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Effectiveness of a Metacognitive Scaffolding-Based Adaptive Learning Clinic Model on Students' Learning Outcomes in Quadratic Equations

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ABSTRACT

Students' difficulties in solving quadratic equations involve more than procedural algebraic skill. They also involve the ability to identify appropriate strategies, monitor solution steps, and evaluate whether answers are correct. Addressing these difficulties calls for an instructional model that responds to students' diverse learning needs by diagnosing difficulties, providing differentiated support, and strengthening metacognitive regulation. This study aimed to determine the effectiveness of the Adaptive Learning Clinic model based on Metacognitive Scaffolding (ALC-MS) on the quadratic equation learning outcomes of prospective mathematics teachers. A quasi-experimental method with a nonequivalent pretest–posttest control group design was employed. Participants were 75 students from the Mathematics Education Study Program at Universitas Negeri Makassar: 37 in the experimental group and 38 in the control group. The intervention was implemented over four sessions of 2 × 45 minutes each. Data were collected using a five-item essay test whose content validity was reviewed by two experts and whose reliability was 0.82 (Cronbach's alpha). The data were analyzed using descriptive statistics, N-Gain, ANCOVA, and the Mann–Whitney test. The mean posttest score of the experimental group (89.54) was higher than that of the control group (82.55). After controlling for prior ability, a significant difference in learning outcomes was found between the two groups ($F(1, 72) = 51.60$, $p < .001$, $\eta p^2 = .417$). The mean N-Gain was 0.74 (high category) for the experimental group and 0.50 (moderate category) for the control group. These findings indicate that the ALC-MS model produced better learning outcomes than direct instruction. The model's key characteristic is that it integrates learning needs diagnosis, differentiated clinic services, and metacognitive scaffolding. Together, these support quadratic equation learning that responds to students' learning needs and abilities.

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Introduction

Algebra is an important foundation of mathematics learning because it provides the symbolic language and reasoning framework needed to understand many advanced mathematical concepts (Baybayon & Lapinid, 2024; Gustafsson, 2026). In higher education, algebraic proficiency is a prerequisite for other mathematics courses. It also supports students' ability to represent problems, develop solution strategies, and reason mathematically in a systematic way. For prospective mathematics teachers, algebraic proficiency is also the basis for understanding, explaining, and teaching mathematical concepts accurately (Didiş Kabar, 2023; Gustafsson, 2026; Tendere & Mutambara, 2020). However, students enter university with varying levels of readiness and conceptual mastery of mathematics. Instruction therefore needs to do more than focus on problem solving: it must also identify learning difficulties and support students according to their needs. Quadratic equations are a suitable topic for examining this issue, because solving them involves conceptual understanding, procedural accuracy, strategy selection, and mathematical reasoning (Defiana et al., 2022; Didiş Kabar, 2023; Lisurara' Sura' et al., 2021).

Solving quadratic equations requires an understanding of algebraic expressions, number operations, factoring, and the equivalence of equations, as well as the accurate application of various solution procedures. Previous studies have shown that errors in solving mathematical equations are often related to difficulties with symbolic transformation and procedural skills, including weaknesses in understanding algebraic expressions, fractions, and negative numbers (Defiana et al., 2022). These findings suggest that difficulties in learning quadratic equations cannot be understood merely as an inability to carry out algorithms. Instead, they should be examined in terms of the types of errors made and the thinking processes behind them. Similarly, recent studies have classified mathematical difficulties as conceptual misconceptions, procedural errors, and technical errors, and have emphasized the importance of diagnostic assessment in identifying learning needs more precisely (Buhaerah et al., 2022; Supriyadi et al., 2022). The problems first-year students face with quadratic equations can therefore be grouped into three categories: (1) Prerequisite problems, such as operations on algebraic expressions, fractions, negative numbers, and radicals; (2) Procedural problems, such as factoring errors, sign errors when completing the square, and substitution errors when using the quadratic formula; and (3) Strategic and metacognitive problems, such as choosing inefficient methods, failing to relate the discriminant to the nature of the roots, failing to check the roots obtained, and failing to reject roots that are not meaningful in the context of the problem. Because these problems differ from one student to another, instruction on quadratic equations should include a way to identify each student's difficulties and to provide support that matches the type of difficulty.

Beyond conceptual and procedural mastery, the ability to regulate one's thinking is an important aspect of algebra learning. Students may make errors not only because they have not yet understood a concept, but also because they do not plan their solution strategy, monitor the accuracy of their steps, or evaluate whether their results are reasonable. Planning, monitoring, and evaluating cognitive activity are central components of metacognition (Kamelia & Pujiastuti, 2020; Nasir & Khadijah, 2026; Scarampi et al., 2024). Metacognition is closely related to self-regulated learning, that is, an individual's ability to actively direct and evaluate their own learning (Amini et al., 2020; Shinta et al., 2025). Empirical evidence shows that metacognition contributes to academic achievement beyond the contribution of general intelligence (Dabarera et al., 2014), A meta-analysis by Muncer et al also reported a positive relationship between metacognition and mathematics achievement, with a correlation

coefficient of $r = .37$. In addition, interventions that integrate metacognitive strategies into instruction can support the development of students' self-regulation skills (Hartmann et al., 2024; Nguyen et al., 2025). These findings suggest that improving algebra learning outcomes requires attention to how students plan, monitor, and evaluate their problem-solving processes, not only to how often they practice particular procedures.

One approach that can support these processes is metacognitive scaffolding. Scaffolding refers to temporary assistance that enables learners to complete tasks they cannot yet perform independently. The support is tailored to the learner and gradually withdrawn as the learner's competence develops (Dassa et al., 2024; Dassa et al., 2024). This concept is consistent with the notion of the zone of proximal development, which emphasizes the role of support in developing individual abilities. Dassa et al., (2024) emphasized that contingency, fading (the gradual withdrawal of support), and transfer of responsibility are key characteristics of scaffolding. In mathematics instruction, such support can take the form of guiding questions and prompts that lead students to plan strategies, justify their choice of procedures, check each step, and evaluate their final answers. This support is not meant to replace students' thinking; rather, it helps them develop the ability to regulate their own thinking independently. Research on computer-based scaffolding in STEM education has shown positive effects on cognitive outcomes (Deibl et al., 2023; Menekse et al., 2025), Studies of technology-enhanced learning have likewise shown that metacognitive support can help learners manage complex learning processes (Ambarwati & Wahyuni, 2023; Dabarera et al., 2014; Haataja et al., 2019). The improve approach, which integrates metacognitive questioning, cooperative learning, feedback, and remedial activities, has also been reported to improve mathematics achievement in heterogeneous classrooms (Matsuda et al., 2020). Other studies have shown that metacognitive training can support mathematical reasoning (Rosy et al., 2025), mathematical problem solving (Kamelia & Pujiastuti, 2020; Sukmawati, 2022), and mathematical proof among prospective teachers. Taken together, these findings support the relevance of metacognitive scaffolding, although its effectiveness still needs to be tested across different contexts, participant characteristics, and subject matter.

The potential of metacognitive scaffolding can be strengthened through adaptive learning, an approach that adjusts the form of support, the activities, or the learning pathway according to learners' needs and progress. A systematic review by Xie et al. (2024) documented the growth of research on technology-based adaptive and personalized learning. In algebra instruction, adaptivity can be achieved by identifying students' difficulties, grouping students by learning needs, providing different forms of support for different types of errors, and evaluating progress to determine the next level of support. Adaptive learning therefore does not always have to be delivered through digital systems. It can also be implemented by organizing face-to-face learning services that respond to students' needs. Advances in research on adaptive scaffolding, including support from generative artificial intelligence, have further opened opportunities to develop mathematics instruction that is more responsive to individual needs (Imran et al., 2024; Intang Sappaile et al., 2024). Nevertheless, the use of technology and adaptive approaches should still be grounded in sound pedagogical goals and relevant empirical evidence.

Although research on metacognition, scaffolding, and adaptive learning has grown, there is still room to integrate all three into a single instructional model designed specifically for first-year university students. First, much of the metacognitive scaffolding research cited in this study involved secondary school students or focused on problem solving and reasoning. Its

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effectiveness for university students' learning outcomes in elementary algebra therefore requires further investigation. Second, adaptive learning has largely been developed through technology-based systems. A face-to-face mathematics clinic integrated into regular coursework, by contrast, requires a design that specifies how diagnosing difficulties, providing assistance, and monitoring student progress are linked. Third, it remains unclear to what extent integrating diagnostic assessment, differentiated learning clinic services, and gradually faded metacognitive scaffolding can produce better learning outcomes than direct instruction on quadratic equations. These gaps provided the rationale for developing and testing the Adaptive Learning Clinic model based on Metacognitive Scaffolding (ALC-MS). The model integrates four elements: identifying learning needs, providing support matched to students' specific difficulties, using metacognitive questions to guide problem solving, and gradually fading assistance to foster learner independence. The proposed novelty lies in integrating these components into an instructional design for elementary algebra in higher education, not in claiming that each component is an entirely new approach. Empirical testing is needed to determine whether this integration contributes to students' learning outcomes.

Accordingly, this study aimed to examine the effectiveness of the ALC-MS model on first-semester Mathematics Education students' learning outcomes in quadratic equations. Specifically, the study aimed to: (1) describe and compare the learning outcomes of students taught with the ALC-MS model and those taught with direct instruction; (2) examine differences in posttest learning outcomes between the two groups while controlling for students' prior ability; and (3) compare the improvement in learning outcomes between the two groups. The findings are expected to provide empirical evidence on adaptive learning that integrates diagnostic assessment and metacognitive scaffolding in university-level elementary algebra instruction. They are also expected to offer an alternative instructional design that responds to students' learning difficulties and supports their independence as learners.

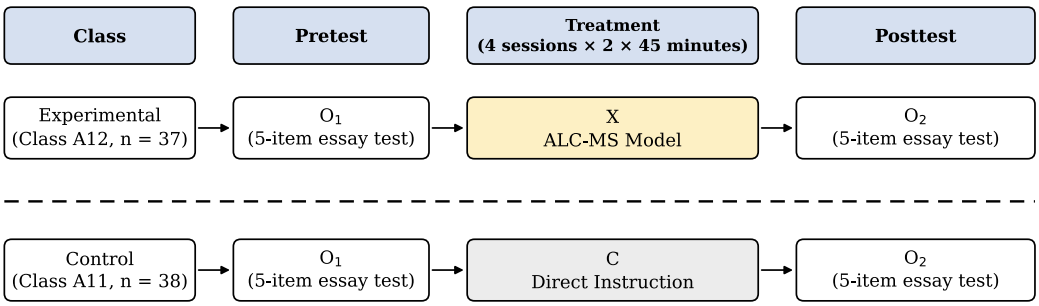
The Adaptive Learning Clinic Model Based on Metacognitive Scaffolding (ALC-MS)

The ALC-MS model implements adaptive learning by adjusting learning services to the needs and difficulties identified through diagnostic assessment. At the beginning of each session, the lecturer administers a short diagnostic test to determine students' mastery of prerequisite concepts and of the procedures for solving quadratic equations. Based on the results, students are directed to one of three learning clinic stations: prerequisite reinforcement, procedural consolidation, or enrichment. Each station provides different activities and levels of support according to the nature of students' difficulties. Adaptivity in the ALC-MS model therefore goes beyond grouping students; it also involves adjusting learning activities and assistance to match the learning needs identified. This adaptive component is integrated with metacognitive scaffolding through guiding questions that are introduced gradually as students work on problems. The lecturer guides students to plan their strategies, monitor the accuracy of their solution steps, and evaluate their results. The type of assistance depends on the difficulties that arise. It starts with general questions and moves to more specific hints if students remain stuck, and it is then gradually withdrawn as students become able to solve problems independently. At the end of each session, evaluation results and formative quizzes are used as the basis for feedback and for adjusting clinic services in the next session. By integrating these two components, ALC-MS links learning needs diagnosis, differentiated intervention, and ongoing metacognitive support within a single instructional model.

Method

Research Type

This study used a quantitative approach with a quasi-experimental method and a nonequivalent pretest–posttest control group design. This design was chosen because instruction took place in intact classes already assigned by the study program, so students could not be randomly assigned to treatment groups. A pretest was given to both groups for two purposes: to check whether the groups were equivalent in prior ability, and to serve as a covariate in the analysis. This ensured that observed differences in learning outcomes could not be attributed solely to differences in prior ability. The experimental class was taught with the ALC-MS model, and the control class received direct instruction. Both classes covered the same material, had the same time allocation, and were taught by the same lecturer. The research design is presented in Figure 1.



Note. O_1 = pretest; O_2 = posttest; X = ALC-MS model treatment; C = direct instruction; dashed line = groups were not randomly assigned (intact classes).

Figure 1. Nonequivalent Pretest–Posttest Control Group Research Design

Population and Sample

The population of this study comprised all students in the Mathematics Education Study Program, Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, who were enrolled in the Elementary Algebra course in the 2026/2027 academic year. The sample consisted of two intact classes: Class A12 as the experimental class ($n = 37$) and Class A11 as the control class ($n = 38$), for a total of 75 students. All participants belonged to the 2026 cohort. They had recently completed secondary education, had followed the same curriculum, and were in the early stage of transition to university-level mathematics. All participants completed both the pretest and the posttest, so there were no missing data. The demographic characteristics of the participants are presented in Table 1.

Table 1. Demographic Characteristics of the Participants

Characteristic	Category	Experimental ($n = 37$)	Control ($n = 38$)	Total ($n = 75$)
Gender	Male	12 (32.43%)	7 (18.42%)	19 (25.33%)
	Female	25 (67.57%)	31 (81.58%)	56 (74.67%)
Cohort	2026	37 (100%)	38 (100%)	75 (100%)
Prior ability	Pretest mean (*SD*)	64.95 (8.35)	66.47 (7.71)	65.72 (8.01)

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Instruments

The research instrument was an essay-type achievement test consisting of five items on quadratic equations. The essay format was chosen because it allowed the researchers to assess not only students' final answers but also their understanding of the problem, choice of strategy, procedural accuracy, and habit of checking their answers, all of which are directly related to metacognitive activity. The five items were developed based on the course learning outcome indicators. They covered solving quadratic equations by factoring and by completing the square, analyzing the nature of the roots using the discriminant, applying the sum and product of roots, and modeling contextual problems. Each item was scored using an analytic rubric with a maximum score of 20, consisting of problem understanding (4), solution strategy (4), procedural and computational accuracy (8), and checking and drawing conclusions (4). Total scores therefore ranged from 0 to 100. The content validity of the instrument was reviewed by two experts in mathematics education, specializing in learning evaluation and achievement test development. Test reliability was estimated using Cronbach's alpha, yielding $\alpha = .82$, which indicates good internal consistency. A description of the test items is presented in Table 2.

Table 2. Description of the Quadratic Equation Achievement Test Items

Test Item	Item Characteristics
Item #1. Find the solution set of the equation $2x^2 - 7x + 3 = 0$ by factoring, then verify your answer by substitution.	Students must (1) rewrite $2x^2 - 7x + 3$ as $(2x - 1)(x - 3)$; (2) apply the zero-product property; and (3) verify the roots $x = ½$ and $x = 3$ by substitution. Maximum score: 20.
Item #2. Solve the equation $x^2 + 6x - 11 = 0$ by completing the square. Express the roots in simplest radical form.	Students must transform the equation into $(x + 3)^2 = 20$ and simplify the radical to obtain $x = -3 \pm 2\sqrt{5}$. This item reveals procedural accuracy and sign errors. Maximum score: 20.
Item #3. Find all values of m such that the equation $x^2 - (m + 1)x + 4 = 0$ has two equal real roots. Explain your reasoning.	Students must relate the condition for repeated roots to the discriminant $D = 0$, solve $(m + 1)^2 - 16 = 0$ to obtain $m = 3$ or $m = -5$, and justify their choice of this condition. Maximum score: 20.
Item #4. The roots of the equation $2x^2 - 5x - 4 = 0$ are α and β. Without first finding the roots, determine (a) the value of $\alpha^2 + \beta^2$, and (b) a new quadratic equation whose roots are $(\alpha + 1)$ and $(\beta + 1)$.	Students must use $\alpha + \beta = 5/2$ and $\alpha\beta = -2$ to obtain $\alpha^2 + \beta^2 = 41/4$, and then construct the new equation $2x^2 - 9x + 3 = 0$. This item requires strategic planning without computing the roots directly. Maximum score: 20.
Item #5. A rectangular garden measuring 20 m × 14 m is surrounded by a path of uniform width on all sides. If the total area of the garden and the path is 432 m², find the width of the path.	Students must model the problem as $(20 + 2x)(14 + 2x) = 432$, simplify it to $x^2 + 17x - 38 = 0$, solve it, and reject the root $x = -19$ because it is not meaningful in context, giving a path width of 2 m. Maximum score: 20.

Procedure and Data Collection

The study was conducted in the odd (fall) semester of the 2026/2027 academic year in four stages. The preparation stage involved developing the lesson plans, student worksheets, diagnostic assessment items, metacognitive prompt cards, and test instrument, and validating these materials. In the second stage, the pretest was administered to both classes. In the third stage, the intervention was implemented over four sessions of 2 × 45 minutes each. The experimental class was taught using the ALC-MS model, which consists of five phases, as

presented in Table 3. The control class received direct instruction, which began with the lecturer's explanation of concepts, followed by worked examples, individual practice, and whole-class discussion. In the fourth stage, the posttest was administered after all sessions had been completed, followed by rubric-based scoring and data analysis. The complete research procedure is presented in Figure 2.

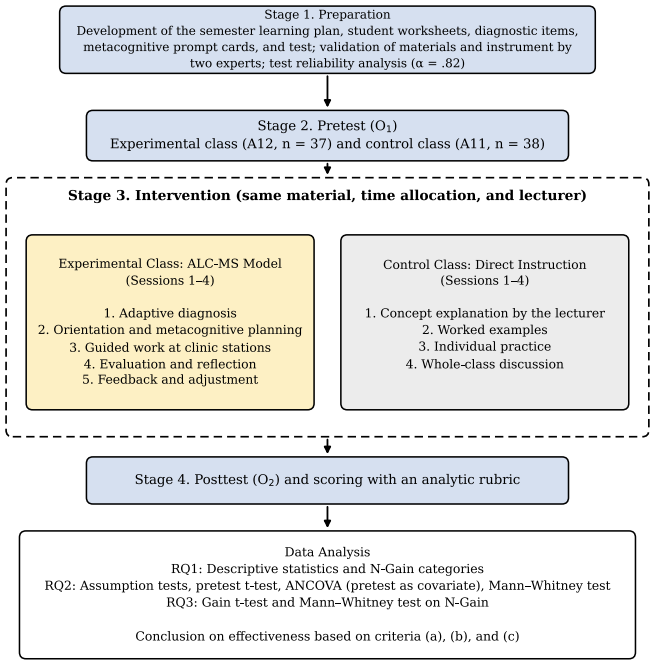


Figure 2. Research Procedures

Table 3. Syntax of the Adaptive Learning Clinic Model Based on Metacognitive Scaffolding (ALC-MS)

Phase	Lecturer Activities	Student Activities
1. Adaptive diagnosis	Administers 3–4 short diagnostic items and assigns students to clinic stations based on the results (prerequisite reinforcement, procedural consolidation, or enrichment).	Complete the diagnostic items and rate their confidence in their answers.
2. Orientation and metacognitive planning	Presents a trigger problem and planning prompts, such as "What information is given?" and "Which method is the most efficient, and why?"	Identify the given information, select a solution strategy, and write a work plan.
3. Guided work at the learning clinic	Circulates among the stations and provides tiered metacognitive scaffolding, from general monitoring questions to specific hints, then gradually fades this support.	Complete the station-specific worksheets, monitor each step, and discuss with peers at the same station.
4. Evaluation and reflection	Provides evaluation prompts, such as "How can you make sure your answer is correct?", and facilitates comparison of solution methods.	Check their answers by substitution, compare methods, and write an error-reflection journal.
5. Feedback and adjustment	Administers a short formative quiz, gives feedback, and uses the results to adjust student grouping for the next session.	Complete the quiz, receive feedback, and set their next learning goals.

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The core of the ALC-MS model lies in two components. The adaptive component is implemented through a short diagnostic assessment at the beginning of each session, the results of which are used to place students in clinic stations according to their needs: prerequisite reinforcement, procedural consolidation, or enrichment. The metacognitive scaffolding component is implemented through tiered prompts that guide students to plan strategies, monitor their solution steps, and evaluate their answers. Assistance begins with general questions and escalates to more specific hints only when necessary. It is then gradually faded as students become able to work independently.

Data Analysis

The data were analyzed descriptively and inferentially. The descriptive analysis included the mean, standard deviation, median, and minimum and maximum scores for the pretest, posttest, and gain of each class. The magnitude of improvement in learning outcomes was calculated using the normalized gain (N-Gain) with the following formula:

$$g = \frac{S_{\text{post}} - S_{\text{pre}}}{S_{\text{maks}} - S_{\text{pre}}}$$

where g is the N-Gain value, S_{post} is the posttest score, S_{pre} is the pretest score, and S_{maks} is the maximum possible score (100). The g values were categorized as high if $g \geq 0.7$, moderate if $0.3 \leq g < 0.7$, and low if $g < 0.3$.

Before hypothesis testing, the Shapiro–Wilk test was used to check normality and Levene's test was used to check homogeneity of variances. Equivalence of prior ability was examined using an independent-samples t-test on the pretest scores. Differences in learning outcomes were tested using analysis of covariance (ANCOVA), with posttest scores as the dependent variable, class as the factor, and pretest scores as the covariate, after the assumption of homogeneity of regression slopes had been checked. Because the posttest and N-Gain scores of the experimental class were not normally distributed, owing to the large number of maximum scores, differences in these two variables were also tested using the Mann–Whitney test as a complementary analysis. Effect sizes were reported as partial eta squared (ηp^2), Cohen's d, and $r = z/\sqrt{N}$. All tests were conducted at a significance level of $\alpha = .05$. The ALC-MS model was considered effective if it met three criteria: (a) the learning outcomes of the experimental class were significantly higher than those of the control class after controlling for prior ability; (b) the mean N-Gain of the experimental class was in the high category; and (c) the N-Gain of the experimental class was significantly higher than that of the control class.

Research Findings

The results are presented in four parts: a description of learning outcomes, prerequisite testing and equivalence of prior ability, testing of differences in learning outcomes, and analysis of improvement in learning outcomes.

Implementation of the Adaptive Learning Clinic Model Based on Metacognitive Scaffolding (ALC-MS)

The ALC-MS model was implemented in the experimental class over four sessions on quadratic equations. All five phases of the model were implemented: adaptive diagnosis, orientation and metacognitive planning, guided work at the learning clinic, evaluation and

reflection, and feedback and adjustment. Each phase actively involved both the lecturer and the students.

In the adaptive diagnosis phase, the lecturer administered diagnostic items to identify students' initial mastery of quadratic equations. Based on their performance, students were directed to clinic activities suited to their individual needs: prerequisite concept reinforcement, procedural consolidation, or enrichment. In the orientation and metacognitive planning phase, the lecturer presented problems and guiding questions to help students identify the given information, determine a strategy, and plan their solution steps. In the guided work phase, students completed worksheets matched to their learning needs. The lecturer provided assistance through gradually tiered metacognitive questions, particularly when students had difficulty understanding concepts or deciding on solution procedures (Figure 3). In the evaluation and reflection phase, students rechecked their answers, compared solution strategies, and identified the errors they had made. In the final phase, the lecturer administered a formative quiz and gave feedback, which served as the basis for planning instruction in the next session (Table 4).

Table 4. Implementation of the ALC-MS Model in Each Session

Session	Learning Focus	Implementation of Adaptive Learning	Implementation of Metacognitive Scaffolding
1	Basic concepts of quadratic equations and solving by factoring	The lecturer administered a diagnostic assessment to identify mastery of algebraic operations and factoring. Students were directed to the prerequisite reinforcement, procedural consolidation, or enrichment clinic based on the diagnostic results.	Students were guided to identify the information in the equation, choose a factoring strategy, justify their choice of strategy, and verify the roots by substitution.
2	Solving quadratic equations by completing the square	The lecturer administered a diagnostic assessment to determine students' understanding of algebraic manipulation and squaring operations. Activities at each clinic were adjusted to the difficulties identified.	The lecturer posed guiding questions to help students plan the transformation of the equation, monitor the accuracy of each step, and evaluate their solutions.
3	Using the discriminant and the sum and product of roots	The diagnostic results were used to determine whether students needed reinforcement of the discriminant concept, consolidation of formula use, or enrichment in applying the relationships between roots.	Students were guided to select relevant concepts, justify their use of the discriminant or root relationships, check the accuracy of their calculations, and compare solution strategies.
4	Applying quadratic equations to contextual problems and consolidating the material	The lecturer diagnosed students' understanding of modeling contextual problems and solving quadratic equations. Clinic activities were adjusted to the remaining difficulties.	Students planned the mathematical model, monitored the solution process, checked whether the results fit the problem context, and reflected on their errors. The lecturer administered a formative quiz and gave feedback to plan follow-up instruction.

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Figure 3. Documentation of the Learning Implementation Using the ALC-MS Model

Description of Learning Outcomes

Descriptive statistics for the pretest, posttest, gain, and N-Gain scores of both classes are presented in Table 5. The mean pretest scores of the two classes were nearly equal: 64.95 for the experimental class and 66.47 for the control class, with the control class scoring slightly higher. After the intervention, the mean posttest score of the experimental class reached 89.54, which was 6.99 points higher than that of the control class (82.55). The mean gain of the experimental class (24.59) was also greater than that of the control class (16.08), with a narrower spread (*SD* = 4.45 vs. 5.57). The lowest posttest score was 73 in the experimental class and 62 in the control class. In addition, 9 students (24.3%) in the experimental class achieved the maximum score of 100, compared with only 1 student (2.6%) in the control class.

Table 5. Descriptive Statistics of Elementary Algebra Learning Outcomes

Variable	Class	*n*	*M*	*SD*	*Mdn*	Min	Max
Pretest	Experimental	37	64.95	8.35	65.00	48	83
	Control	38	66.47	7.71	67.00	49	81
Posttest	Experimental	37	89.54	8.40	90.00	73	100
	Control	38	82.55	9.05	83.00	62	100
Gain	Experimental	37	24.59	4.45	25.00	14	33
	Control	38	16.08	5.57	16.00	5	27
N-Gain	Experimental	37	0.74	0.19	0.74	0.37	1.00
	Control	38	0.50	0.20	0.46	0.13	1.00

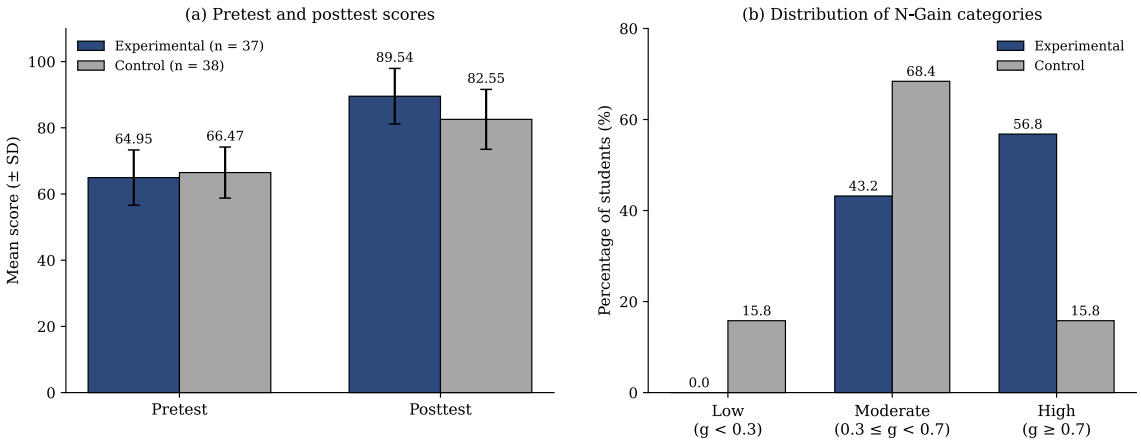


Figure 4. (a) Mean Pretest and Posttest Scores and (b) Distribution of N-Gain Categories in Both Classes

Figure 4 shows that the two classes started from relatively similar baselines, but the experimental class showed a steeper increase. The distribution of N-Gain categories also differed markedly. In the experimental class, 21 students (56.8%) were in the high category and 16 students (43.2%) were in the moderate category, with none in the low category. The control class was dominated by the moderate category (26 students; 68.4%), with 6 students (15.8%) in each of the high and low categories.

Prerequisite Tests and Equivalence of Prior Ability

The results of the prerequisite tests are presented in Table 6. Pretest and gain scores were normally distributed in both classes, whereas the posttest and N-Gain scores of the experimental class were not normally distributed (p = .012 and p = .023, respectively). This non-normality was associated with a ceiling effect, as many students in the experimental class achieved the maximum score. Variances were homogeneous between the two classes for all variables (p > .05).

Table 6. Results of the Normality and Homogeneity of Variance Tests

Variable	Shapiro-Wilk Experiment	Shapiro-Wilk Control	Levene
Pretest	W = 0,982; p = 0,814	W = 0,986; p = 0,897	F = 0,216; p = 0,643
Posttest	W = 0,921; p = 0,012	W = 0,981; p = 0,752	F = 0,039; p = 0,844
Gain	W = 0,962; p = 0,236	W = 0,976; p = 0,586	F = 3,075; p = 0,084
N-Gain	W = 0,930; p = 0,023	W = 0,961; p = 0,211	F = 0,098; p = 0,756

An independent-samples t-test on the pretest scores showed no significant difference between the experimental and control classes, $t(73) = -0.82$, $p = .413$, $d = -0.19$. The mean difference was −1.53 points, with a 95% confidence interval of [−5.23, 2.17]. Because this interval includes zero, the two classes can be considered equivalent in prior ability. Both classes showed significant improvement from pretest to posttest, in the experimental class, $t(36) = 33.62$, $p < .001$, and in the control class, $t(37) = 17.79$, $p < .001$. The main research question was therefore whether the improvement in the experimental class was greater than that in the control class.

Testing of Differences in Learning Outcomes

Before conducting the ANCOVA, the assumption of homogeneity of regression slopes was examined by testing the interaction between class and pretest. The interaction was not significant, $F(1, 71) = 0.19$, $p = .666$, indicating that the assumption was met. The model residuals were normally distributed ($W = 0.994$, $p = .975$), and their variances were homogeneous across classes ($F = 2.82$, $p = .097$). The ANCOVA results are presented in Table 7.

Table 7. ANCOVA Results for Posttest Scores with Pretest as the Covariate

Source of Variation	JK	db	RK	F	p	η_p^2
Pretest (Covariate)	3.765,80	1	3.765,80	149,90	< 0,001	0,676
Class	1.296,20	1	1.296,20	51,60	< 0,001	0,417
Error	1.808,78	72	25,12			

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Table 7 shows that, after controlling for prior ability, class had a significant effect on posttest scores, $F(1, 72) = 51.60$, $p < .001$, $\eta p^2 = .417$. The adjusted posttest mean was 90.23 ($SE = 0.83$) for the experimental class and 81.88 ($SE = 0.81$) for the control class. The adjusted mean difference was 8.35 points, 95% CI [6.04, 10.67]. An ηp^2 of .417 indicates that approximately 42% of the posttest variance not explained by the pretest was accounted for by the difference in instructional model, which represents a large effect. The Mann–Whitney test, used as a complementary analysis, led to the same conclusion. The mean posttest rank of the experimental class (46.11) was higher than that of the control class (30.11), $U = 1003.0$, $z = 3.19$, $p = .001$, $r = .37$.

Improvement in Learning Outcomes

The analysis of improvement in learning outcomes reinforced these findings. The mean gain of the experimental class was 8.52 points higher than that of the control class, 95% CI [6.19, 10.84], $t(73) = 7.30$, $p < .001$, $d = 1.69$. The mean N-Gain of the experimental class (0.74) was in the high category, whereas that of the control class (0.50) was in the moderate category. The Mann–Whitney test showed that the N-Gain of the experimental class was significantly higher, with mean ranks of 49.55 and 26.75, respectively, $U = 1130.5$, $z = 4.54$, $p < .001$, $r = .52$. Thus, all three effectiveness criteria were met. The learning outcomes of the experimental class were significantly higher after controlling for prior ability; the mean N-Gain of the experimental class was in the high category; and the N-Gain of the experimental class was significantly higher than that of the control class. The ALC-MS model was therefore effective in improving students' elementary algebra learning outcomes on quadratic equations.

Discussion

The findings of this study indicate that the effectiveness of ALC-MS was reflected not only in differences in final learning outcomes but also in the magnitude of learning gains when students' prior ability was taken into account. This pattern matters because the advantage of the experimental class cannot be attributed solely to participants' initial conditions; it was consistent with the outcomes obtained after the instructional model was implemented. Nevertheless, because the study used a quasi-experimental design with intact classes, causal interpretations should still consider possible factors other than the intervention. Theoretically, these results can be explained by the way ALC-MS integrates diagnostic assessment, adaptive learning, and metacognitive scaffolding. Diagnostic assessment identifies students' initial difficulties, and adaptive support directs instructional assistance toward their differing needs. Metacognitive scaffolding then helps students plan their solutions, monitor their work, and evaluate the accuracy of their results. All three components are relevant to algebra learning because success in solving quadratic equations depends not only on procedural mastery but also on the ability to understand relationships between concepts, select strategies, and detect errors. ALC-MS thus conceptually links the diagnosis of difficulties with instructional intervention and with the regulation of students' thinking.

This explanation is consistent with the findings of Xie et al. (2024), whose meta-analysis of 147 studies involving 698,096 participants found a positive relationship between metacognition and mathematics achievement. Alfageh et al. (2024) also reported that metacognitive training had a positive effect on algebraic reasoning. Both studies support the argument that developing the ability to regulate one's thinking is an important part of mathematics learning. However, neither study directly tested ALC-MS with university students

learning quadratic equations. The present study therefore extends this evidence to the context of algebra learning in higher education.

The advantage of ALC-MS can also be understood through the principle of tailoring learning support to students' needs. Diagnostic assessment enables the lecturer to recognize both conceptual and procedural errors before deciding what assistance is needed. In algebra learning, students who do not yet understand the relationship between factored form and the roots of an equation need different support from students who understand the concept but are careless in symbolic manipulation (Ambarwati & Wahyuni, 2023; Dabarera et al., 2014; Haataja et al., 2019). Adaptive instruction can therefore make interventions more targeted than instruction that gives the same support to all students. Findings by Alfageh et al., (2024) and Chen & McDunn (2022) show that adaptive diagnostic assessment can help teachers group students by learning needs, plan instruction, and provide more focused feedback. Although these studies were conducted in primary education, the principles of diagnosis and instructional adjustment are relevant in explaining the mechanisms that may underlie the effectiveness of ALC-MS.

The findings also highlight the importance of distinguishing between improvement that results from instruction in general and the greater improvement observed in the class taught with ALC-MS. Both classes improved significantly, which suggests that instruction in both conditions contributed to students' development. However, the experimental class improved more, as indicated by both gain and N-Gain scores, and the difference remained after prior ability was controlled for through ANCOVA. This strengthens the interpretation that ALC-MS provided additional benefits beyond the control instruction in the context of this study. The magnitude of this difference should be interpreted in light of the research design and implementation conditions, rather than as evidence that the model will produce the same effect across all topics and student groups.

This interpretation should also be situated within research on metacognitive scaffolding, which has not always produced uniform results. A study of metacognitive scaffolding in algebraic equation learning by Matsuda et al. (2020) reported improvement in equation-solving ability after the intervention but found no significant difference in effectiveness among the three learning conditions compared. Similarly, a study of scaffolding adaptivity among prospective mathematics teachers found no significant benefit of adaptivity for improving judgment accuracy, although there were indications that the adaptation process influenced participants' activity during learning (Kamelia & Pujiastuti, 2020; Nasir & Khadijah, 2026; Scarampi et al., 2024). These findings show that the presence of scaffolding or adaptivity alone does not automatically guarantee better outcomes; effectiveness depends on how well the support matches learning needs, on the adaptation mechanism, and on the outcomes measured. The results for ALC-MS therefore provide empirical evidence supporting the potential of integrating these components, while also showing the need to examine how they work in greater depth.

In terms of learning outcomes, the greater improvement in the experimental class may indicate that students not only had additional practice opportunities but also received more targeted assistance in overcoming their difficulties. Metacognitive support can help students locate their errors, reconsider the strategies they used, and check whether their answers are reasonable. In solving quadratic equations, for example, students need to select an appropriate strategy, carry out algebraic manipulations correctly, and verify the roots they obtain. When this process is accompanied by appropriate guiding questions and feedback, students have the opportunity to revise their strategies rather than simply repeat flawed procedures. However,

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because the results reported here focus on test scores, this explanation of metacognitive processes remains a theoretical interpretation. Direct measurement through observation, analysis of student work, or interviews is needed to confirm that these mechanisms actually occurred during the implementation of ALC-MS.

Another issue to consider is that some students in the experimental class achieved the maximum score. This shows that several students reached the highest score on the instrument, but it also suggests a possible ceiling effect. Such an effect may limit the test's ability to discriminate among students who have already reached a high level of mastery. The non-normality of the posttest and N-Gain scores in the experimental class should therefore be interpreted with caution. The use of ANCOVA, whose model assumptions were met, together with the Mann–Whitney test as a complementary analysis, provided consistent support for the between-class difference. Nevertheless, future studies could use instruments with a wider range of item difficulty so that improvement among high-ability students can be measured more sensitively.

In terms of novelty, the contribution of this study lies in testing the effectiveness of the ALC-MS model, which integrates diagnostic assessment, adjustment of learning support, and metacognitive scaffolding in university-level elementary algebra instruction. Previous studies have examined the relationship between metacognition and mathematics achievement, metacognitive training for algebraic reasoning, and the use of adaptive diagnostic assessment. This study extends that evidence at the level of instructional design by testing the outcomes of integrating these three components in the teaching of quadratic equations. The novelty lies mainly in this pedagogical integration and its empirical testing, not in a claim that each component is an entirely new concept. To establish this novelty more firmly, future research should specify operationally how diagnostic results determine the type of assistance, how metacognitive support is provided and gradually faded, and how students' responses are used to adjust the intervention.

Overall, the results support the effectiveness of ALC-MS in improving students' elementary algebra learning outcomes compared with the control instruction in the context of this study. Theoretical support and previous research strengthen the likelihood that the diagnosis of difficulties and metacognitive regulation contributed to this improvement. In practical terms, lecturers should consider using diagnostic assessment as a basis for targeted assistance, accompanied by guiding questions that help students plan, monitor, and evaluate their problem solving. Nevertheless, the results should be generalized with caution, because the study was limited to one topic and one group of students. Future research should examine the retention of learning outcomes, transfer of understanding to other algebra topics, and the relative contribution of each ALC-MS component to the development of students' abilities.

Conclusion

The Adaptive Learning Clinic model based on metacognitive scaffolding was effective in improving the quadratic equation learning outcomes of Mathematics Education students. With equivalent prior ability, students taught with this model achieved higher learning outcomes than those who received direct instruction. Their mean improvement was in the high category, and none of them remained in the low improvement category. This advantage is likely attributable to the combination of learning needs diagnosis, differentiated clinic services, and gradual metacognitive support that accustoms students to planning, monitoring, and rechecking their solutions. Theoretically, this study contributes by showing that the principles of adaptive learning and metacognitive scaffolding can be combined in face-to-face first-year university

courses. Practically, the syntax of the ALC-MS model can be readily adopted by lecturers of foundational courses. This study has four limitations, each of which provides a basis for recommendations for future research. First, the study used two intact classes from a single institution without random assignment, which limits the generalizability of the results; future studies should involve more classes and institutions or use designs with random assignment. Second, the study covered only quadratic equations; the ALC-MS model should be tested on other algebra topics, such as functions, inequalities, and systems of equations. Third, metacognitive skills were not measured directly, so the role of metacognitive scaffolding in improving learning outcomes remains an interpretation; future studies should measure metacognitive awareness as a mediating variable through questionnaires, observation, or interviews. Fourth, some students in the experimental class achieved the maximum score, resulting in a ceiling effect, and the retention of learning outcomes was not tested; future studies should use instruments with a wider range of difficulty and delayed tests to measure retention.

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Declarations

Conflict of Interest : The authors declare that there are no conflicts of interest.

Auhor Contributions : N.N.: Conceptualization, Investigation.
A.: Conceptualization, Methodology, Data curation, Formal analysis
S.: Conceptualization, Methodology, Data curation, Formal analysis
M.A.N.: Conceptualization, Methodology, Data curation, Formal analysis
M.N.H.: Conceptualization, Methodology, Data curation, Formal analysis
M.H.: Conceptualization, Methodology, Data curation, Formal analysis

Data Availability Statement : The data supporting the findings of this study are available from the corresponding author, S., upon reasonable request

AI Statement : The authors declare that generative AI tools were used to improve the clarity, grammar, and readability of the English language.

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