PAEDAGOGIA
Jurnal Penelitian Pendidikan
http://jurnal.uns.ac.id/paedagogia

DOI: 10.20961/Paedagogia.v29i3.127184
Vol. 29, No. 3, 2026, pp. 434-450
p-ISSN 0126-4109
e-ISSN 2549-6670

Visualizing Volume through Unit Cubes: The Effect of Tinkercad 3D Design on Elementary Students' Conceptual Understanding

Titah Eka Finanda[1], Ramadhan Kurnia Habibie[1]*, Wiryanto[2], Zaenal Abidin[1], Erika Maulita Zuliyawati[3]
[1] Department of Elementary School Teacher Education, Faculty of Education, Surabaya State University, Surabaya, Indonesia.
[2] Departement of Elementary Education, Faculty of Education, Surabaya State University, Surabaya, Indonesia.
[3] Pradah Kalikendal 1 State Elementary School, Surabaya, Indonesia

Keywords: *Conceptual Understanding; Cuboid Volume; Tinkercad 3D Design*

Article history
Received: 14 August 2026
Revised: 10 October 2026
Accepted: 20 October 2026
Published: 31 October 2026

*Corresponding Author Email:
ramadhanhabibie@unesa.ac.id

DOI: 10.20961/paedagogia.v29i3.127184

© 2026 The Authors. This open-access article is distributed under a CC BY-SA 4.0 DEED License

Abstract: Understanding the concept of cuboid volume requires learning experiences that enable students to connect spatial representations with mathematical relationships meaningfully. This study aimed to analyze the effect of Tinkercad 3D Design on improving students' conceptual understanding of cuboid volume and to examine differences in conceptual improvement between students who learned using Tinkercad 3D Design and those who used concrete learning media. A quantitative approach was employed using a quasi-experimental method with a Nonequivalent Control Group Design. The participants comprised 54 fourth-grade students from an elementary school in Surabaya, Indonesia, who were assigned to an experimental group and a control group. Data were collected through pretests, posttests, student response questionnaires, and teacher observation guidelines. Data analysis included descriptive statistics, prerequisite tests, a Paired-Samples t-test to examine improvements in conceptual understanding, N-Gain analysis, the Mann–Whitney U test, and effect size analysis. The results indicated that students who learned using Tinkercad 3D Design demonstrated greater improvement in conceptual understanding than those who learned using concrete media, with a moderate effect size. Students' responses also indicated a highly positive acceptance of the media, particularly in supporting visualization, exploration, and understanding the relationship between dimensions and the volume of cuboids. These findings suggest that Tinkercad 3D Design provides an interactive three-dimensional learning environment that enables students to visualize, manipulate, and explore geometric objects directly. Therefore, Tinkercad 3D Design can serve as an alternative instructional medium to support students' conceptual understanding of cuboid volume through visual, active, and exploratory learning experiences.

How to cite: Finanda, T. E., Habibie, R. K., Wiryanto, Abidin, Z. & Zuliyawati, E. M. (2026). Visualizing Volume through Unit Cubes: The Effect of Tinkercad 3D Design on Elementary Students' Conceptual Understanding. *PAEDAGOGIA, 29*(3), 434-450. DOI: 10.20961/paedagogia.v29i3.127184

INTRODUCTION

Mathematics is an important subject in education and an integral part of students' learning across various levels of schooling. Mathematics is a universal discipline that plays a significant role in understanding various fields of knowledge and responding to the dynamics of contemporary digital innovation (Weigand et al., 2024). Mathematics education extends beyond procedural knowledge by fostering mathematical and critical thinking abilities (Monteleone et al., 2023). One of the key objectives of mathematics education is to develop mathematical proficiency; this framework comprises conceptual comprehension, procedural proficiency, strategic ability, adaptive reasoning, and a positive and productive attitude toward mathematics (Elsayed, 2022). Among these competencies, conceptual understanding serves as a fundamental component because it enables students to understand underlying mathematical concepts and relationships rather than merely perform calculations (Cai et al., 2026). Students with strong conceptual understanding are able to explain mathematical concepts in their own words, recognize

relationships among ideas, and apply mathematical knowledge to various problem contexts (Giriansyah et al., 2022).

However, students' conceptual understanding of mathematics, particularly in relation to cuboid volume, remains a challenge. A preliminary study was conducted in February 2026 involving 27 fourth-grade students at an elementary school in Surabaya, Indonesia. The preliminary data were obtained from an analysis of students' practice exercises, classroom observations, and interviews with the fourth-grade teacher. The analysis of students' practice exercises showed that 12 of the 27 students obtained scores below the established mastery criterion, representing 44.44% of the students. Furthermore, classroom observations and teacher interviews indicated that students tended to apply the formula $p \times l \times t$ directly without fully understanding volume as a measure of the space occupied by a solid. The preliminary findings also indicated that 21 of the 27 students relied directly on the formula when solving cuboid volume problems but experienced difficulties in explaining the relationship between cuboid volume and the arrangement of unit cubes, representing 77.78% of the students. These findings suggest that students' understanding of volume remained predominantly procedural, which may contribute to misconceptions, particularly the perception that volume is merely the numerical result obtained by applying a formula.

This issue is consistent with the broader state of mathematics education, which continues to place greater emphasis on the application of formulas than on developing deep conceptual understanding (Hasani et al., 2025). At the national level, the 2026 National Mathematics Competency Assessment (*Tes Kemampuan Akademik* or TKA) for elementary schools, as reported by the Ministry of Primary and Secondary Education (Kemendikdasmen), recorded an average score of 43.41. Furthermore, Indonesia's mathematics performance in PISA 2025, with a score of 364, remained below the OECD average, indicating persistent challenges in students' ability to understand and apply mathematical concepts (OECD, 2026). This condition is consistent with the findings of Hong & Runnalls (2022), who reported that students held misconceptions about volume formulas and had difficulty connecting visual representations of three-dimensional shapes to the underlying concept of volume. Therefore, instruction on volume should provide learning experiences that enable students to visualize cuboids, understand the dimensions of length, width, and height, and meaningfully relate these dimensions to the space occupied by the solid (Özdemir & Özçakır, 2026).

Learning that incorporates direct experience and visualization is also consistent with Jerome Bruner's discovery learning theory and Pierre van Hiele's theory of geometric thinking development. Bruner emphasized the importance of the enactive stage, in which students construct knowledge through active actions and manipulation of objects (Doz et al., 2025). Meanwhile, van Hiele proposed that geometric understanding develops from the visual recognition of shapes toward more formal levels of understanding and reasoning (Arnal-Bailera & Manero, 2024). Accordingly, mathematics instruction should encourage students to construct conceptual understanding through direct, visual, and meaningful learning experiences (Theodore J et al., 2022).

One instructional medium that has the potential to support such learning is Tinkercad 3D Design. This web-based medium enables students to visualize and manipulate three-dimensional objects interactively (Rosalina et al., 2025). Through its three-dimensional features, students can observe and rotate objects from different perspectives, allowing the shape of a cuboid to be represented more concretely (Abrori & Fadhail, 2025). Furthermore, the representation of unit cubes within a three-dimensional space enables students to connect the dimensions of length, width, and height with the process of filling space, thereby potentially facilitating a more visual and manipulative understanding of the concept of volume.

Previous studies have shown that Tinkercad can support learning in various contexts, including 3D modeling for understanding solid geometry among junior high school students, 3D modeling training for pre-service teachers, and coding simulation for developing students' critical thinking and technological literacy (Abrori & Fadhail, 2025; Khuzaini & Suswanti, 2021; Putri et al., 2024). These studies generally reported positive findings, such as improved conceptual understanding of solid geometry, enhanced 3D modeling skills, and strengthened students' critical and logical thinking through interactive digital features. However, the previous studies focused on junior high school students, pre-service teachers, or coding and science learning, whereas the present study focuses on elementary school students'

conceptual understanding of cuboid volume through Tinkercad 3D Design. Therefore, the research gap lies in the limited use of Tinkercad 3D Design in elementary mathematics learning, particularly for enabling students to construct and visualize unit-cube representations to understand volume as the amount of space occupied by a cuboid. Research examining the use of Tinkercad 3D Design for geometry instruction at the elementary school level, particularly in teaching cuboid volume, remains limited. In addition, previous studies have demonstrated that three-dimensional learning media, including GeoGebra, Cabri 3D, and Virtual Reality, can enhance students' conceptual understanding of mathematics across various educational levels (Zulaiha et al., 2024). However, the use of Tinkercad 3D Design to support elementary students in constructing and visualizing unit-cube representations within a three-dimensional space to develop an understanding of volume as the amount of space occupied by a solid has received limited attention. Therefore, the novelty of the present study lies in utilizing Tinkercad 3D Design as a mathematics instructional medium that enables students to visualize and construct unit-cube representations in a three-dimensional environment, thereby facilitating a more meaningful understanding of cuboid volume.

Based on the identified problem and research gap, this study aimed to analyze the effect of Tinkercad 3D Design on improving elementary school students' conceptual understanding of cuboid volume. Accordingly, the following research questions were formulated: (1) Does the use of Tinkercad 3D Design in the experimental class have a significant effect on improving elementary school students' conceptual understanding of cuboid volume? (2) Is there a significant difference in the improvement of conceptual understanding of cuboid volume between students in the experimental class who use Tinkercad 3D Design and those in the control class?

METHOD

Research Design

The research was grounded in a quantitative framework and implemented through a quasi-experimental research design. A Nonequivalent Control Group Design was selected because the study was conducted in an existing elementary school setting in which students had already been organized into established classes, making individual random assignment impractical due to school administrative and instructional considerations. The existing classes were therefore designated as the experimental and control groups, while maintaining the same learning objectives, content, and instructional duration in both groups. Both groups completed a pretest to assess their initial conceptual understanding and a posttest to measure changes following the instructional intervention. The pretest results also provided a basis for examining the comparability of the two groups before the intervention, while the comparison of posttest and improvement scores enabled the effect of Tinkercad 3D Design to be examined more systematically (Sugiyono, 2023).

The study was conducted at an elementary school in Surabaya, Indonesia, during the 2026 academic year. The research was implemented over four instructional sessions. The school was selected because it had two existing fourth-grade classes that could be assigned as the experimental and control groups, while also providing suitable conditions for the implementation of the activities in a classroom.

Participants

The population comprised 54 fourth-grade students at an elementary school in Surabaya, Indonesia, selected because cuboid volume is taught at this level. Total sampling involved Class IV A and IV B (27 students each), with one class assigned as the experimental group using Tinkercad 3D Design and the other as the control group using a cuboid-shaped cardboard model. Permission to conduct the study was obtained from the school, and consent was sought from the students and their parents or guardians prior to data collection. To protect the participants' privacy, the school and students' identities were anonymized in the publication. All data were used solely for research purposes and handled confidentially.

Data Collection Techniques and Instruments

Data collection used a test, questionnaire, and observation guideline to assess students' conceptual understanding. The *pretest* and *posttest* measured understanding of cuboid volume, the

questionnaire examined students' perceptions of learning with Tinkercad 3D Design, and observations monitored instructional activities in both classes. The learning outcomes were based on the Merdeka Curriculum, while the learning objectives were formulated by the researchers based on their analysis of the curriculum. The test indicators were adapted from Pangestu & Ruqoyyah (2023) and aligned with the learning objectives and the research variable, namely students' conceptual understanding of cuboid volume. The test indicators are presented in the following Table 1.

Table 1. Test Indicators

Learning Outcomes	Learning Objectives	Indicators
Measuring and estimating area and volume using appropriate units	1. Students are able to explain the concept of cuboid volume as a measure of the space occupied by a three-dimensional object and describe the relationship between base area and height using appropriate units (C2). 2. Students are able to analyze and determine the volume of cuboids in various situations, including word problems, using appropriate units and accurately explain the solution procedures (C4).	1. Understand the concept of volume in cuboids. 2. Calculate the volume of cuboids correctly. 3. Solve problems related to cuboid volume accurately.

Validity and Reliability

Before being used for data collection, the test, questionnaire, observation guideline, and teaching module were validated by three validators, consisting of two university lecturers with relevant expertise and one fourth-grade elementary school teacher. The validation was conducted using an expert judgment procedure with a structured rating scale. The validity score was calculated using the formula:

$$V = \left(\frac{TSe}{TSh}\right) \times 100\% \quad (1)$$

Where (TSe) represents the total empirical score obtained from the validators and (TSh) represents the maximum possible score. The final validation score was obtained by averaging the validation scores from the three validators, following the procedure used in recent educational research (Bili & Harta, 2023). The resulting percentage scores were interpreted using validity criteria in which scores of 86–100% were categorized as Very Valid and 71–85% as Valid (Hasanah & Risnasari, 2025). Based on this procedure, the test, questionnaire, observation guideline, and teaching module obtained mean validation scores in Table 2.:

Table 2. Mean Scores of Expert Validation Results

	Test	Questionnaire	Observation Guideline	Teaching Module
Score	95	96,2	88,3	94
Interpretation	Very Valid	Very Valid	Very Valid	Very Valid

The expert validation results indicate that the research instruments and instructional materials demonstrated good levels of validity. These findings suggest that all instruments and instructional materials met the established eligibility criteria for use in the study, although the observation guideline obtained a relatively lower score than the other components. Overall, the expert validation results confirm that the research instruments and instructional materials possessed adequate validity for implementation in the study.

In addition, the quality of the research instruments was further examined through validity and reliability testing and item analysis. Item validity was assessed using the Product–Moment Correlation to determine whether each test item appropriately measured the intended construct in accordance with the research objectives. The internal consistency of the research instrument was determined by applying the *Cronbach's Alpha* reliability coefficient. Additionally, each test item was analyzed to determine its level of

difficulty and its ability to distinguish between students with different performance levels. The outcomes of the analysis are displayed in Table 3.

Table 3. Results of Validity, Reliability, and Item Analysis

		Pretest	Posttest
Validity		20	21
Reliability		0,884	0,886
Item Difficulty	Difficult	6	6
	Moderate	10	9
	Easy	4	5
Item Discrimination	Very Good	1	1
	Good	10	8
	Fair	9	11
	Poor	0	0
	Very Poor	0	0
Distractor Effectiveness	Very Good	31	25
	Good	25	31
	Fair	4	4
	Poor	0	0
	Very Poor	0	0

Instrument analysis showed that 20 pretest and 21 posttest items were valid, with 20 items from each test used in the study. The reliability coefficients were 0.884 and 0.886, respectively, indicating strong internal consistency. The pretest comprised 6 difficult, 10 moderate, and 4 easy items, while the posttest included 6 difficult, 9 moderate, and 5 easy items. All items showed fair to very good discrimination, with none classified as poor or very poor. Most distractors were very good or good, with only 4 poor distractors in each test. Overall, the instruments demonstrated adequate validity, reliability, difficulty, discrimination, and distractor effectiveness and were suitable for the study.

Research Procedure

The research procedure was conducted systematically to examine the influence of Tinkercad 3D Design on students' conceptual understanding of the volume of a cuboid. The procedure consisted of research method, participant selection, instrument preparation and validation, pretest, learning intervention for the experimental and control groups, posttest, and data analysis. The procedure is shown in Figure 1. As shown in Figure 1, the experimental and control groups received different learning interventions before completing the posttest and subsequent data analysis.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical procedures. Descriptive analysis was conducted to summarize the minimum, maximum, mean, and standard deviation of students' pretest and posttest scores (Ghozali, 2021). Inferential analysis began with the Shapiro–Wilk normality test because each group consisted of 27 students (Demir, 2022) and Levene's Test to assess the homogeneity of variances between the experimental and control groups (Ghozali, 2021). The significance level was set at 0.05, with $p > 0.05$ indicating normally distributed data or homogeneous variances, whereas $p \leq 0.05$ indicated non-normal data or non-homogeneous variances. The results of these assumption tests determined the subsequent hypothesis testing procedures. For within-group analysis, the Paired-Samples t-test was used to examine differences between pretest and posttest scores when the parametric assumptions were satisfied, while the Wilcoxon Signed-Rank Test was used when the normality assumption was not met (Isbell & Jiang, 2025). For between-group analysis, the Independent-Samples t-test was applied when the parametric assumptions were satisfied (Creswell & Creswell, 2023), whereas the Mann–Whitney U Test was used when the normality assumption was not satisfied (Isbell & Jiang, 2025). A p-value < 0.05 indicated a statistically significant difference, while $p \geq$

0.05 indicated no statistically significant difference. The N-Gain score was calculated to determine the level of improvement in students' conceptual understanding using the formula:

$$\text{N Gain} = \frac{(\text{Posttest Score} - \text{Pretest Score})}{(\text{Maximum Score} - \text{Pretest Score})} \quad (2)$$

With scores ≥ 0.70 categorized as high, 0.30–0.69 as medium, and < 0.30 as low (Widyastuti & Airlanda, 2021). Finally, *effect size* analysis was conducted to determine the magnitude of the instructional effect beyond statistical significance, with its interpretation based on the criteria corresponding to the effect size measure used (Tobler, 2024).

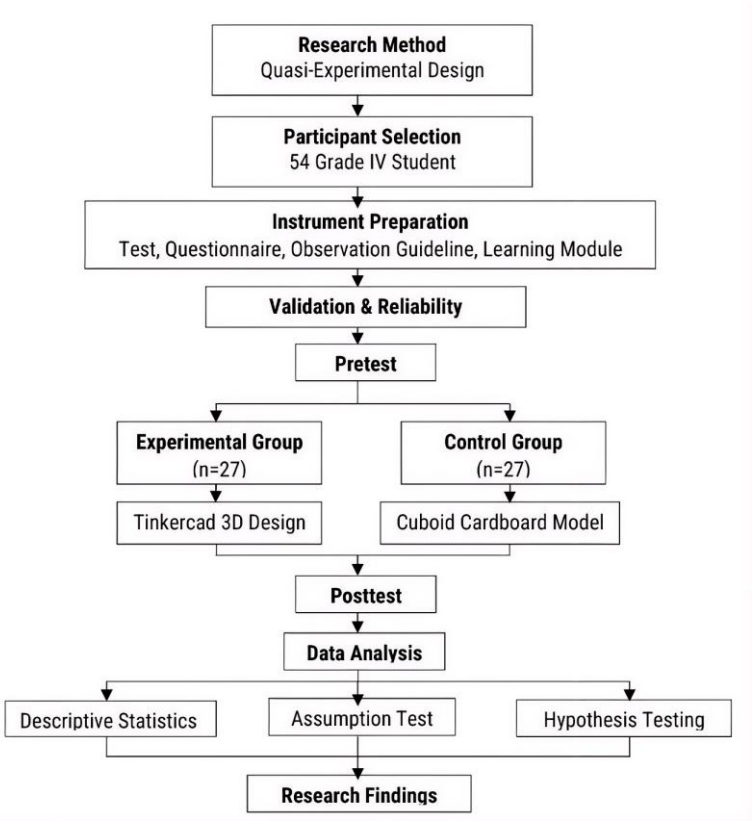


Figure 1. Flowchart of the Research Procedure

RESULT AND DISCUSSION

The Effect of Tinkercad 3D Design on Improving Students' Conceptual Understanding of Cuboid Volume

The effect of Tinkercad 3D Design on students' conceptual understanding of cuboid volume was first assessed by examining the changes between pretest and posttest scores obtained by the experimental group. This comparison was conducted to identify differences in students' achievement between the pre- and post-intervention assessments, followed by an N-Gain analysis to quantify the extent of their learning improvement. The experimental group's descriptive statistics for students' conceptual understanding are reported in Table 4.

Table 4. Descriptive Analysis of the Experimental Group

	N	Min	Max	Mean	Std. Deviation
Pretest	27	15	90	57,41	24,391
Posttest	27	45	100	84,63	17,261
Valid N (listwise)	27				

Based on the descriptive statistical analysis of 27 students, the pretest scores ranged from a minimum of 15 to a maximum of 90, with a mean of 57.41 and a standard deviation of 24.391. Following

the implementation of instruction using Tinkercad 3D Design, the posttest scores ranged from 45 to 100, with a mean of 84.63 and a standard deviation of 17.261. Thus, the mean score increased by 27.22 points from the pretest to the posttest. The lower standard deviation in the posttest indicates a more homogeneous distribution of students' scores compared with the pretest. Descriptively, these results indicate an enhancement in students' mastery of the concept of cuboid volume following instruction using Tinkercad 3D Design.

To establish the statistical significance of the change in students' conceptual understanding following the intervention, the experimental group's pretest and posttest scores were subjected to a comparative analysis. Before proceeding with hypothesis testing, the normality of the pretest–posttest difference scores was assessed. The analysis produced a significance value of 0.283, which exceeded the 0.05 threshold. The analysis confirmed that the difference scores followed a normal distribution. Therefore, a Paired-Samples t-test was conducted to determine whether the change in students' conceptual understanding reached statistical significance. The test results are shown in Table 5.

Table 5. Results of the Hypothesis Test for the Experimental Group

	Mean Differences	t	df	Sig. (2-tailed)	Interpretation
Experimental Pretest – Experimental Posttest	-27,222	-10,286	26	< 0,001	Significant Difference

Analysis using the Paired-Samples t-test indicated a mean pretest–posttest difference of −27.222, demonstrating that students achieved higher scores following the intervention. The obtained *t* statistic was −10.286 with 26 degrees of freedom (*df*), accompanied by a two-tailed significance value of < 0.001. Since the significance level was lower than 0.05, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_a) was supported, indicating that the implementation of Tinkercad 3D Design was associated with a statistically significant improvement in students' conceptual understanding of cuboid volume. An effect size analysis was then conducted to assess the magnitude of this intervention effect, with the corresponding results reported in Table 6.

Table 6. Effect Size Analysis for the Experimental Group

Analysis	Value	Interpretation
Cohen's d	-1.980	Very Large

The practical significance of the intervention is reflected in the obtained Cohen's *d* of −1.980. Considering its absolute magnitude, the effect size reaches 1.980, substantially surpassing the 0.80 benchmark and consequently falling within the very large effect category. This result suggests that the implementation of Tinkercad 3D Design produced a pronounced difference in students' conceptual understanding when their performance before and after the intervention was compared. To complement the effect size findings, the students' learning gains were also quantified through an *N-Gain* analysis using their respective pretest and posttest scores. The descriptive statistics resulting from this analysis for the experimental group are displayed in Table 7.

Table 7. Descriptive Statistics of N-Gain Scores for the Experimental Group

N	Minimal	Maximal	Mean N-Gain	Category
27	0,2	1,0	0,715	High

Analysis of the normalized gain showed that students in the experimental group achieved a high level of improvement in their understanding of cuboid volume. The mean N-Gain was 0.715, with individual scores ranging from 0.20 to 1.00. These findings demonstrate that instruction using Tinkercad 3D Design led to a substantial improvement in students' conceptual understanding from their initial level to their post-instruction performance. The high N-Gain category suggests that the improvement was not merely reflected in students' final achievement scores but also represented meaningful progress relative to their initial understanding. Thus, the N-Gain results provide further evidence that the use of Tinkercad 3D

Design contributed to a high level of the enhancement of the experimental group's conceptual mastery of cuboid volume.

The observed gains in students' conceptual understanding may be explained by the distinctive features of Tinkercad 3D Design, which provides opportunities for enabling learners to interact with and examine three-dimensional representations firsthand. Through this medium, students can construct cuboid models, adjust their length, width, and height, and observe the resulting changes in the dimensions and shape of the objects. Such activities provide visual and interactive instructional experiences designed to actively engage learners to establish meaningful connections between three-dimensional representations and the concept of volume. Consequently, students' understanding is developed not solely through the application of the volume formula but also through direct observation of the relationships among the dimensions of a cuboid and the space it occupies (Özdemir & Özçakır, 2026).

The results are in line with the perspective of Van Hiele, which explained that learners' comprehension of geometric concepts develops through a gradual and sequential process through distinct levels, ranging from the visual recognition of shapes to the analysis of their properties and relationships (Yalley et al., 2021). The use of Tinkercad 3D Design provides students with three-dimensional visual representations that enable them to observe cuboids more explicitly, identify their constituent elements, and examine the relationships among length, width, and height. Such representations support the development of students' geometric understanding by enabling them to move beyond perceiving a cuboid merely as a visual form toward recognizing its defining characteristics and relating its dimensions to the concept of volume.

The improvement in students' conceptual understanding can also be interpreted through Jerome S. Bruner's Discovery Learning theory. In learning activities supported by Tinkercad 3D Design, students are provided with opportunities to explore objects, manipulate their dimensions, experiment with different measurements, observe the resulting changes, and identify relationships between the dimensions of a cuboid and its volume. This process allows students to construct understanding through active exploration and discovery rather than merely receiving mathematical concepts in the form of information or formulas from the teacher (Kokkonen & Schalk, 2021; Theodore J et al., 2022). Accordingly, the interactive characteristics of Tinkercad 3D Design, which allow students to manipulate and investigate three-dimensional objects, support the implementation of discovery-oriented learning in teaching the concept of cuboid volume.

The present results corroborate earlier studies indicating that technology-enhanced and visualization-oriented learning media can support students in developing a deeper understanding of mathematical concepts by providing more concrete representations and opportunities for active exploration (Zulaiha et al., 2024). Previous research on the use of Tinkercad 3D Design in learning has similarly indicated that a three-dimensional design environment can provide learning experiences in which students actively observe, manipulate, and explore objects (Karaismailoglu & Yildirim, 2024). This consistency further supports the finding that digital three-dimensional media can facilitate the learning of geometric concepts, particularly when students are required to establish meaningful relationships among geometric forms, their dimensions, and the underlying mathematical concepts.

Differences in the Improvement of Conceptual Understanding Between the Experimental and Control Groups

To assess the differences in students' conceptual mastery of cuboid volume across the two groups, the analysis considered their pretest, posttest, and N-Gain outcomes. Pretest performance served as an indicator of students' baseline understanding, whereas posttest results reflected the changes that occurred after the learning intervention. The N-Gain analysis was subsequently used to quantify the extent of improvement attained by each group. The comparative results of students' conceptual understanding of cuboid volume in the experimental and control groups are reported in Table 8.

Table 8 shows that the experimental group started with a mean pretest score of 57.41, slightly higher than the control group's mean of 54.44. After the instructional intervention, the experimental group reached a mean posttest score of 84.63, while the control group achieved 77.22. A similar pattern was observed in the N-Gain results, where the experimental group recorded a mean of 0.715 compared with 0.567 for the control group. Overall, these descriptive findings suggest that the experimental group

experienced a greater increase in conceptual understanding than the control group. Before examining the differences in learning gains, an initial ability analysis was performed using the pretest results to establish whether the two groups had comparable conceptual understanding at the beginning of the study.

Table 8. Comparison of Students' Conceptual Understanding of Cuboid Volume Between the Experimental and Control Groups

		N	Min	Max	Mean	Std. Deviation
Experimental Group	Pretest	27	15	90	57,41	24,391
	Posttest	27	45	100	84,63	17,261
	N-Gain	27	0,2	1,0	0,715	0,2397
Control	Pretest	27	15	90	54,44	24,781
	Posttest	27	45	100	77,22	19,823
	N-Gain	27	0,2	1,0	0,567	0,2434

An initial ability analysis was conducted to determine whether the experimental and control groups had comparable levels of conceptual understanding prior to the intervention. The pretest data were first assessed for normality using the Shapiro–Wilk test, which produced significance values of 0.068 for the experimental group and 0.065 for the control group. Since both values were greater than 0.05, the pretest scores were considered normally distributed. The homogeneity of variance was then examined using Levene's Test, resulting in a significance value of 0.810 (> 0.05). This finding confirms that the score variances between the two groups were homogeneous. Therefore, the pretest data met both normality and homogeneity assumptions, allowing parametric statistical procedures to be applied in the subsequent analysis. The results of the pretest analysis are presented in Table 9.

Table 9. Results of the Independent-Samples *t*-Test for Pretest Scores

Levene's Test Sig.	t	df	Sig. (2-tailed)	Interpretation
0,810	0,443	52	0,660	Not Significantly Different

The initial ability analysis revealed that the experimental and control groups did not differ significantly in their conceptual understanding before the intervention. Thus, both groups can be considered to have started from a relatively similar level of conceptual mastery, establishing a suitable baseline for further comparison of their learning gains after the instructional process.

N-Gain scores were computed for both groups to assess differences in the extent to which students' conceptual understanding improved. Before comparing the groups, the distribution of the N-Gain data was examined through a normality test to identify the most suitable statistical method for the subsequent analysis. The findings of the normality assessment are presented in Table 10.

Table 10. Normality Test Results for N-Gain Scores

Data	Shapiro-Wilk Sig.	Interpretation
Experimental N-Gain	0,036	Not Normally Distributed
Control N-Gain	0,028	Not Normally Distributed

The Shapiro–Wilk analysis produced significance values of 0.036 for the experimental group and 0.028 for the control group. Both values fell below the 0.05 criterion, indicating that the N-Gain distributions in the two groups did not satisfy the assumption of normality. The analysis was therefore continued with a homogeneity test to assess whether the variance of N-Gain scores was equivalent across the experimental and control groups. Levene's Test was applied to evaluate this assumption, and the results are displayed in Table 11.

Levene's Test produced a significance value of 0.875, which was higher than the 0.05 criterion, confirming that the N-Gain variances were homogeneous across the experimental and control groups. Thus, although the normality requirement was not fulfilled, the variance assumption was satisfied. Given these conditions, the Mann–Whitney U Test was selected as the appropriate non-parametric method to

determine whether the two groups differed significantly in the improvement of students' conceptual understanding. The results of the hypothesis testing are presented in Table 12 and Table 13.

Table 11. Homogeneity Test Results for N-Gain Scores

Data	Levene Statistic	df1	df2	Sig.	Interpretation
Experimental N-Gain - Control N-Gain	0,025	1	52	0,875	Homogeneous

Table 12. Mann-Whitney U Test: Ranks

Group	N	Mean Rank	Sum of Rank
Experimental N-Gain	27	32,19	869,00
Control N-Gain	27	22,81	616,00
Total	54		

Table 13. Mann-Whitney U Test: Test Statistics

	Value
Mann-Whitney U	238,000
Wilcoxon W	616,000
Z	-2,210
Asymp. Sig. (2-tailed)	0,027

The Mann–Whitney U analysis resulted in an Asymp. Sig. (2-tailed) value of 0.027, which was lower than the 0.05 significance level. This result led to the rejection of H_0 and acceptance of H_a, confirming that the two groups differed significantly in their improvement of conceptual understanding of cuboid volume. The mean rank also favored the experimental group, which achieved 32.19 compared with 22.81 for the control group. This pattern indicates that students who learned through Tinkercad 3D Design attained greater gains in conceptual understanding than those who participated in the control condition. Hence, the implementation of Tinkercad 3D Design was associated with a significantly greater improvement in students' conceptual understanding of cuboid volume than the learning approach applied to the control group.

Furthermore, the calculated effect size was 0.301, which falls within the medium-effect category. The results provide evidence that the use of Tinkercad 3D Design produced a meaningful effect on the improvement of elementary school students' conceptual understanding of cuboid volume. Although the effect was moderate in magnitude, the difference identified between the experimental and control groups therefore reflects not only statistical significance but also meaningful practical implications for enhancing students' conceptual understanding. The use of Tinkercad 3D Design enables students to observe and manipulate cuboid representations, allowing the relationships among length, width, height, and volume to be explored through concrete and interactive visual representations (Karaismailoglu & Yildirim, 2024). Thus, the medium effect size further supports the potential of visual and interactive digital media as an alternative instructional approach for facilitating meaningful understanding of cuboid volume.

The first indicator was students' understanding of the concept of cuboid volume. Figure 2 presented the experimental group showed a 20% improvement, from 72% on the pretest to 92% on the posttest, while the control group increased by 16%. This improvement indicates that Tinkercad 3D Design supported students in developing an initial conceptual understanding of volume through three-dimensional visualization. During the learning activities, students constructed cuboids from unit cubes. They manipulated their dimensions, allowing them to observe the relationship between length, width, height, the arrangement of unit cubes, and the space occupied by the cuboid. This activity provided students with a visual representation of volume rather than requiring them to rely solely on the volume formula. The finding is consistent with van Hiele's theory, particularly the visualization level, in which students develop geometric understanding through the recognition and manipulation of visual representations (Arnal-Bailera & Manero, 2024). It also supports previous findings that three-dimensional

visualization can facilitate students' understanding of geometric concepts by connecting abstract mathematical ideas with observable representations (Bernabeu et al., 2024; Sudirman et al., 2024).

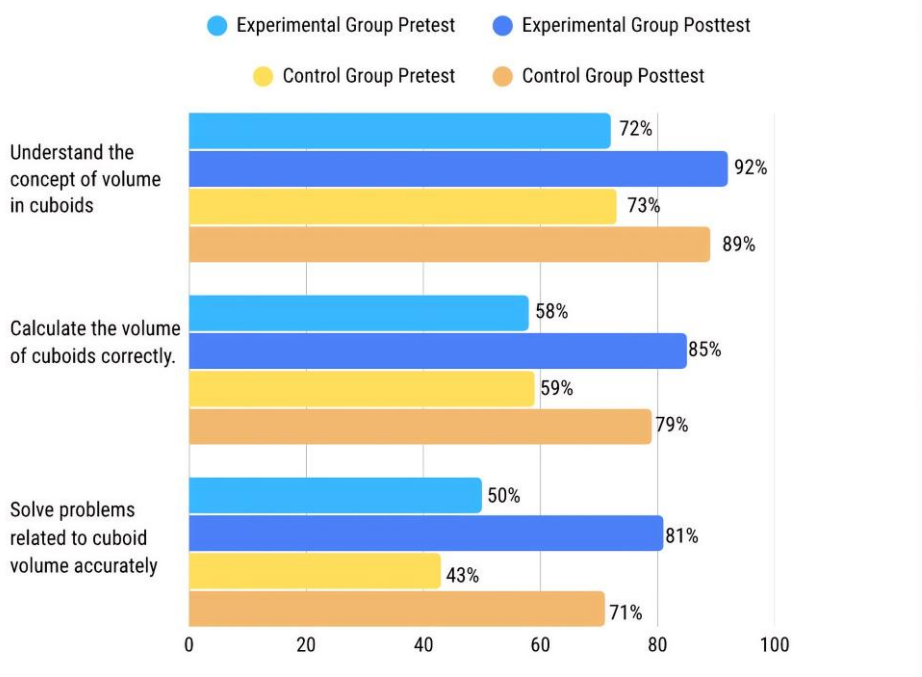


Figure 2. Comparison of Cuboid Volume Conceptual Understanding by Indicator

The second indicator concerned students' ability to calculate the volume of a cuboid. The experimental group showed a 27% improvement, whereas the control group increased by 20%. The greater improvement in the experimental group can be associated with the learning activities in Tinkercad 3D Design, where students could modify the length, width, and height of cuboids and directly observe changes in the number and arrangement of unit cubes. Through this exploration, students were encouraged to discover the relationship between the dimensions of a cuboid and its volume before applying the formal calculation procedure. Such activities are consistent with Bruner's Discovery Learning perspective, which emphasizes that students can construct mathematical knowledge through direct exploration and discovery. Similar findings have shown that interactive and visual learning environments can help students connect mathematical representations with calculation procedures and develop a deeper understanding of geometric concepts (Karaismailoglu & Yildirim, 2024). Thus, the use of Tinkercad 3D Design not only supported students in obtaining correct calculations but also provided a conceptual basis for understanding why the calculation procedure works.

The third indicator was students' ability to solve problems involving the volume of cuboids. This indicator showed the greatest improvement in both groups, with an increase of 31% in the experimental group and 28% in the control group. In the experimental group, students applied their understanding of cuboid dimensions and volume to contextual problems after exploring three-dimensional representations through Tinkercad 3D Design. The opportunity to construct, manipulate, and examine cuboids helped students identify relevant information in problems and connect it to the concept of volume before performing calculations. This finding is in line with previous studies indicating that conceptual understanding and multiple representations can support students in applying mathematical knowledge to problem-solving situations (Giriansyah et al., 2022; Kokkonen & Schalk, 2021). Meanwhile, the improvement in the control group may be attributed to the use of concrete cardboard models, teacher explanations, and worked examples, which also provided students with opportunities to observe cuboid dimensions and apply the volume procedure (Siller & Ahmad, 2024). However, the higher improvement in the experimental group suggests that the interactive manipulation provided by Tinkercad 3D Design offered additional support for connecting visual representations with mathematical problem-solving.

Overall, the three indicators showed improvement in both groups, but the magnitude of improvement differed. In the experimental group, the gains increased progressively from understanding the concept of cuboid volume (20%) to calculating cuboid volume (27%) and finally solving cuboid-volume problems (31%). A similar pattern was observed in the control group, with gains of 16%, 20%, and 28%, respectively. The greatest improvement in both groups occurred in problem solving, followed by calculation and conceptual understanding. This pattern suggests that students were increasingly able to apply their understanding after developing basic conceptual and computational knowledge. Nevertheless, the consistently higher gains in the experimental group indicate that Tinkercad 3D Design provided a more integrated learning experience by combining visualization, manipulation, exploration, and mathematical application. These activities helped students move beyond procedural use of the volume formula toward a more meaningful understanding of the relationship between unit cubes, cuboid dimensions, and volume.

Taken together, the greater improvement in conceptual gains demonstrated by the experimental group suggests that Tinkercad 3D Design provides learning experiences that support understanding of cuboid volume through visualization, exploration, and manipulation of three-dimensional objects. Students were able to observe the relationships among length, width, height, unit-cube arrangements, and volume in a more concrete and meaningful way. These learning experiences are consistent with van Hiele's theory, which emphasizes the development of geometric understanding through visual representations, as well as Bruner's Discovery Learning theory, which underscores the significance of exploration and discovery in constructing knowledge. This sequence of learning experiences enabled students to establish a more meaningful connection between the dimensions of a cuboid and its volume. Consequently, the use of Tinkercad 3D Design had a greater effect on improving students' conceptual understanding of cuboid volume than the instructional approach implemented in the control group.

Implementation of the Learning Process

The learning process in the experimental and control groups was implemented using the same instructional content, learning objectives, activity stages, and time allocation. The primary difference in the treatment concerned the instructional media used, namely Tinkercad 3D Design (Figure 4) in the experimental group and a cuboid-shaped cardboard model in the control group. This instructional equivalence was maintained to ensure that both groups received relatively comparable learning experiences, allowing differences in the improvement of conceptual understanding to be associated with the different instructional media. In the second meeting worksheet, students in both groups learned the concept of volume through unit cubes. In the third meeting worksheet, students subsequently related the number of unit cubes to length, width, and height to develop an understanding of the volume formula.

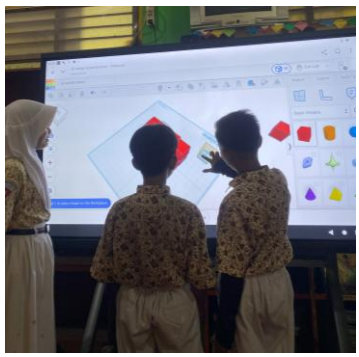


Figure 3. Student Using Tinkercad 3D Design

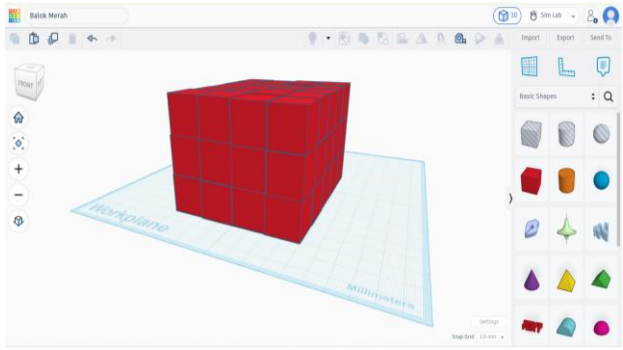


Figure 4. Tinkercad 3D Design Workplane

In the experimental group (Figure 3), Tinkercad 3D Design was used to construct, observe, and manipulate cuboid objects in a three-dimensional environment. During the implementation of the instruction, students were able to modify the length, width, and height of the cuboid and directly observe changes in its shape and unit-cube arrangement. Meanwhile, students in the control group engaged in comparable activities by observing and measuring a cuboid-shaped cardboard model. These activities provided students with opportunities to understand volume through observation, exploration, and the discovery of relationships between the dimensions of a cuboid and the number of unit cubes comprising

it. This process is consistent with Bruner's theory, which emphasizes the development of understanding through observation and exploration (Kokkonen & Schalk, 2021), as well as van Hiele's theory, which describes the development of geometric understanding from visualization toward the analysis of characteristics and relationships within solid geometric figures (Arnal-Bailera & Manero, 2024).

The implementation within the instructional process, as indicated by teacher observations, yielded the same percentage for both groups: 79%. In each group, six aspects of the researcher's activities were successfully implemented, while one aspect was not implemented. Similarly, five aspects of student activities were implemented, whereas two aspects were not implemented. These findings indicate that the instructional stages in both groups were generally implemented in accordance with the planned learning design. Throughout the learning process, students engaged with the worksheets, observed the objects, conducted exploratory activities, and completed the assigned tasks. The primary difference in the learning experience was attributable to the characteristics of the instructional media: students in the experimental group experienced visual and interactive learning through the manipulation of objects using Tinkercad 3D Design, while the control group interacted directly with a concrete physical object. Given the comparable level of instructional implementation in both groups, the greater conceptual gains achieved by the experimental group compared with the control group indicate that Tinkercad 3D Design can support the learning of cuboid volume by providing visual, active, and exploratory learning experiences (Karaismailoglu & Yildirim, 2024).

Students' Responses to the Use of Tinkercad 3D Design

In light of the questionnaire administered to 27 students after participating in learning activities using Tinkercad 3D Design, an average of 87% of students expressed agreement with the use of the medium, while 13% expressed disagreement. These results indicate that students' overall responses to the use of Tinkercad 3D Design were categorized as very good. Regarding conceptual understanding, 96% of students reported that the medium helped them understand the relationship among length, width, and height in determining the volume of a cuboid, while 93% indicated that they understood the rationale for using the volume formula. In addition, 81% of students reported that the medium made it easier to visualize the shape of a cuboid and understand the concept of volume. These findings suggest that Tinkercad 3D Design facilitates connections between three-dimensional visual representations and mathematical concepts, enabling students not only to apply the volume formula procedurally but also to understand the relationship between the dimensions of a cuboid and its volume. This finding is consistent with van Hiele's theory, which positions visualization and the analysis of geometric forms and dimensions as components of the development of students' geometric understanding (Bernabeu et al., 2024).

The positive responses were also associated with the characteristics of the learning activities, which provided students with opportunities to observe, manipulate, and explore objects before identifying the underlying mathematical relationships. These characteristics are consistent with Bruner's Discovery Learning theory, which emphasizes students' active involvement in discovering concepts through exploratory activities (Weinhandl et al., 2025). Through the activities provided in the second and third meeting worksheets, students observed cuboid representations, explored unit-cube arrangements, modified object dimensions, and related their observations to length, width, height, and volume. Thus, the use of Tinkercad 3D Design supported the development of conceptual understanding through visual and exploratory experiences rather than relying solely on teacher explanations or formula-based procedures.

These findings provide practical guidance for mathematics teachers implementing Tinkercad 3D Design in cuboid volume learning. Teachers can guide students to construct and manipulate cuboids, vary their length, width, and height, explore unit-cube arrangements, and predict the volume before performing formal calculations. Students can then compare their predictions with the calculated results and explain how the number of unit cubes relates to the dimensions of the cuboid. Such activities allow teachers to use students' visual observations as a basis for discussing and justifying the volume formula, thereby helping students move from procedural use of the formula toward a more conceptual understanding of why it works.

In terms of the learning experience, 93% of students reported that they could follow the learning procedures easily, 89% felt actively engaged, 85% perceived the learning activities as more interesting,

and 93% felt more confident in explaining the concept of cuboid volume. Furthermore, 78% of students indicated that the medium helped them complete the tasks in the worksheets. Although this represented the lowest percentage among the indicators, it still suggests that the majority of students perceived the medium as beneficial for completing learning tasks. This finding may indicate that translating the results of visual exploration into formal mathematical solutions requires further reinforcement and practice (Annisa et al., 2025). Meanwhile, 85% of the students indicated that they would be interested in using comparable learning media for other subject areas, indicating positive acceptance of and interest in digital media-based learning.

Overall, the students' responses indicate that Tinkercad 3D Design was very well received and provided a visual, active, and exploratory learning experience in teaching cuboid volume. Positive responses were particularly evident in students' ability to understand the relationships among length, width, height, and volume, as well as the extent of students' participation during instruction. These results further support the findings on conceptual understanding, showing that the experimental group achieved greater gains than the control group. Nevertheless, the questionnaire data serve as supporting evidence rather than as the sole basis for determining the effect of the instructional medium. Therefore, students' responses further reinforce the finding that Tinkercad 3D Design can support the learning of cuboid volume through interactive and meaningful learning experiences.

Research Limitations

This study has several limitations. The participants were limited to 54 fourth-grade students from one elementary school, so the findings may not be directly generalizable to students with different characteristics and learning contexts. The study also focused only on cuboid volume and was conducted within the available instructional time and technological facilities. In addition, differences in students' digital skills and access to devices and internet connectivity required additional guidance during the implementation of Tinkercad 3D Design.

Recommendations

Based on the findings, teachers are recommended to integrate Tinkercad 3D Design with structured worksheets and exploratory activities, such as constructing and manipulating cuboids, varying their dimensions, exploring unit-cube arrangements, and explaining the relationship between dimensions and volume. These activities can strengthen students' visualization, exploration, and mathematical reasoning in geometry learning. Schools can support implementation by providing adequate digital facilities and internet access, while future research may involve larger, more diverse samples, additional geometry topics, and longer implementation periods.

CONCLUSION

The findings indicate that the use of Tinkercad 3D Design had a significant positive effect on fourth-grade students' conceptual understanding of cuboid volume. Students in the experimental group demonstrated significant improvement following the intervention, indicating that Tinkercad 3D Design contributed to their understanding of cuboid volume. Furthermore, the improvement in conceptual understanding was significantly greater in the experimental group than in the control group, which used concrete cuboid models. The improvement was evident across all conceptual-understanding indicators, including understanding the concept of cuboid volume, calculating volume, and solving volume-related problems. These findings suggest that Tinkercad 3D Design supports students in visualizing three-dimensional structures, exploring volume through unit cubes, and connecting visual representations with mathematical reasoning. The findings are consistent with van Hiele's theory, which emphasizes visualization as a foundation for geometric understanding, and Bruner's Discovery Learning theory, which highlights exploration and discovery in learning. Future research should involve larger, more diverse samples, longer intervention periods, and additional three-dimensional geometry topics to examine whether similar effects can be observed across different learning contexts.

AI USE STATEMENT

OpenAI's ChatGPT was used solely to assist with refining the grammar and language clarity of the manuscript. It was not used to generate or write the manuscript's content, develop the research arguments, analyze or interpret the data, or generate the research findings. All intellectual contributions, data analyses, interpretations, and conclusions were conducted by the authors, who take full responsibility for the content of the manuscript.

REFERENCES

Abrori, F. M., & Fadhail, M. A. (2025). 3-Dimensional Modeling Training for Pre-Service Teachers Through the Tinkercad Platform. *Communautaire: Journal of Community Service*, *4*(1), 83. https://doi.org/10.61987/communautaire.v4i1.1017

Annisa, R., Ramadani, F., & Haliq, A. (2025). Inovasi Pembelajaran dengan Media Visual: Studi Pengalaman di Sekolah Dasar. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, *10*(02), 379–389. https://doi.org/https://doi.org/10.23969/jp.v10i02.25092

Arnal-Bailera, A., & Manero, V. (2024). A Characterization of Van Hiele's Level 5 of Geometric Reasoning Using the Delphi Methodology. *International Journal of Science and Mathematics Education*, *22*(3), 537–560. https://doi.org/10.1007/s10763-023-10380-z

Bernabeu, M., Moreno, M., & Llinares, S. (2024). Polygon Class Learning Opportunities: Interplay Between Teacher's Moves, Children's Geometrical Thinking, and Geometrical Task. *International Journal of Science and Mathematics Education*, *22*(6), 1381–1403. https://doi.org/10.1007/s10763-023-10425-3

Bili, F. G., & Harta, J. (2023). Development of Augmented Reality-Assisted Interactive Student's Worksheet on the Topic of Molecular Shape. *Journal of Chemistry Education Research*, *7*(2), 267–276. https://doi.org/10.26740/jcer.v7n2.p267-276

Cai, J., Ding, M., & Hwang, S. (2026). Fostering Students' Mathematical Understanding: Toward a Teoretical Framework. In *Asian Journal for Mathematics Education*. SAGE Publications Ltd. https://doi.org/10.1177/27527263261442721

Creswell, J. W., & Creswell, J. D. (2023). *Research Design Qualitative, Quantitative, and Mixed Methods Approaches* (6th ed.). Sage. https://archive.org/details/researchdesignO000unse

Demir, S. (2022). Comparison of Normality Tests in Terms of Sample Sizes under Different Skewness and Kurtosis Coefficients. *International Journal of Assessment Tools in Education*, *9*(2), 397–409. https://doi.org/10.21449/ijate.1101295

Doz, D., Žakelj, A., & Cotič, M. (2025). Inquiry-based learning in Grade 9 mathematics: assessing outcomes across Gagné's taxonomy. *Educational Studies in Mathematics*, *120*(2), 269–298. https://doi.org/10.1007/s10649-025-10417-w

Elsayed, S. A. M. (2022). The Effectiveness of Learning Mathematics according to the STEM Approach in Developing the Mathematical Proficiency of Second Graders of the Intermediate School. *Education Research International*, *2022*. https://doi.org/10.1155/2022/5206476

Ghozali, I. (2021). *Aplikasi Analisis Multivariate dengan Program IBM SPSS 26 Edisi 10*. Badan Penerbit Universitas Diponegoro.

Giriansyah, F. E., Pujiastuti, H., Ihsanudin, I., Matematika, P., Keguruan, F., Pendidikan, I., Sultan, U., Tirtayasa, A., Raya, J., Km, P., Sindangsari, K., Serang, P., & Banten, I. (2022). Kemampuan Pemahaman Matematis Siswa Berdasarkan Teori Skemp Ditinjau dari Gaya Belajar. *Jurnal Cendekia: Jurnal Pendidikan Matematika*, *07*(01), 751–765. https://doi.org/10.31004/cendekia.v6i3.1515

Hasanah, A., & Risnasari, M. (2025). Android-based Virtual Laboratoty With Starter Experiment Approach for Learning Vertebrate Organ System in High School. *Jurnal Inovasi Teknologi Pendidikan*, *12*(1). https://doi.org/https://doi.org/10.21831/jitp.v12i1.78848

Hasani, L. M., Junus, K., Sadita, L., Hirashima, T., & Hayashi, Y. (2025). The Effect of Kit-Build Concept Mapping for Organizing Information on Conceptual and Procedural Knowledge in Mathematics: A

Comparative Study. *International Journal of Information and Education Technology*, *15*(11), 2498–2510. https://doi.org/10.18178/ijiet.2025.15.11.2445

Hong, D. S., & Runnalls, C. (2022). "I don't think they need any help with the formula": Examining elementary preservice teachers' responses to volume tasks. *School Science and Mathematics*, *122*(3), 155–168. https://doi.org/10.1111/ssm.12521

Isbell, D. R., & Jiang, X. (2025). Comparing Two Related Samples. In *The Encyclopedia of Applied Linguistics* (pp. 1–7). Wiley. https://doi.org/10.1002/9781405198431.wbeal0165.pub2

Karaismailoglu, F., & Yildirim, M. (2024). The Effect of 3D Modeling Performed Using Tinkercad or Concrete Materials in the Context of the Flipped Classroom on Pre-Service Teachers' Spatial Abilities. *Research in Science and Technological Education*, *42*(4), 1264–1283. https://doi.org/10.1080/02635143.2023.2223134

Khuzaini, N., & Suswanti. (2021). A 3D Modelling Menggunakan Tinkercard Untuk Pembelajaran Materi Bangun Ruang Sisi Datar Ditinjau Dari Pemahaman Konsep Matematika Pada Siswa SMP. *Eduscope*, *06*(02), 39–47.

Kokkonen, T., & Schalk, L. (2021). One Instructional Sequence Fits all? A Conceptual Analysis of the Applicability of Concreteness Fading in Mathematics, Physics, Chemistry, and Biology Education. In *Educational Psychology Review* (Vol. 33, Number 3, pp. 797–821). Springer. https://doi.org/10.1007/s10648-020-09581-7

Monteleone, C., Miller, J., & Warren, E. (2023). Conceptualising Critical Mathematical Thinking in Young Students. *Mathematics Education Research Journal*, *35*(2), 339–359. https://doi.org/10.1007/s13394-023-00445-1

OECD. (2026). *PISA 2025 Results (Volume I) Future-Ready Students*.

Özdemir, D., & Özçakır, B. (2026). Augmented Reality in Mathematics Education: Enhancing Middle School Students' Comprehension of Volume Concepts and Classroom Dynamics. *International Journal of Science and Mathematics Education*, *24*(1). https://doi.org/10.1007/s10763-025-10626-y

Pangestu, I. A., & Ruqoyyah, S. (2023). Pembelajaran Daring Materi Bangun Ruang pada Siswa Kelas V SD Menggunakan Pendekatan Realistic Mathematics Education (RME). *Journal of Elementary Education*, *06*(02), 228–234. https://doi.org/10.22460/collase.v6i2.7403

Putri, A. J., Setiawan, M. A., & Putro, H. Y. S. (2024). Pendampingan Minat Bakat Tinkercad Coding Simulator Mengasah Kemampuan Berpikir Kritis Siswa untuk Penguatan Literasi Numerasi. *Jurnal Pembelajaran Pemberdayaan Masyarakat (JP2M)*, *5*(3), 535–545. https://doi.org/10.33474/jp2m.v5i3.21983

Rosalina, R., Ma'mun, A. H., Wiranata, A. D., Sulistiawati, S., Mukhtar, A. A., Rabbani, A. D., & Maulana, N. B. (2025). Pelatihan Desain 3D Menggunakan Aplikasi Tinker-Cad bagi Guru SMP Muhammadiyah 4 Jakarta Timur. *Jurnal Abdi Masyarakat Indonesia*, *5*(5), 2289–2298. https://doi.org/10.54082/jamsi.2079

Siller, H. S., & Ahmad, S. (2024). The Effect of Concrete and Virtual Manipulative Blended Instruction on Mathematical Achievement for Elementary School Students. *Canadian Journal of Science, Mathematics and Technology Education*, *24*(2), 229–266. https://doi.org/10.1007/s42330-024-00336-y

Sudirman, S., Dejarlo, J., Susandi, A. D., & Triyono, D. (2024). Institutionalization of the 5E Instructional Model Integrated Augmented Reality Interactive Book (5E-IMARIB): Its Impact in Increasing Students' Understanding of 3D Geometry Concepts and Self-Efficacy? *Jurnal Pendidikan MIPA*, *25*(1), 195–209. https://doi.org/10.23960/jpmipa/v25i1.pp195-209

Sugiyono. (2023). *Metode Penelitian Kuantitatif, Kualitatif, dan R&D* (Sutopo, Ed.; 2nd ed.). CV Alfabeta. www.cvalfabeta.com

Theodore J, R., Jenna R, O., Jeffrey E, B., Craig J, C., Douglas H, C., Julie Sarama, & George Rutherford. (2022). Children's Construction of a Volume Calculation Algorithm for a Rectangular Prism with a Dynamic Virtual Manipulative. *The Journal of Mathematical Behavior*, *67*. https://doi.org/10.1016/j.jmathb.2022.100998

Tobler, S. (2024). Context matters: Interpreting effect sizes in education meaningfully. *MethodsX*, *13*. https://doi.org/10.1016/j.mex.2024.103023

Weigand, H. G., Trgalova, J., & Tabach, M. (2024). Mathematics Teaching, Learning, and Assessment in the Digital Age. *ZDM - Mathematics Education*, *56*(4), 525–541. https://doi.org/10.1007/s11858-024-01612-9

Weinhandl, R., Baldinger, S., & Riegler, V. (2025). Design Characteristics for Discovery Learning within Digital Mathematics Learning Environments from Students' Perspectives. *International Journal of Science and Mathematics Education*, *23*(8), 3981–4009. https://doi.org/10.1007/s10763-025-10619-x

Widyastuti, R. T., & Airlanda, G. S. (2021). Efektivitas Model Problem Based Learning terhadap Kemampuan Pemecahan Masalah Matematika Siswa Sekolah Dasar. *Jurnal Basicedu*, *5*(3), 1120–1129. https://doi.org/10.31004/basicedu.v5i3.896

Yalley, E., Armah, G., & Ansah, R. K. (2021). Effect of the VAN Hiele Instructional Model on Students' Achievement in Geometry. *Education Research International*, *2021*. https://doi.org/10.1155/2021/6993668

Zulaiha, E., Shabrina Anshor, A., & Humairah, E. (2024). Pengaruh Media Visual Tiga Dimensi terhadap Hasil Belajar Matematika pada Materi Volume Kubus dan Balok Kelas V SD. *Journal of Basic Educational Studies*, *4*(3), 1752–1767. https://doi.org/47467/eduinovasi.v4i3.4773