttest mathematical problem-solving assessments. Data analysis included descriptive statistics, normalized gain (N-gain), the Wilcoxon Signed-Rank Test, and effect size.
Results: The chatbot achieved 80.00% validity, while teacher and student practicality scores reached 82.50% and 86.18%, respectively. Students demonstrated moderate improvement (N-gain = 0.45), with a significant difference between pretest and posttest scores ($Z = -3.939$, $p < .05$) and a large effect size ($r = 0.82$).
Conclusion: The developed scaffolding chatbot demonstrated strong validity and practicality and provided promising evidence for supporting mathematical problem-solving development through gradual guidance, prompts, and feedback rather than direct solutions.

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INTRODUCTION

Mathematical problem-solving is a fundamental competency that enables students to apply mathematical knowledge and reasoning when addressing both academic tasks and contextual situations. Within the Merdeka Curriculum, the development of problem-solving skills is emphasized as an essential component of mathematics learning because students are expected to understand mathematical situations, formulate appropriate representations, determine solution strategies, and evaluate the results they obtain. These competencies become particularly important in learning Three-Variable Linear Equation Systems, where students must coordinate several forms of mathematical reasoning within a single problem-solving process (Ariski & Arni, 2023; Hidayanto & Lisrahmat, 2023; Lamowa et al., 2022). Solving problems in this topic requires students to identify relevant information from contextual situations, distinguish known and unknown quantities, translate relationships into mathematical equations, perform appropriate algebraic procedures, and verify the resulting solutions (Ariski & Arni, 2023; Hidayanto & Lisrahmat, 2023). However, these interconnected processes can become challenging when students have difficulty interpreting the information contained in a problem or relating contextual situations to mathematical representations. The preliminary study conducted in this research revealed that students

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experienced considerable difficulties in understanding problems and transforming the available information into appropriate mathematical models. Students were frequently unable to identify known and required information accurately, resulting in incorrect formulations of systems of equations and unsystematic subsequent solution procedures. These difficulties indicate that weaknesses occurring during the initial stages of problem solving can influence students' performance throughout the entire solution process. Consequently, mathematics learning should not focus exclusively on obtaining correct final answers but should also facilitate the reasoning processes through which students progressively construct and evaluate their solutions. This condition highlights the importance of providing learning environments that offer appropriate assistance throughout different stages of mathematical problem solving.

The effectiveness of such assistance is closely related to the capacity of instructional media and teachers to respond to students' difficulties during the learning process. In classroom practice, mathematics instruction frequently relies on conventional resources such as textbooks and presentation materials that are useful for delivering content but provide relatively limited opportunities for sustained and individualized interaction (Santika et al., 2025). Such resources generally present predetermined information and therefore may not adequately accommodate differences in students' understanding, reasoning processes, and levels of assistance required when solving mathematical problems (Setiani et al., 2025; Zhou et al., 2025). As a result, students who encounter difficulties may remain dependent on direct teacher assistance or continue the solution process without receiving appropriate guidance at the point where misconceptions emerge. Scaffolding offers a relevant pedagogical approach to this challenge because it provides temporary and structured learning support that can be adjusted according to students' progress and gradually reduced as greater independence develops (Adebanjo et al., 2025; Vygotsky, 1978; Wood et al., 1976). In mathematical problem solving, scaffolding can be operationalized through guiding questions, prompts, hints, cues, and feedback that direct students toward relevant information without immediately providing complete solutions (Swanepoel, 2026). This form of support can help students clarify what is known and required, construct appropriate mathematical models, select and implement solution strategies, and reconsider the correctness of their reasoning (Huda et al., 2025; Zhou et al., 2025). Nevertheless, continuous individualized scaffolding is difficult to implement when teachers must simultaneously accommodate students with diverse learning needs within limited classroom time (Setiani et al., 2025). The challenge is therefore not merely to provide additional learning materials but to develop an instructional medium capable of extending structured guidance in a practical, interactive, and responsive manner. Integrating scaffolding principles with digital learning technology provides a potential means of addressing this need while maintaining students' active involvement in constructing mathematical solutions.

Recent developments in artificial intelligence have created new possibilities for designing digital learning environments that provide interactive assistance during students' learning processes. Educational chatbots are particularly promising because they enable two-way interactions in which students can communicate with a digital system while engaging with mathematical tasks (Chang et al., 2023; Cheng et al., 2024). Unlike static instructional resources, a chatbot can sustain an interactive dialogue by responding to students' inputs and providing subsequent assistance as the problem-solving process progresses. However, the pedagogical value of such technology depends on whether chatbot interactions encourage mathematical reasoning rather than simply accelerate access to answers. When a chatbot primarily supplies explanations or complete solutions, students may have fewer opportunities to identify relevant information, formulate strategies, recognize errors, and independently evaluate their mathematical reasoning. Integrating scaffolding into chatbot interactions offers an alternative design in which technology functions as a learning companion that guides students toward solutions without replacing their cognitive engagement (Huda et al., 2025; Zhou et al., 2025). Through guiding questions, prompts, hints, and reflective feedback, a scaffolding chatbot can support students as they move from understanding contextual information to constructing mathematical models, carrying out solution procedures, and verifying their results. Such structured interaction is particularly relevant to Three-Variable Linear Equation Systems because successful problem solving requires students to coordinate conceptual interpretation, algebraic modeling, procedural execution, and solution verification (Ariski & Arni, 2023; Hidayanto & Lisrahmat, 2023). The integration of chatbot technology and scaffolding therefore shifts the function of digital assistance from answer provision toward process-oriented support for mathematical reasoning. Nevertheless, the systematic development and evaluation of chatbot-based scaffolding organized around successive stages of mathematical problem solving remains an area requiring further investigation, particularly within specific secondary mathematics topics.

Although artificial intelligence and chatbot technologies have increasingly been integrated into mathematics education, existing studies have predominantly focused on the broader application of AI in mathematics learning, responsive teaching, personalized instruction, and AI-supported mathematical problem solving (Awang et al., 2025; Cheng et al., 2024; Guler et al., 2024; Lee et al., 2025; Lee & Yeo, 2022). Recent research has further demonstrated the potential of AI chatbots and generative AI environments to support students' mathematical problem-solving performance through personalized assistance and technology-enhanced learning experiences (Bayaga, 2024; Chau et al., 2025; Liu et al., 2025). In parallel, chatbot-based scaffolding has been investigated in instructional design, argumentative writing, corrective feedback, self-regulated learning, and inquiry-based learning, demonstrating the potential of structured chatbot assistance across diverse educational contexts (Bai et al., 2025; Chen et al., 2026; Guo et al., 2022; Soyoof et al., 2026; Zhang et al., 2021). Studies on adaptive scaffolding have similarly emphasized personalized support, self-regulated learning, cognitive load, engagement, and adaptive learning environments (Azevedo et al., 2022; Faber et al., 2024; Lim et al., 2023; Munshi et al., 2023). Nevertheless, the intersection between chatbot-based scaffolding and the successive cognitive stages involved in mathematical problem solving remains comparatively underexplored, particularly in secondary mathematics contexts. Specifically, limited attention has been directed toward developing a chatbot that systematically provides guiding questions, prompts, and feedback as students progress from understanding a problem and formulating a mathematical model to carrying out a solution and verifying the result, rather than primarily functioning as an answer-generating or general instructional support tool. Moreover, evidence concerning the development and evaluation of such scaffolding-oriented chatbots for Three-Variable Linear Equation Systems remains limited. Therefore, the present study addresses this gap by developing and evaluating a scaffolding chatbot designed to provide structured guidance throughout successive stages of mathematical problem solving, thereby extending existing research on AI-supported mathematics learning toward a more explicitly scaffolded and process-oriented approach.

Building on these educational and technological considerations, this study aims to develop a scaffolding chatbot designed to enhance students' mathematical problem-solving skills in Three-Variable Linear Equation Systems. The chatbot is conceptualized as a complementary learning medium that provides structured assistance rather than functioning primarily as a source of direct answers or complete mathematical solutions. Its interaction design incorporates guiding questions, prompts, hints, and reflective feedback intended to encourage students to construct their reasoning progressively. The scaffolding process is organized around four interconnected stages comprising understanding the problem, formulating a mathematical model, carrying out the solution process, and verifying the obtained result. At each stage, students are encouraged to reconsider relevant information and develop their responses before progressing to subsequent problem-solving activities. The chatbot is also integrated with student worksheets that provide instructions and structure students' engagement with the digital learning environment. Through this combination, the developed learning medium is intended to maintain students' active participation while providing accessible assistance throughout the mathematical problem-solving process. The study evaluates the quality of the developed chatbot in terms of validity and practicality and examines changes in students' mathematical problem-solving performance following its classroom implementation. This approach is expected to provide empirical evidence regarding the feasibility of embedding structured scaffolding within chatbot-supported mathematics learning. Ultimately, the study seeks to contribute to technology-enhanced mathematics education by demonstrating how chatbot-based scaffolding can be designed and implemented to support students' systematic and increasingly independent mathematical problem solving.

LITERATURE REVIEW

Mathematical problem-solving is a central component of mathematics learning because it requires students to integrate conceptual knowledge, mathematical reasoning, representation, and procedural skills when addressing unfamiliar situations. Problem-solving competence extends beyond obtaining a correct numerical result and involves understanding the structure of a problem, identifying relevant information, determining mathematical relationships, selecting appropriate strategies, and evaluating the resulting solution (Han & Kim, 2020; Leavy & Hourigan, 2020; Szabo et al., 2020; Torres-Peña et al., 2025). These processes require students to coordinate several cognitive activities rather than apply mathematical procedures mechanically. In Three-Variable Linear Equation Systems, such coordination becomes particularly important because contextual information must first be transformed into a system of mathematical equations before appropriate algebraic procedures can be implemented (Ariski & Arni, 2023; Hidayanto & Lisrahmat, 2023). Students may encounter difficulties when identifying known and unknown quantities, interpreting relationships among variables, or representing contextual information mathematically. Errors occurring during problem interpretation can subsequently influence model formulation, calculation procedures, and the accuracy of final solutions. Mathematical problem-solving instruction should therefore provide opportunities for students to examine how solutions are constructed rather than focusing exclusively on procedural accuracy. Developing this competence also requires learning environments that encourage students to explain their reasoning, reconsider inappropriate strategies, and verify whether their solutions correspond to the original problem. From this perspective, mathematical problem-solving skills can be understood as a progressive coordination of understanding, modeling, execution, and verification processes. Accordingly, instructional approaches for Three-Variable Linear Equation Systems should support these interconnected processes while preserving students' active role in constructing mathematical meaning.

Scaffolding provides a theoretical and pedagogical framework for supporting students when learning tasks temporarily exceed what they can accomplish independently. Rooted in sociocultural perspectives on learning, scaffolding emphasizes assistance that enables learners to progress toward greater competence and independence through interaction and appropriately structured support (Alanazi et al., 2025; Puntambekar, 2022; Sarmiento-Campos et al., 2022). The assistance is not intended to replace students' thinking but to create conditions in which they can perform cognitive activities that might otherwise remain inaccessible. Effective scaffolding therefore requires support to correspond to the difficulty encountered by learners and to become less intensive as their competence increases (Adebanjo et al., 2025). In mathematics learning, scaffolding can be implemented through guiding questions, hints, prompts, explanations, cues, and feedback that direct students' attention toward important relationships within a problem (Swanepoel, 2026). These forms of assistance can encourage students to reconsider incomplete reasoning and identify errors before proceeding to subsequent problem-solving stages. Scaffolding is particularly relevant to mathematical problem solving because students may require different types of assistance when interpreting a problem, constructing a mathematical model, implementing a strategy, or evaluating a solution (Huda et al., 2025; Zhou et al., 2025). Appropriate scaffolding can consequently support both cognitive processes related to mathematical reasoning and metacognitive processes associated with monitoring and evaluating solution strategies. However, effective scaffolding requires a balance between providing sufficient assistance and maintaining students' intellectual responsibility for constructing solutions. Thus, scaffolding in mathematics education should be conceptualized as structured and progressively adjusted support that facilitates students' movement from assisted problem solving toward increasingly independent mathematical reasoning.

The increasing application of artificial intelligence in education has expanded the possibilities for providing interactive and personalized support through educational chatbots. Educational chatbots are digital conversational systems that allow learners to interact with technological environments through question-and-response exchanges during learning activities. Their conversational characteristics distinguish them from conventional digital resources because learning support can be delivered dynamically in response to students' inputs. Chatbot-supported environments have been associated with increased opportunities for interaction, feedback, personalized assistance, and learner engagement across educational contexts (Chang et al., 2023; Straková & Válek, 2024). Within mathematics education, chatbots can support students by providing explanations, responding to mathematical questions, facilitating tutoring interactions, and assisting learners while completing mathematical tasks (Straková & Válek, 2024). More recent applications indicate that AI chatbots can also contribute to personalized mathematics instruction and provide assistance related to students' mathematical problem-solving processes (Chau et al., 2025). Nevertheless, technological responsiveness alone does not guarantee that chatbot interactions will produce pedagogically meaningful mathematical learning. A system that immediately generates complete explanations or solutions may facilitate access to information while providing limited opportunities for students to construct and monitor their own reasoning. Therefore, educational chatbot design needs to consider not only the accuracy and immediacy of system responses but also the pedagogical structure through which assistance is delivered. The educational value of chatbots in mathematics learning consequently depends on whether conversational technology is aligned with instructional principles that encourage active reasoning, reflection, and progressive learner independence.

Integrating scaffolding principles into chatbot-based environments provides a means of connecting conversational technology with structured pedagogical assistance. A scaffolding chatbot differs conceptually from an answer-oriented chatbot because its primary function is to guide learners toward constructing solutions rather than immediately generating complete answers (Ahsan et al., 2026). This guidance can be operationalized through sequences of questions, hints, prompts, feedback, and reflective cues that respond to students' progress during learning activities. Previous research has demonstrated that chatbot-based learning environments can incorporate scaffolding and adaptive feedback to support learner interaction, self-regulation, metacognition, and mathematical learning (Huda et al., 2025; Sofnidar et al., 2023; Zhou et al., 2025). In mathematical problem solving, such interactions can be organized to direct students' attention toward relevant information while allowing them to retain responsibility for determining the next reasoning step. When students experience difficulty understanding a problem, for example, the chatbot can prompt them to identify known quantities and determine what needs to be found before introducing further assistance. Similar scaffolding can be provided during mathematical modeling, procedural execution, and solution verification, thereby establishing continuity of guidance across the problem-solving process (Çakmak Gürel, 2025; Ding et al., 2026; Kaplar et al., 2026; Looi et al., 2026). This process-oriented function distinguishes scaffolding chatbots from systems primarily designed to provide information, explanations, or completed mathematical procedures. Furthermore, embedding scaffolding into chatbot interactions may help extend individualized instructional support when teachers cannot continuously respond to every learner during classroom problem solving. Therefore, a scaffolding chatbot can be conceptualized as a technology-mediated instructional environment in which conversational interaction is deliberately structured to facilitate mathematical reasoning while progressively supporting learner autonomy.

The pedagogical integration of scaffolding and chatbot technology is particularly relevant to Three-Variable Linear Equation Systems because solving these problems requires coordination across multiple stages of mathematical reasoning. Students must first interpret contextual information and identify relationships among quantities before representing those relationships through three mathematical equations. They must then select and execute appropriate algebraic procedures and subsequently determine whether the obtained values meaningfully satisfy the conditions presented in the original problem. Difficulties at one stage can influence subsequent reasoning, making it important for instructional support to address the process through which a solution develops rather than merely evaluate the final answer. A scaffolding chatbot can organize this assistance around four interconnected processes: understanding the problem, formulating mathematical models, carrying out the solution, and verifying the result (Looi et al., 2026; Shahbari, 2026; Vo et al., 2025). During these processes, guiding questions can focus students' attention on relevant information, prompts can encourage the construction of mathematical relationships, and reflective feedback can stimulate evaluation of intermediate and final responses. Such a design positions the chatbot as a mediator of mathematical reasoning rather than a substitute for students' cognitive activity. The accompanying student worksheet can further structure the interaction by directing students to use chatbot assistance as part of an organized mathematical learning sequence. The conceptual integration of scaffolding, chatbot interaction, and mathematical problem-solving stages therefore provides the theoretical foundation for developing a learning medium that combines technological responsiveness with explicit pedagogical guidance. On this basis, the present study operationalizes scaffolding within chatbot-supported interactions to facilitate students' progression through the problem-solving processes required in Three-Variable Linear Equation Systems.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using the ADDIE model to develop and evaluate a scaffolding chatbot intended to enhance students' mathematical problem-solving skills in Three-Variable Linear Equation Systems. The ADDIE model comprises five interconnected stages: analysis, design, development, implementation, and evaluation. This developmental framework was used to systematically organize the process from identifying instructional needs to evaluating the quality of the final learning medium. The analysis stage focused on identifying students' learning difficulties, instructional needs, and requirements for learning media through classroom observations and teacher interviews. The design stage involved constructing the chatbot interaction flow, designing the user interface, preparing the accompanying student worksheet, and developing the research instruments. During the development stage, the scaffolding chatbot and student worksheet were produced and subsequently subjected to expert validation and revision. A small-group trial was then conducted to obtain preliminary information regarding the usability and clarity of the developed learning medium. The implementation stage involved classroom use of the revised chatbot with eleventh-grade students to evaluate its practicality and students' mathematical problem-solving performance. Evaluation was conducted throughout the development process to identify aspects requiring improvement and to refine the chatbot progressively. Through these stages, the study examined the developed product in terms of validity, practicality, and effectiveness while maintaining the systematic characteristics of the ADDIE development process.

Participant

The study was conducted during the second semester of the 2025/2026 academic year at a senior high school in Malang, Indonesia. Participants were eleventh-grade students who were involved at different stages of the product-development process. The small-group trial involved four students representing different levels of academic achievement, including high, medium, and low achievement levels. The involvement of students with different achievement characteristics was intended to provide preliminary feedback on whether the developed learning medium could be understood and used by students with varying academic abilities. At this stage, students interacted with the chatbot and the accompanying student worksheet before providing feedback regarding their learning experience. Information obtained from the small-group trial was subsequently considered during product refinement before the larger classroom implementation. Following this stage, the field trial involved 23 students from Grade XI-6. These students participated in the implementation of the scaffolding chatbot within mathematics learning on Three-Variable Linear Equation Systems. The field-trial participants also completed mathematical problem-solving assessments and provided responses regarding the practicality of the developed learning medium. Thus, participant involvement progressed from a limited preliminary trial to a broader classroom implementation in accordance with the developmental nature of the study.

Instrument

The research instruments consisted of an expert validation sheet, teacher and student practicality questionnaires, and mathematical problem-solving tests administered as pretest and posttest. The expert validation sheet was employed to assess the appropriateness of the developed scaffolding chatbot before its classroom implementation. The validation process provided quantitative evaluation and qualitative feedback that were used as the basis for revising the developed product. Practicality questionnaires were employed to collect information concerning users' experiences when interacting with the chatbot and its accompanying learning materials. During the small-group trial, student responses were collected to identify aspects related to the readability, clarity, and ease of use of the developed learning medium. Following the classroom implementation, practicality data were obtained from both the teacher and students to evaluate the usability of the chatbot in mathematics learning. Students' mathematical problem-solving performance was measured using pretest and posttest assessments administered before and after the implementation of the developed learning medium. The assessment focused on four indicators of mathematical problem solving: understanding the problem, formulating mathematical models, carrying out the solution process, and verifying the solution. Quantitative data were therefore obtained from expert validation, practicality questionnaires, and students' pretest and posttest performance, while qualitative information was derived from feedback provided during the development and evaluation processes. These multiple sources of data were used to provide evidence concerning the validity, practicality, and effectiveness of the developed scaffolding chatbot.

Data Analysis

The collected data were analyzed using qualitative and quantitative approaches according to the characteristics and purposes of each dataset. Qualitative information obtained from expert, teacher, and student feedback was reviewed to identify weaknesses and recommendations for improving the developed chatbot. This feedback was incorporated into the revision process to improve the content, interaction flow, interface, and usability of the learning medium. Quantitative data obtained from the expert validation sheet were converted into percentage scores to determine the validity level of the developed product. Responses from the teacher and students were similarly calculated as percentage scores to determine the practicality of the scaffolding chatbot during learning activities. Students' pretest and posttest scores were analyzed descriptively to identify changes in mathematical problem-solving performance following the implementation. Normalized gain (N-gain) analysis was subsequently used to determine the magnitude of improvement between students' initial and final mathematical problem-solving performance. Prior to inferential hypothesis testing, a normality test was conducted to determine the appropriate statistical procedure for comparing pretest and posttest scores. A paired-samples t-test was specified for normally distributed data, whereas the Wilcoxon Signed-Rank Test was employed when the data did not satisfy the normality assumption, with statistical significance established at 0.05. Effect size analysis was additionally performed to determine the magnitude of the difference between students' mathematical problem-solving performance before and after the implementation of the scaffolding chatbot.

Research Procedure

The research procedure was systematically organized according to the five stages of the ADDIE model, beginning with analysis and continuing through design, development, implementation, and evaluation. During the analysis stage, classroom observations and teacher interviews were conducted to identify students' learning difficulties, characteristics, instructional needs, and limitations of the learning media currently used in mathematics instruction. The findings of this stage provided the basis for determining the need for a learning medium capable of providing structured scaffolding during mathematical problem solving. During the design stage, the chatbot interaction flow and user interface were prepared together with the student worksheet and research instruments required for product evaluation. The chatbot interaction was structured to support four stages of mathematical problem solving, namely understanding the problem, formulating mathematical models, carrying out the solution process, and verifying the solution. During the development stage, the scaffolding chatbot and student worksheet were created, after which the product was evaluated by an expert and revised according to the feedback obtained. The revised product was subsequently evaluated through a small-group trial involving four students with different levels of academic achievement to identify issues related to its preliminary usability and clarity. During the implementation stage, the refined scaffolding chatbot was used in mathematics learning with 23 eleventh-grade students, with pretest and posttest assessments administered to examine changes in their mathematical problem-solving performance. Teacher and student practicality questionnaires were also administered during the implementation process to obtain information regarding the usability of the developed learning medium in classroom practice. Finally, evaluation was conducted continuously throughout the ADDIE stages by incorporating information from the needs analysis, expert validation, small-group trial, and classroom implementation to progressively refine the scaffolding chatbot and determine its overall quality.

Figure 1. illustrates the systematic research procedure based on the ADDIE framework, encompassing the analysis, design, development, implementation, and evaluation stages. Each stage integrates specific activities, participants, instruments, and analytical procedures to ensure the systematic development and evaluation of the scaffolding chatbot. The process concludes with effectiveness analysis using descriptive statistics, N-gain, inferential statistics, and effect size, resulting in a validated, practical, and effective scaffolding chatbot for supporting students' mathematical problem-solving skills in Three-Variable Linear Equation Systems.

Figure 1. Research Method Flow

RESULTS AND DISCUSSION

Results

The analysis stage was conducted to identify the learning needs, curriculum requirements, students' characteristics, and instructional media requirements for developing the scaffolding chatbot. The results of the needs analysis are summarized in Table 1.

Table 1. Results of the Needs Analysis

Analysis Aspect	Findings
Curriculum analysis	The Merdeka Curriculum emphasizes mathematical problem-solving skills as an essential competency, particularly in the topic of Three-Variable Linear Equation Systems (SPLTV).
Student analysis	Students experienced difficulties in understanding contextual problems, identifying known and required information, and formulating appropriate mathematical models.
Teacher needs analysis	Teachers had limited instructional time to provide individualized scaffolding and develop more interactive learning media.
Learning media analysis	Existing learning media were predominantly limited to textbooks and PowerPoint presentations, which provided one-way instruction and did not facilitate adaptive learning support.

The results of the needs analysis indicate that both students and teachers require learning media capable of providing gradual and adaptive learning support throughout the mathematical problem-solving process. Therefore, a scaffolding chatbot was developed to guide students through each stage of problem solving by providing guiding questions, prompts, and feedback tailored to students' responses. Based on the results of the needs analysis, the scaffolding chatbot was designed to facilitate students' mathematical problem-solving skills through scaffolded interactions. The chatbot interaction flow was structured according to four problem-solving stages: understanding the problem, formulating mathematical models, carrying out the solution, and reviewing the final answer. The interaction flow of the scaffolding chatbot is presented in Figure 2.

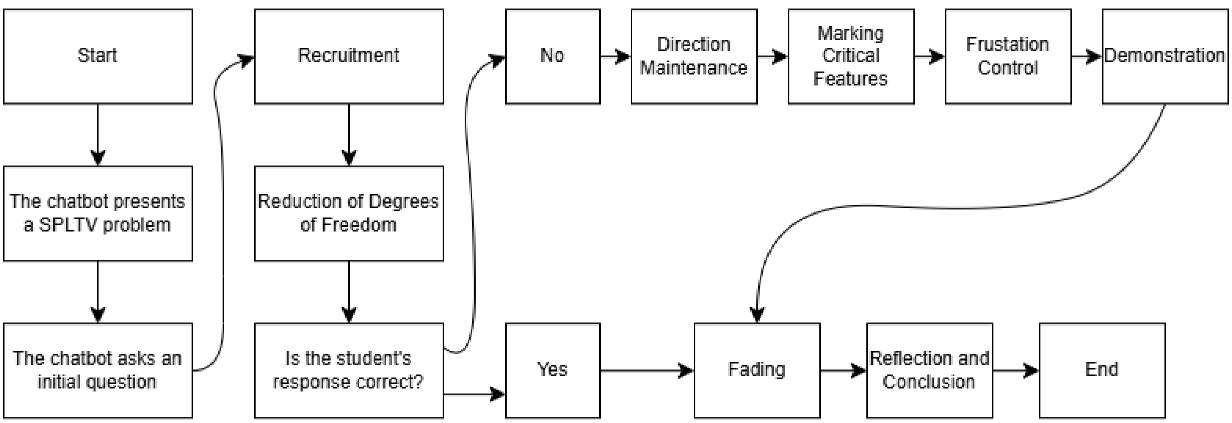


Figure 2. Flowchart of the Scaffolding Chatbot

As shown in Figure 2, the chatbot interaction was designed to provide learning support at each stage of problem solving through guiding questions that adapt to students' responses. Rather than providing direct answers, the chatbot gradually guides students to identify relevant information, construct mathematical models, perform solution procedures, and verify the correctness of their answers. This interaction flow was designed to encourage students to actively engage in the mathematical problem-solving process. In addition, the chatbot interface was designed to consist of two main components: an initial page and a chat interface that facilitates interactions between students and the chatbot throughout the learning process. The interface design is presented in Figure 3.

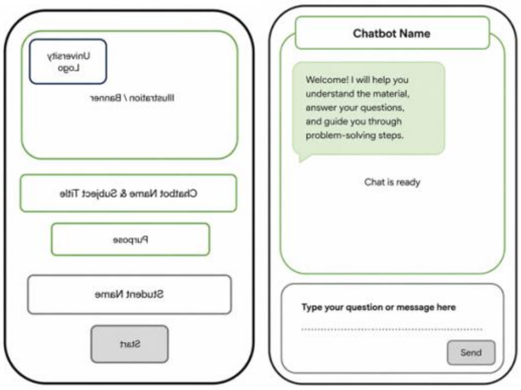
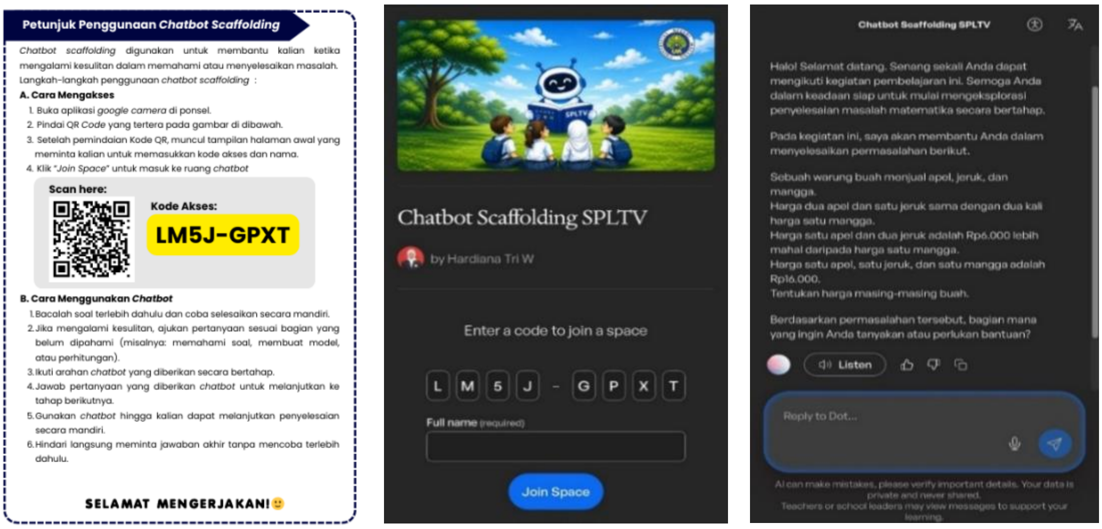


Figure 3. Initial Interface and Chat Interface of the Scaffolding Chatbot

Figure 3 shows that the initial interface serves as the introductory page, while the chat interface functions as the primary environment for students to interact with the chatbot during mathematical problem solving. The interface was designed with a simple and user-friendly layout to facilitate ease of use and support students' learning activities. At the development stage, the scaffolding chatbot was developed using the SchoolAI platform and accompanied by a student worksheet (LKPD) as a guide for using the learning media. The developed chatbot was subsequently validated by an expert and evaluated through a small-group trial to obtain feedback regarding readability, interface clarity, and ease of use. The developed media are presented in Figure 4.



(a) Instructions for Using the Chatbot in student worksheet | (b) Initial Interface | (c) Chat Interface

Figure 4. Results of the development of the scaffolding chatbot platform

As shown in Figure 4, students first read the usage instructions provided in the student worksheet (Figure 4a), which explain how to access and use the chatbot. Students then entered the chatbot's initial interface (Figure 4b) before interacting with the chatbot through the chat interface (Figure 4c) during the mathematical problem-solving process. Following the development process, the chatbot was evaluated by an expert to determine its validity. The validation results are presented in Figure 5.

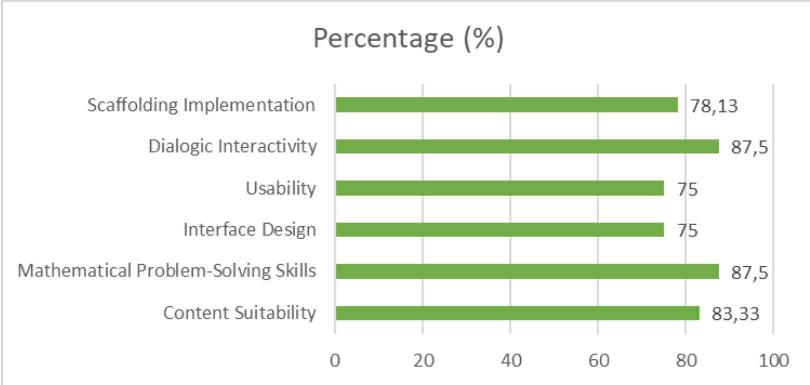


Figure 5. Expert Validation Results of the Scaffolding Chatbot

Figure 5 shows that the scaffolding chatbot achieved an overall validity score of 80.00%, which falls into the valid category. The results indicate that the developed media met the established validity criteria and were considered suitable for mathematics learning. The content suitability, support for mathematical problem-solving skills, dialogic interactivity, interface design, usability, and scaffolding implementation were all evaluated within the valid to highly valid categories. Based on the validator's suggestions, several revisions were made before conducting the field implementation. These revisions included improving the clarity of chatbot prompts, refining the contextual problems, and enhancing the readability of the user interface. After the revision process, the chatbot was evaluated through a small-group trial involving four students representing different academic achievement levels. The practicality results of the small-group trial are presented in Table 2.

Table 2. Practicality Results of the Small-Group Trial

No.	Student	Obtained Score	Maximum Score	Percentage (%)	Category
1	AF	26	28	92,86	Highly Practical
2	AZRS	22	28	68,75	Practical
3	MFA	24	28	85,71	Highly Practical
4	AAF	23	28	82,14	Highly Practical
Average		23,75	28	84,82	Highly Practical

Table 2 shows that the scaffolding chatbot obtained an average practicality score of 84.82%, which is categorized as highly practical. The results indicate that students were able to use the chatbot easily and that the developed media effectively supported the learning interaction during the preliminary trial. Based on these findings, the scaffolding chatbot was considered appropriate for implementation in the larger field trial. At the implementation stage, the revised scaffolding chatbot was implemented in mathematics learning involving 23 eleventh-grade students. During the learning activities, students accessed the chatbot using the instructions provided in the student worksheet (LKPD). After completing the learning activities, both the teacher and students completed practicality questionnaires to evaluate the usability of the developed media. The practicality results are presented in Table 3.

Table 3. Practicality Evaluation Results

Respondent	Percentage (%)	Category
Teacher	82,50	Highly Practical
Students	86,18	Highly Practical

As presented in Table 3, the scaffolding chatbot was categorized as highly practical based on both teacher and student evaluations. The teacher rated the chatbot as highly practical with a percentage of 82.50%, while students gave a practicality score of 86.18%, which also falls within the highly practical category. These findings indicate that the developed chatbot was easy to use and effectively supported mathematics learning during classroom implementation. In addition to the practicality evaluation, the effectiveness of the developed media was measured through students' mathematical problem-solving tests administered before and after the implementation. The comparison of the average pretest and posttest scores is presented in Figure 6.

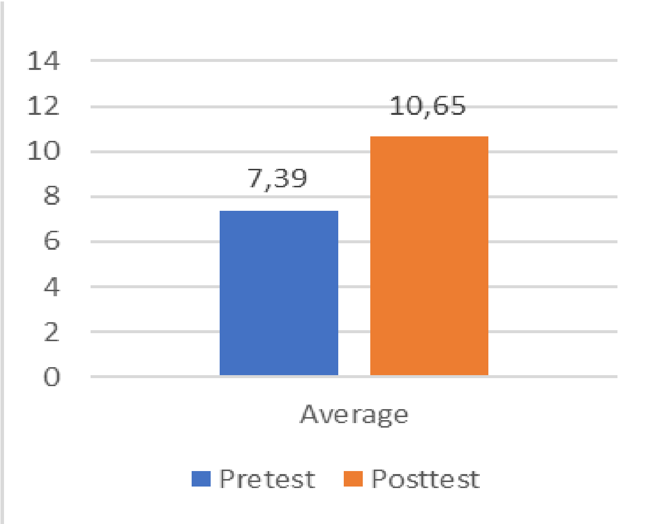


Figure 6. Comparison of the Average Pretest and Posttest Scores

Figure 6 shows that the average posttest score was higher than the average pretest score, indicating an improvement in students' mathematical problem-solving skills after using the scaffolding chatbot. The normalized gain (N-gain) analysis yielded an average score of 0.45, which falls into the medium category. These results indicate that students' mathematical problem-solving skills improved following the implementation of the developed chatbot. To determine whether the improvement was statistically significant, an inferential analysis was conducted. The Shapiro–Wilk test on the difference scores between the posttest and pretest indicated that the data were not normally distributed ($p = 0{,}008; p < 0.05$). Therefore, the Wilcoxon Signed-Rank Test was employed. The results of the Wilcoxon Signed-Rank Test are presented in Figure 7.

Test Statistics[a]

	posttest - pretest
Z	-3.939[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Figure 7. Results of the Wilcoxon Signed-Rank Test

As shown in Figure 7, the Wilcoxon Signed-Rank Test indicated a statistically significant difference between the pretest and posttest scores ($Z = -3.939, p < 0.05$). The effect size was also calculated using the formula $r = \frac{Z}{\sqrt{N}}$, resulting in an effect size of 0.82, which is categorized as a large effect. This finding indicates that the scaffolding chatbot had a substantial impact on improving students' mathematical problem-solving skills in the topic of Three-Variable Linear Equation Systems. The evaluation stage was conducted formatively throughout each phase of the ADDIE development model to refine the scaffolding chatbot. The evaluation process incorporated feedback obtained from the needs analysis, media design, expert validation, small-group trial, and classroom implementation. Revisions were made at each stage to improve the chatbot's content, interaction flow, interface, and usability. The final evaluation indicated that the developed scaffolding chatbot met the established criteria for validity, practicality, and effectiveness. Therefore, the chatbot was considered suitable for facilitating students' mathematical problem-solving skills in learning Three-Variable Linear Equation Systems.

Discussion

The findings demonstrate that the developed scaffolding chatbot achieved a high level of validity, indicating that its content, interaction structure, interface, usability, and scaffolding components were sufficiently aligned with the intended mathematics learning objectives. The overall validity score of 80.00% suggests that integrating scaffolding principles into chatbot-based learning can produce a pedagogically appropriate digital environment for supporting mathematical problem solving. This result is consistent with previous research demonstrating that educational chatbots become more pedagogically meaningful when their technological capabilities are integrated with explicit instructional strategies rather than being used merely as information-delivery systems (Cheng et al., 2024; Lee & Yeo, 2022). Similar findings have been reported in research on chatbot-supported scaffolding, where structured conversational assistance facilitated learning by directing students toward relevant cognitive activities while maintaining learner participation in constructing responses (Bai et al., 2025; Guo et al., 2022). In the present study, this principle was operationalized through guiding questions, prompts, hints, and feedback corresponding to successive stages of mathematical problem solving. Such an interaction structure is particularly relevant because scaffolding should provide sufficient assistance to enable learners to progress while avoiding excessive intervention that could replace their independent reasoning. The revisions made following expert validation, particularly improvements to prompt clarity, contextual problems, and interface readability, further illustrate the importance of simultaneously considering pedagogical and technological dimensions when developing AI-supported learning media. This finding aligns with studies emphasizing that the educational effectiveness of AI-based environments depends not only on technical functionality but also on the quality of interaction design and the pedagogical relevance of the support provided (Chau et al., 2025; Liu et al., 2025). Consequently, the validity findings support the conceptual position that a mathematics chatbot should be designed as a structured learning environment rather than simply as a conversational interface capable of producing mathematical answers. The developed chatbot therefore extends the educational function of chatbot technology by embedding problem-solving-oriented scaffolding directly within the interaction sequence used by students.

The practicality findings further demonstrate that the scaffolding chatbot could be implemented effectively from the perspective of its intended users, with an average small-group practicality score of 84.82% and field-trial scores of 82.50% from the teacher and 86.18% from students. These consistently high evaluations indicate that the chatbot and accompanying student worksheet provided an accessible structure for engaging students in technology-supported mathematical problem solving. The result is consistent with previous studies showing that chatbot-based environments can facilitate accessible and interactive learning experiences by allowing students to obtain instructional assistance through conversational exchanges (Chang et al., 2023; Cheng et al., 2024). The slightly higher practicality evaluation provided by students than by the teacher may reflect students' positive experience with the immediacy and interactive nature of chatbot-supported assistance, although this interpretation requires further empirical investigation. Importantly, the practicality of the developed system was not determined solely by the chatbot interface because the student worksheet also provided procedural guidance for accessing and interacting with the digital environment. This combination differs from approaches in which students interact with a general-purpose chatbot without an explicit instructional sequence, as the worksheet helped situate chatbot use within organized mathematical learning activities. Previous research on educational chatbots has similarly suggested that the usefulness of conversational technologies increases when their implementation is connected to clearly structured learning tasks and instructional objectives (Jančařík et al., 2023; Straková & Válek, 2024). Furthermore, the high practicality ratings suggest that structured scaffolding can be incorporated into chatbot interaction without making the learning environment excessively complicated for students. From the teacher's perspective, such technology may also provide an additional mechanism for extending learning assistance when individualized guidance for every learner is difficult to sustain during classroom instruction. Therefore, the practicality results reinforce the feasibility of combining chatbot interaction, structured scaffolding, and worksheet-guided activities as an integrated approach to supporting mathematics learning.

The effectiveness analysis provides promising evidence that students' mathematical problem-solving performance improved following the implementation of the scaffolding chatbot. The N-gain value of 0.45 indicates a moderate level of improvement, suggesting that students developed better problem-solving performance after participating in chatbot-supported learning, although considerable room for further development remained. Inferential analysis strengthened this finding by revealing a statistically significant difference between pretest and posttest scores ($Z = -3.939$, $p < .05$), while the effect size of $r = 0.82$ indicated a large magnitude of change between the two measurements. These findings are broadly consistent with previous research reporting that AI-supported mathematics environments can contribute positively to mathematical problem solving by providing interactive, personalized, and responsive learning assistance (Bayaga, 2024; Chau et al., 2025; Liu et al., 2025). They also correspond with studies showing that personalized mathematics teaching supported by AI chatbots can create opportunities for students to engage more actively with mathematical problem-solving activities. However, the present findings extend this line of research by emphasizing the structure of the assistance rather than simply the availability of AI-generated mathematical support. Instead of immediately supplying complete solutions, the developed chatbot encouraged students to identify relevant information, formulate mathematical models, carry out mathematical procedures, and review their answers through successive prompts. This mechanism is theoretically consistent with scaffolding research indicating that guided assistance can support learners in performing cognitive activities while gradually maintaining greater responsibility for their own learning processes (Huda et al., 2025; Zhou et al., 2025). The observed improvement may therefore be associated with repeated opportunities for students to articulate intermediate reasoning and reconsider their responses before proceeding to subsequent stages, although the present design does not permit this mechanism to be established causally. Accordingly, the results provide preliminary empirical support for the proposition that chatbot-based assistance may be more educationally meaningful when its interaction structure is explicitly aligned with the cognitive processes involved in mathematical problem solving.

The findings are particularly relevant to learning Three-Variable Linear Equation Systems because students' initial difficulties were concentrated in understanding contextual problems and translating information into appropriate mathematical models. These difficulties are consequential because inaccurate interpretation at the beginning of a problem can propagate into equation formulation, procedural execution, and final-answer verification. The scaffolding chatbot addressed this issue by organizing assistance around four interconnected stages: understanding the problem, formulating mathematical models, carrying out the solution process, and verifying the solution. This process-oriented organization distinguishes the developed medium from AI applications that primarily emphasize answer generation, general tutoring, or unrestricted mathematical assistance (Chaiprasurt et al., 2022; Guler et al., 2024). It also complements recent studies that have used generative AI and chatbot-supported environments for mathematical word-problem solving and personalized mathematical problem-solving instruction (Chau et al., 2025; Liu et al., 2025). Whereas these studies demonstrate the broader potential of AI to support mathematical learning, the present study positions scaffolding as the pedagogical mechanism that determines how and when assistance is delivered throughout the solution process. Similar process-oriented principles have emerged in chatbot-based scaffolding studies outside mathematics, where conversational systems have been used to support argumentative writing, self-regulated learning, inquiry processes, and instructional design through structured prompts and feedback (Bai et al., 2025; Chen et al., 2026; Guo et al., 2022). The current findings therefore suggest that these scaffolding principles can be meaningfully transferred to secondary mathematics when the conversational sequence is aligned with domain-specific problem-solving demands. Importantly, the chatbot does not eliminate students' cognitive responsibility because students remain required to interpret information, construct equations, execute procedures, and evaluate their own answers. In this sense, the main pedagogical contribution of the developed chatbot lies not in automating mathematical problem solving but in mediating students' progression through it.

Taken together, the validity, practicality, N-gain, inferential, and effect-size findings provide complementary evidence regarding the educational potential of the developed scaffolding chatbot. The study contributes to the growing literature on artificial intelligence in mathematics education by demonstrating a design in which chatbot technology is explicitly organized around scaffolding and successive mathematical problem-solving processes. This contribution is important because recent reviews and empirical studies indicate rapid growth in AI applications within mathematics education while simultaneously highlighting the need to connect technological innovation with pedagogically grounded learning designs. Compared with chatbot approaches centered predominantly on content delivery, question answering, or general personalized assistance, the present design emphasizes guided progression through students' reasoning processes. It also complements research on adaptive and personalized scaffolding, which has shown that strategically delivered support can facilitate learner regulation, engagement, and performance across digital learning environments (Azevedo et al., 2022; Faber et al., 2024; Lim et al., 2023; Munshi et al., 2023). Nevertheless, the findings should be interpreted as evidence of promising educational potential rather than definitive causal proof of chatbot effectiveness because the field implementation involved only 23 students and did not include a comparison group. The significant pretest–posttest difference and large effect size demonstrate substantial within-group change, but they cannot independently exclude alternative influences such as regular instruction, repeated testing, students' prior knowledge, or other contextual factors. For this reason, the principal contribution of the study lies in establishing the feasibility, validity, practicality, and preliminary effectiveness of a process-oriented scaffolding chatbot rather than claiming superiority over other instructional approaches. Future investigations using larger samples, comparison groups, longer intervention periods, and multiple mathematical topics would provide stronger evidence regarding the effectiveness and generalizability of the proposed approach. Overall, the findings support the continued development of scaffolding-oriented chatbot environments in which artificial intelligence complements rather than replaces students' mathematical reasoning and progressively supports more independent problem solving.

Implications

The findings of this study provide important implications for the integration of scaffolding and chatbot technology in mathematics education. Pedagogically, the developed chatbot provides structured guidance through questions, prompts, hints, and feedback across successive stages of mathematical problem solving. This approach positions the chatbot as a learning companion rather than merely a tool for generating mathematical answers. For students, scaffolded interactions can encourage active reasoning, reflection, and greater independence when solving Three-Variable

Linear Equation Systems. For teachers, the chatbot can complement classroom instruction by extending learning assistance when individualized guidance is difficult to provide continuously. The integration of the chatbot with student worksheets also enables its use to remain connected to structured learning activities. From a technological perspective, the findings emphasize that educational chatbots should be designed around pedagogical objectives rather than technological capabilities alone. The validity and practicality results indicate that content quality, scaffolding strategies, interaction flow, and usability are important considerations in chatbot development. The observed improvement in students' problem-solving performance further suggests the potential value of process-oriented chatbot support in mathematics learning. However, the chatbot should complement rather than replace teachers' instructional roles. Theoretically, this study demonstrates how scaffolding principles can be operationalized through conversational technology within mathematical problem solving. Overall, the findings support the development of AI-assisted learning environments that promote more systematic, reflective, and independent mathematical problem solving.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting its findings. First, the field trial involved only 23 eleventh-grade students from a single school, limiting the generalizability of the results. Second, the absence of a comparison group prevents strong causal conclusions regarding the effectiveness of the scaffolding chatbot. Third, the chatbot was developed specifically for Three-Variable Linear Equation Systems, and its effectiveness across other mathematical topics remains uncertain. The relatively limited implementation period also did not allow the study to examine the long-term retention of students' problem-solving skills. In addition, the evaluation primarily focused on quantitative outcomes and did not deeply investigate students' reasoning during chatbot interactions. Future studies should therefore involve larger and more diverse samples from multiple educational settings. Experimental or quasi-experimental designs with comparison groups are recommended to provide stronger evidence of effectiveness. Further research should also examine the application of scaffolding chatbots across different mathematical topics and levels of difficulty. Qualitative approaches, such as interviews, think-aloud protocols, and chatbot interaction logs, could provide deeper insights into students' responses to scaffolding. Longitudinal studies are also needed to examine the sustainability of improvements in mathematical problem-solving skills. These directions could provide stronger evidence for the development of more responsive, scalable, and pedagogically grounded scaffolding chatbots in mathematics education.

CONCLUSION

This study successfully developed a scaffolding chatbot designed to facilitate senior high school students' mathematical problem-solving skills in learning Three-Variable Linear Equation Systems (SPLTV). The chatbot was developed as a technology-assisted learning medium that integrates structured scaffolding into successive stages of mathematical problem solving. Its interaction mechanism employs guiding questions, prompts, and reflective feedback to assist students in understanding problems, formulating mathematical models, carrying out solution procedures, and verifying their answers. Rather than directly providing final solutions, the chatbot encourages students to remain actively involved in constructing and evaluating their mathematical reasoning. The evaluation results demonstrated that the developed chatbot met the established criteria for validity and practicality, indicating its suitability for classroom implementation. Students also demonstrated improvement in mathematical problem-solving performance following the chatbot-supported learning activities. These findings provide promising evidence that structured chatbot interactions can support students as they progress through different stages of mathematical problem solving. The integration of scaffolding into chatbot interactions therefore extends the function of educational chatbots beyond information delivery toward process-oriented mathematical learning support. In this context, the chatbot serves as a complementary learning companion that assists students while preserving their responsibility for developing mathematical solutions independently. The developed medium may also provide teachers with an alternative means of extending structured learning assistance when continuous individualized guidance is difficult to provide during classroom instruction. Overall, this study highlights the potential of scaffolding-oriented chatbot design to promote more interactive, structured, and student-centered mathematics learning. Further implementation across larger and more diverse student populations and mathematical topics is needed to establish the broader effectiveness and applicability of this approach.

AUTHOR CONTRIBUTIONS STATEMENT

Hardian Tri Wulandari contributed to conceptualization, methodology, investigation, data collection, formal analysis, software development, visualization, and writing the original draft. Santi Irawati contributed to conceptualization, methodology, validation, supervision, and manuscript review and editing. Susiswo contributed to methodology, validation, supervision, interpretation of findings, and manuscript review and editing. All authors contributed to the development and refinement of the manuscript, reviewed the final version, and approved it for publication.

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