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Effects of Direct Instruction Supported by Algebrator on Learning Outcomes in Linear Equation Systems

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ABSTRACT

Students' understanding of systems of linear equations in two variables is often limited due to the abstract nature of the topic and the requirement for logical and systematic reasoning skills. To address this issue, an appropriate instructional model supported by effective learning media is needed. This study aimed to examine the effect of the Direct Instruction learning model supported by Algebrator on students' learning outcomes in systems of linear equations . This study employed a quasi-experimental method using a control group pretest–posttest design. The participants were eighth-grade students at a public Islamic junior high school. The sample consisted of two classes, with 25 students in the experimental group and 25 students in the control group. The experimental group was taught using the Direct Instruction model supported by Algebrator, while the control group received conventional instruction without technological media. Data were analyzed using descriptive statistics and an independent samples t-test at a significance level of 0.05. The results showed that the mean posttest score of the experimental group was 83.44, which was higher than that of the control group, which obtained a mean score of 76.76. The t-test results indicated a significant difference between the two groups ($t = 2.35$, $p < 0.05$). These findings demonstrate that students taught using the Direct Instruction model supported by Algebrator achieved significantly better learning outcomes than those taught using conventional methods. This study indicates that the integration of technological learning media such as Algebrator can effectively enhance students' understanding and learning outcomes in mathematics, particularly in systems of linear equations . The findings provide empirical support for the use of technology-assisted Direct Instruction in mathematics classrooms.

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Introduction

Mathematics learning is an intellectual process that requires a strong connection between concepts, procedures, and reasoning (De Chenne & Lockwood, 2022; Pepin, 2021; Sand et al., 2022). In the field of education, the interaction between teachers and students not only functions as a transmission of information, but also as a process of knowledge construction that requires appropriate, systematic, and contextual (Remillard et al., 2021). Mathematics as an abstract discipline requires an approach that bridges students' understanding from concrete concepts to more complex symbolic representations (Wilkie & Hopkins, 2024). This condition emphasizes the importance of learning designs that facilitate a gradual and meaningful internalization of concepts.

When mathematics learning is applied in the classroom, the quality of interaction and the effectiveness of teaching strategies become the main determinants of student success. Observations in class VIII of MTS Negeri 1 Manado show that mathematics learning outcomes are still at an alarming level, with only a small percentage of students meeting the proficiency standards. This disparity indicates fundamental obstacles in the learning process, ranging from a weak understanding of basic concepts, low levels of student activity, to a lack of learning media that provides lively and meaningful learning experiences (Koskinen & Pitkäniemi, 2022). These problems reveal the need for renewal efforts that touch on methodological and pedagogical aspects.

The transition towards the need for a solution arises when considering the characteristics of the Two Variable Linear Equation System material, which is abstract and requires the ability to accurately connect symbolic representations with mathematical procedures. Materials not only requires the ability to construct mathematical models, but also requires precision in manipulating algebraic forms. Without strong conceptual guidance, students easily get caught up in procedural errors and misinterpretations of the meaning of variables and linear relationships. This condition requires a learning model that is able to provide a clear, focused, and gradual thinking structure.

The Direct Instruction model is one relevant approach because it emphasizes explicit, sequential teaching that focuses on the skills students must master in stages (Sormunen et al., 2020; Turan & Koç, 2018). Through examples, guided practice, and gradual reinforcement, Direct Instruction builds a bridge between basic concepts and procedural application (Habsyi et al., 2022). However, the abstract nature of algebra often requires more than just verbal or symbolic explanations; visualization and dynamic representation are essential for a deeper understanding of mathematical structures and relationships. This shows that direct teaching requires the support of digital media to reinforce the internalization of concepts.

Algebrator provides this opportunity because it is able to present visual representations, systematic solution steps, and algebraic simulations that are easy for students to understand (Kosko, 2020; Patahuddin et al., 2022). The presence of this technology gives students the opportunity to see how an equation is manipulated sequentially, so that they not only memorize the procedure, but are able to understand the reasoning behind each step. Previous research findings show that the use of Algebrator has a positive impact on conceptual understanding, problem solving, and learning outcomes in algebra (Öçal et al., 2020). The integration of Direct Instruction with Algebrator opens up space for a more structured, interactive, and visually-rich learning process.

The need to test the integration of the two is even stronger when considering that previous studies generally examined the effectiveness of Direct Instruction or Algebrator separately. This gap indicates significant research space to assess how the combination of a systematic learning model and interactive digital media can improve learning outcomes, especially in

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LINEAR EQUATIONS material. This integration is expected to improve the obstacles that have arisen in the learning process, such as procedural errors, low interest in learning, and a lack of understanding of algebraic structures. Based on this context, this study aims to evaluate whether the learning outcomes of students who participate in Direct Instruction assisted by Algebrator show a more significant improvement compared to students who learn through Direct Instruction without digital media support. The focus of this study is not only on the effectiveness of the model but also on its contribution to improving the quality of mathematics learning, especially in building students' conceptual and procedural understanding in a more in-depth and continuous manner.

Method

Type and Design of Research

This study used a quantitative approach with (*quasi-experimental research*) design because the researcher could not fully randomize the subjects into classes. The experimental design used was a *pre-test-post-test control group design*, which provided an opportunity to compare changes in learning outcomes before and after treatment in two different groups. In this design, the experimental class received Direct Instruction learning assisted by Algebrator media, while the control class received Direct Instruction learning without digital media. This design was chosen because it provides a clear picture of the effect of the treatment on improving student learning outcomes, while minimizing bias that may arise from differences in students' initial abilities. Both groups took a pre-test first, then received different treatments, and finally took the same post-test to see the difference in learning achievement improvement.

Table 1. Experimental Design (*Pre-test-Post-test Control Group Design*)

Group	***Pre-test***	***Treatment***	***Post-test***
Experiment	X_1	X	X_2
Control	X_1	Y	X_2

Keterangan:
X_1 = *Pre-test*
X_2 = *Post-test*
X = Learning using the *Direct Instruction* learning model assisted by the *Algebrator* learning media.
Y = Learning using the *Direct Instruction* learning model without the assistance of *Algebrator* learning media.

Research Subject

In this study, subjects were selected by randomly sampling two classes from six classes. Class VIII B, consisting of 25 students, was used as the experimental class, while class VIII C, also consisting of 25 students, was used as the control class.

Instruments

The main instrument in this study was a learning outcome test used to measure students' abilities in the subject of Two-Variable Linear Equation Systems. The test consisted of five essay questions, designed to evaluate students' abilities in understanding concepts, manipulating equations, interpreting information, and applying various methods to solve LINEAR EQUATIONS accurately. Essay questions were chosen for assessment because they are able to capture students' thought processes, reasoning skills, and mathematical accuracy more comprehensively than multiple- choice questions. The instrument was developed in several stages, namely: (1) identification of basic competencies and learning indicators, (2) development of a grid based on indicators, difficulty levels, and cognitive domains, (3) development of questions in accordance with the predetermined indicators, and (4) verification of the instrument through a process of expert validation to ensure the quality of the content and construction of the questions. Each question was designed to reflect variations in cognitive abilities ranging from basic knowledge (C1) and comprehension (C2) to application (C3), in accordance with Bloom's revised taxonomy. The grid served as a guide to ensure that the instruments developed were consistent with the learning indicators and covered all the abilities to be measured. The structure of the grid also ensures that the composition of the difficulty level of the questions is balanced between easy, medium, and difficult questions.

Table 2. Test Item Matrix Table

No	Question Indicator	Question Number	Cognitive Domain	Question Weight	Difficulty Level
1	Students can determine the solution of a two-variable linear equation	1	C1 (Knowledge)	10	Easy
2	Students can recognize the form of the linear equations system	2	C1 (Knowledge)	10	Easy
3	Students can solve linear equations using the graphical method	3	C2 (Understanding)	20	Moderate
4a	Students can solve linear equations using the elimination method	4a	C2 (Understanding)	15	Difficult
4b	Students can solve linear equations using the substitution method	4b	C2 (Understanding)	15	Difficult
5a	Students can formulate a linear equations mathematical model from contextual problems	5a	C3 (Application)	10	Difficult
5b	Students can calculate the solution to linear equations from contextual problems using a combined method	5b	C3 (Application)	20	Difficult

Explanation:
C1 = knowledge
C2 = Understanding
C3 = Application

Procedure

The research procedure was carried out in three main stages, namely the preparation stage, the implementation stage, and the final stage. These three stages were designed systematically to Ensuring that the treatment given to the experimental class and control class is consistent with the research design and produces valid and reliable data. During the preparation stage, the researcher first conducted direct observations at MTS Negeri 1 Manado to understand the learning context, classroom conditions, and the readiness of school facilities and environment for the implementation of the research. After that, the researcher compiled a research schedule that was adjusted to the lesson schedules of both classes so that the learning process in the experimental and control classes could take place without disrupting regular teaching and learning activities. At this stage, the researcher developed learning tools consisting of two types

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of teaching modules, namely the Direct Instruction module assisted by Algebrator media for the experimental class and the Direct Instruction module without Algebrator media for the control class. Both modules were designed for three meetings, each lasting 2 × 45 minutes. In addition, the researcher developed a research instrument in the form of a five-item essay test used to measure learning outcomes before and after the treatment.

The next stage was the implementation stage, which was the core stage of administering treatment to both research groups. The experimental class and control class were first given a pre-test to determine the students' initial abilities in the subject of Two Variable Linear Equation Systems. Next, the experimental class received Direct Instruction learning aided by Algebrator media, which was used as a tool for interactive visualization of the steps for solving linear equations. At the same time, the control class received Direct Instruction learning without digital media support, so that all material delivery was done conventionally. After all meetings were completed, both classes were given a post-test to determine the learning progress of each student and compare the improvements that occurred between the experimental class and the control class. In the final stage, the researcher collected all pre-test and post-test data and then processed and analyzed the data. The learning outcome data were analyzed using statistical techniques to determine the changes in scores that occurred during the treatment and to determine whether the Direct Instruction model assisted by Algebrator had a significant effect compared to Direct Instruction without digital media. Activities at this stage included data verification, scoring based on assessment rubrics, data tabulation, and analysis of learning outcome differences between groups. Data were collected using a written essay test, which was administered twice, before the treatment (pre-test) and after the treatment (post-test). This test was used to obtain objective and measurable scores of student learning outcomes, in accordance with the indicators specified in the instrument grid.

Data Analysis

Data analysis in this study was conducted in two main stages, namely statistical assumption testing and hypothesis testing, to ensure that the analysis procedure used met the requirements for the use of parametric techniques. The first stage began with a normality test using Lilliefors at a significance level of $\alpha = 0.05$ to ensure that the distribution of learning scores in the experimental and control classes followed a normal distribution. The data was declared to be normally distributed if the calculated L value was smaller than the table L value. After that, a homogeneity of variance test was performed using the F test to assess the similarity of the variances of the two groups. The variance was considered homogeneous if the calculated F value was smaller than the table F value at $\alpha = 0.05$. The normality and homogeneity tests were conducted to ensure that the parametric test technique used in the next stage could be applied validly.

After the assumptions of normality and homogeneity were met, the analysis continued with hypothesis testing using the independent two-sample t-test. This test was used to determine whether there was a significant difference in learning outcomes between the experimental class that received Direct Instruction assisted by Algebrator and the control class that received Direct Instruction without digital media. The t-test formula used considers the difference between the means of the two groups, the sample size of each group, and the combined standard deviation calculated from the variance of the two groups. The null hypothesis (H_0) states that there is no difference in the average learning outcomes between the two groups, while the alternative hypothesis (H_1) states that the average learning outcomes of the class using Direct Instruction assisted by Algebrator are higher than those of the class without Algebrator. Decisions were made by comparing the calculated t-value and the table t-value at a significance level of $\alpha =$

0.05; the alternative hypothesis was accepted if the calculated t-value was greater than the table t-value. This procedure was chosen because it was appropriate for the characteristics of quasi-experimental research, small sample size, unknown population variance, and data that met the basic assumptions of parametric analysis.

Research Findings

Table 3 shows an overview of the performance of students from two groups who received different treatments. The data show a clear pattern of improvement, but with different developmental characteristics between the experimental class and the control class. First, a comparison of the pretest mean scores shows that both groups started at almost the same initial ability level. The average pretest score for the experimental class was 28.72, while that for the control class was 27.08. The difference of 1.64 points indicates that there was no significant initial difference. This condition is important because it shows that the improvement that occurred at the posttest stage can be attributed to the learning treatment, not to differences in the students' initial abilities.

Second, there was a very significant increase between the pretest and posttest scores in both groups, but the experimental class showed a greater increase. The average posttest score for the experimental class was 83.44, while the control class scored 76.76. The difference in increase of 6.68 points shows that the use of Algebrator in the Direct Instruction model contributed to the mastery of linear equations concepts.Third, the gain score reinforces the evidence that the experimental class gained more benefits. The gain score for the experimental class was 54.72, while that for the control class was 49.68. The difference of about five points shows that Algebrator media improved students' retention, conceptual understanding, and procedural accuracy in solving linear equations. This difference in gain is also consistent with the results of statistical tests showing significance at the 0.05 level.

Fourth, the gain variance provides additional important information about the distribution of student abilities. The variance of the experimental class is 68.21, slightly higher than that of the control class, which was 47.14. The greater variance in the experimental class indicates a wider variation in improvement among students. In other words, some students experienced a huge leap in ability, while others experienced moderate improvement. This phenomenon commonly occurs when students are given access to visual and procedural aids such as Algebrator, because these media are more effective for students who respond more quickly to representation-based learning. Fifth, the larger standard deviation of the experimental class gain (8.26) compared to the control class (6.87) also reinforces the variance pattern. This indicates that Algebrator not only improves the average learning outcomes but also creates internal differentiation in how students process and understand linear equations. However, these differences remain within a reasonable range and do not interfere with the homogeneity of variance, so the learning model can still be considered effective overall.

Table 3. Summary Table of Statistics for Experimental and Control Classes

Statistics	Experimental (n=25)	Control (n=25)
Pretest – Mean	28,72	27,08
Posttest – Mean	83,44	76,76
Gain Score	**54,72**	**49,68**
SD Gain	8,26	6,87
Gain Variance	68,21	47,14

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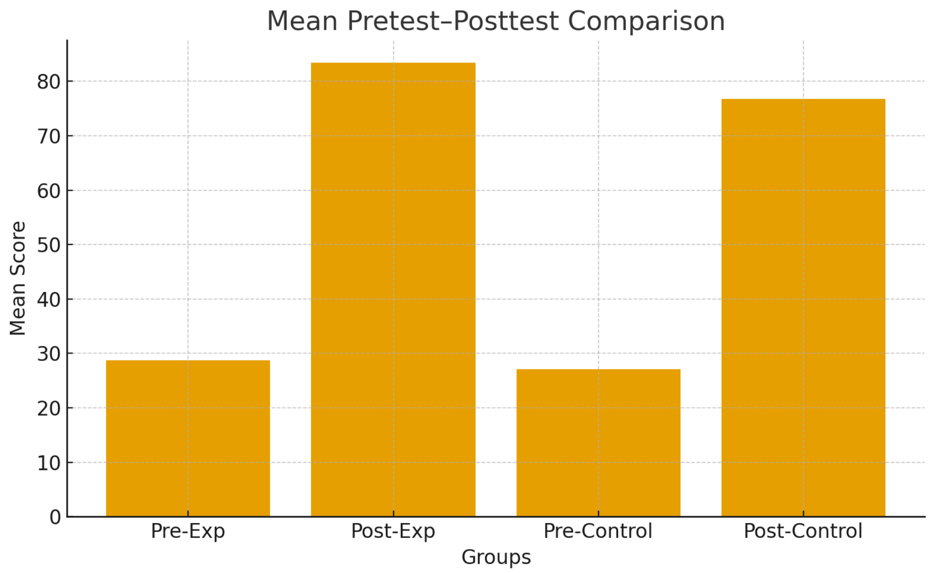

Figure 1. Mean Pretest-Posttest Comparison

The visualization of the pretest–posttest mean comparison shows that both groups began learning with relatively equal initial abilities, as seen from the pretest average of 28.72 for the experimental class and 27.08 for the control class, which are shown through bar graphs with almost the same height. This equality is important because it ensures that the increase in learning outcomes did not come from differences in initial abilities but from the learning treatment provided. At the posttest stage, the graph shows a much higher increase in the experimental class, which reached an average of 83.44, compared to the control class, which only reached 76.76. The difference in the height of the bars in this posttest graph shows that the use of Algebrator in the Direct Instruction model results in more optimal mastery of linear equations material. The sharper increase in scores in the experimental class indicates that digital media contributes significantly to strengthening procedural understanding, mathematical representation skills, and accuracy in solving problems.

Figure 2. Gain Score Comparison

The gain score visualization further emphasizes the difference in effectiveness between the two treatments. The graph shows that the experimental class obtained a gain score of 54.72, higher than the control class, which only reached 49.68. The higher bars on the gain graph for the experimental group illustrate that their learning improvement was not only greater on average but also more consistent. This explains that Algebrator is able to provide visual support and structured solution steps, making it easier for students to understand the relationship between equation systems and the elimination and substitution procedures. Thus, the two graphs together show that the integration of Algebrator media in the Direct Instruction model has a stronger pedagogical impact than conventional Direct Instruction learning, both in terms of final mastery levels and the extent of improvement in student abilities.

The Kolmogorov–Smirnov test results show significance values for the experimental class (Sig. = 0.200) and the control class (Sig. = 0.200). Both values are above the significance threshold of 0.05, so the data distribution is declared normal. The consistency of the results is reinforced by the Shapiro–Wilk test, which also showed Sig. = 0.415 (experimental) and Sig. = 0.684 (control), all of which were greater than 0.05. Thus, the assumption of normality was met, so the data was suitable for use in parametric analysis, including the independent two-sample t-test.

Table 4. Kolmogorov-Smirnov Test

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Experiment	.102	25	.200*	.961	25	.415
Control	.073	25	.200*	.974	25	.684

*This is a lower bound of the true significance.

Table 5. Interpretasi Test of Homogeneity of Variances

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Gain_Score	1.4468	1	48	.236

Levene's test is used to determine whether the variances of two data groups are homogeneous. In this study, the Levene Statistic value is 1.4468 with Sig. = 0.236. Since the Sig. value is greater than 0.05, there is no evidence to reject the assumption of variance homogeneity. In other words, the variances of the experimental and control groups can be considered equal or homogeneous. Because the variances are homogeneous, in the Independent Samples Test section, the analysis must use the "Equal variances assumed" row. This ensures that the t-test applied is in accordance with the data distribution requirements and does not produce biased conclusions.

Table 6. Interpretasi Group Statistics

Group	N	Mean	Std. Deviation	Std. Error Mean
Experimental	25	54.72	8.26	1.65
Control	25	49.68	6.87	1.37

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This section shows an overview of the increase in learning outcomes (gain score) in both groups. The experimental group had an average gain score of 54.72, while the control group had an average gain score of 49.68. The difference in the average of 5.04 points indicates that Direct Instruction learning aided by Algebrator provides higher learning outcomes compared to learning without Algebrator. The standard deviation of the experimental group (8.26) is slightly greater than that of the control group (6.87). This suggests that the improvement in learning outcomes in the experimental class is more diverse, possibly because the Algebrator media has a different impact on each student according to their individual learning speed and style. Descriptive data shows a tendency that the integration of the Algebrator media produces a stronger improvement, but the certainty of the difference must be tested using a t-test in the next section.

Table 7. Two-sample independent t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	df	Sig.(2-tailed)	Mean Diff.
Gain_Score	Equal variances assumed	1.446	.236	2.346	48	.023	5.040

This section displays the main results of the two-sample independent t-test. Since Levene's test shows homogeneous variance, the Equal variances assumed row is the row used to interpret the results. In that row, the t value is 2.346, with a degree of freedom (df) of 48 and a significance value Sig. (2-tailed) = 0.023. The value 0.023 is less than 0.05, which means that there is a statistically significant difference between the gain scores of the experimental class and the control class. The *mean difference* is 5.040, which means that students who received Direct Instruction assisted by Algebrator experienced a 5-point increase in learning outcomes compared to students who studied without Algebrator. These results show that the use of Algebrator significantly improves the understanding of linear equations concepts, enabling students to understand the relationship between variables, the elimination-substitution procedure, and mathematical representations more clearly.

Discussion

The results of this study indicate that the application of the Direct Instruction model integrated with Algebrator leads to higher learning outcomes compared to Direct Instruction without digital media. The experimental group achieved a higher mean score than the control group, and this difference was statistically significant at the 5% level. These results confirm that the integration of Algebrator contributes meaningfully to students' mastery of systems of linear equations in two variables. The findings suggest that students benefit not only from explicit teacher explanations but also from visual representations and structured solution steps provided by the software. The improvement in learning outcomes can be explained through several theoretical perspectives. From the standpoint of Cognitive Load Theory (Agterberg et al., 2022; Yilmaz, 2020), algebraic problem solving often imposes a high intrinsic cognitive load due to the need to simultaneously process symbolic manipulation and abstract representations (Björklund & Palmér, 2022; Tondorf & Prediger, 2022). Algebrator supports learning by presenting solution procedures in a sequential and structured manner, thereby reducing extraneous cognitive load and allowing students to focus more effectively on conceptual understanding rather than procedural complexity. Combining text, symbols, and interactive visual elements facilitates dual-channel processing, which enhances retention, comprehension, and transfer of mathematical knowledge when solving linear equation problems (Zandieh & Andrews-Larson, 2019).

Beyond cognitive outcomes, the findings also suggest positive effects on affective aspects of learning. Drawing on Self-Determination Theory (Street et al., 2022), the use of interactive digital media can enhance students' intrinsic motivation by creating a learning environment that is engaging, relevant, and aligned with students' familiarity with technology. Algebrator provides elements of digital scaffolding that enable students to work independently while remaining guided, which supports autonomy and builds confidence in problem solving. This condition strengthens the effectiveness of Direct Instruction, particularly during guided practice and independent practice phases, as students receive consistent instructional support beyond direct teacher explanations.

From an empirical perspective, the results of this study are consistent with previous national and international research. Previous studies (Fredriksdotter et al., 2022; Fuchs et al., 2020; Sindy Mustika Sari et al., 2022) reported that algebra software enhances students' problem-solving abilities in linear equation topics. Similarly, international studies demonstrated that integrating visual mathematical software increases student engagement, accelerates conceptual understanding, and reduces procedural errors (Harris et al., 2023). The present study extends this body of evidence by demonstrating that such benefits also apply when algebra software is integrated into a structured instructional model such as Direct Instruction. From an instructional design perspective, these findings suggest that technology should not function as a substitute for instruction but rather as a complementary tool that strengthens structured teaching approaches. The effectiveness of Algebrator in this study appears to stem from its alignment with the systematic stages of Direct Instruction, including explanation, modeling, guided practice, and independent practice (Sormunen et al., 2020). This alignment supports coherence between instructional strategy and learning media, which is critical for optimizing learning outcomes in abstract mathematical topics.

Furthermore, this study highlights the importance of selecting technological tools that explicitly support procedural transparency and conceptual clarity. In the context of linear equations , where students often struggle with symbolic transitions and algebraic reasoning, software that visualizes steps and relationships can serve as a bridge between abstract symbols and conceptual understanding (Kontorovich, 2020). This insight has practical implications for mathematics teachers in selecting and integrating digital tools that align with specific learning objectives. Overall, this study demonstrates that combining Direct Instruction with Algebrator not only improves students' learning outcomes but also enriches the learning experience through visual support, digital scaffolding, and enhanced motivation. This instructional integration represents a relevant and effective approach for teaching systems of linear equations , a topic that has consistently posed challenges for junior high school students. The findings reinforce the view that well-integrated educational technology can play a strategic role in addressing persistent difficulties in algebra learning.

Conclusion

The findings of this study confirm that integrating the Direct Instruction model with Algebrator has a significant positive effect on students' learning outcomes in systems of linear equations in two variables, as evidenced by differences in posttest scores and t-test results that are significant at the 5% level. These results suggest that visual and interactive technological media not only enhance the effectiveness of Direct Instruction by reducing cognitive load, but also support deeper conceptual understanding and increase students' motivation to learn.

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From a theoretical perspective, these findings extend empirical evidence supporting the relevance of Cognitive Load Theory, Multimedia Learning Theory, and principles of digital scaffolding in algebra instruction at the junior high school level. The results demonstrate that well-designed technological media can function as effective instructional supports when integrated into structured teaching models. From a practical perspective, this study highlights the importance of incorporating digital media as a supporting component of Direct Instruction to improve clarity in content presentation, strengthen procedural mastery, and provide additional support for students with low prior knowledge. Nevertheless, this study has several limitations, including a limited sample size drawn from a single school, a relatively short intervention period, and assessment instruments that focused primarily on cognitive learning outcomes without examining affective aspects or students' mathematical thinking processes in greater depth. Future research is therefore recommended to involve a larger and more diverse sample, extend the duration of the intervention, integrate both cognitive and non-cognitive assessment measures, and employ mixed methods approaches to explore students' internal learning processes when using technological tools such as Algebrator to develop mathematical understanding in a more comprehensive manner.

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Conflict of Interest

The authors declare that there is no conflict of interest.

Authors' Contributions

The first author, S.M., contributed as the research designer, data collector, and discussion of results. The other authors, M.S. and S.J.A.S., participated in revising and finalizing this article. Contributions to the conceptualization, writing, and correction of this article are as follows: S.M.: 70%, M.S.: 15%, and S.J.A.S.: 15%.

Data Availability Statement

The authors declare that data sharing is not applicable, as no new data were created or analyzed in this study.

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