Jupiter: Jurnal Pendidikan Terapan
Homepage : https://journal.diginus.id/jupiter/index
Email: jurnalpendidikanterapan@gmail.com

p-ISSN : 2985-3214; e-ISSN : 2964-3171
Jupiter, Vol. 4, No. 3, July 2026
Page 716-728

Effects of EduCube Inquiry-Based Learning on Elementary Students' Cube Spatial Visualization, Learning Interest, and Mathematics Achievement: A Quasi-Experimental Study

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ARTICLE INFO

Article history:
Submitted: July 02, 2026
Final Revised: July 15, 2026
Accepted: July 24, 2026
Published: July 31, 2026

Keywords:
Concrete Manipulatives; Cube Spatial Visualization; Elementary Mathematics; Inquiry-Based Learning; Learning Achievement; Learning Interest

ABSTRACT

Spatial visualization is fundamental for elementary geometry learning, yet many students struggle to interpret three-dimensional cube structures because instruction remains dominated by teacher-centered approaches and two-dimensional representations. Although inquiry-based learning, concrete manipulatives, and spatial reasoning have shown educational outcomes, limited empirical evidence has examined their integration while simultaneously investigating students' spatial visualization, learning interest, and mathematics achievement. Accordingly, this study investigated the effects of inquiry-based learning assisted by colorful cube manipulatives on sixth-grade students' learning interest, spatial visualization achievement, and learning responses. A quasi-experimental Matching Only Pretest–Posttest Control Group Design involved 58 sixth-grade students selected through purposive sampling, with 29 students in the experimental group and 29 in the control group. Data were collected using achievement tests, learning-interest and student-response questionnaires, observations, interviews, and documentation and analyzed using descriptive statistics, normality and homogeneity tests, paired- and independent-samples *t*-tests, normalized gain (N-Gain), and Cohen's *d*. Significantly higher learning-interest and posttest achievement scores were obtained by the experimental group than by the control group ($p < .001$). Moderate-to-high learning gains were achieved by 87.9% of students, while average student-response score reached 84.25%, indicating positive perceptions of the learning model. Inquiry-based learning supported by colorful cube manipulatives offers a promising approach for active, meaningful mathematics instruction. Findings should be interpreted considering intact classes from two schools, the absence of random assignment, and post-intervention measurement of learning interest. Results provide empirical evidence supporting the integration of structured inquiry and concrete manipulatives to enhance elementary students' spatial visualization, learning interest, and mathematics achievement.

Doi: https://doi.org/10.61255/jupiter.v4i3.1534

INTRODUCTION

Despite substantial advances in mathematics education, developing students' conceptual understanding, mathematical reasoning, and problem-solving skills remains a persistent challenge in elementary schools. Results from the Programme for International Student Assessment (PISA) 2022 revealed that many students continue to experience difficulties applying mathematical knowledge to unfamiliar contexts, indicating that procedural instruction alone is insufficient for developing higher-order mathematical competencies (OECD, 2023). Consequently, contemporary mathematics education increasingly advocates learning environments that engage students in mathematical exploration, reasoning, and communication to promote meaningful understanding rather than routine memorization (National Council of Teachers of Mathematics (NACTM, 2023). Early learning experiences are particularly important because mathematical achievement develops alongside students' emotions, motivation, and interest in learning. (Rawlings et al., 2023) demonstrated that mathematical emotions and arithmetic fluency develop simultaneously during the early years of schooling, whereas (Lehikoinen et al., 2025) reported that students' mathematics interest and self-concept tend to decline during upper elementary education. Collectively, these findings suggest that effective mathematics instruction should simultaneously strengthen conceptual understanding, positive learning dispositions, and active engagement, particularly in geometry, where spatial reasoning enables students to mentally represent, manipulate, and interpret three-dimensional objects that underpin later mathematical learning.

Spatial reasoning is a fundamental component of geometry learning because it enables students to mentally represent, manipulate, and interpret three-dimensional objects from multiple perspectives. Strong spatial visualization supports mathematical learning by helping students recognize spatial relationships, perform mental rotations, and transform visual information into conceptual understanding (Schenck & Nathan, 2024). Growing evidence indicates that well-developed spatial visualization is consistently associated with higher mathematics achievement and stronger geometric reasoning among elementary students (Harris et al., 2023; Möhring et al., 2024; Medina Herrera et al., 2024). Nevertheless, cube spatial visualization remains challenging because students must identify visible and hidden faces, interpret different viewpoints, and mentally reconstruct three-dimensional structures. Learning experiences that rely primarily on verbal explanations and two-dimensional illustrations often provide insufficient support for these cognitive processes, highlighting the need for learning environments that actively engage students in exploring and manipulating three-dimensional objects.

Inquiry-based learning provides a meaningful pedagogical framework for developing students' spatial visualization because it actively engages learners in observing, questioning, investigating, and constructing mathematical understanding through exploration rather than passive knowledge acquisition. Such learning experiences promote conceptual understanding, mathematical reasoning, and positive engagement by encouraging students to formulate hypotheses, test ideas, and justify conclusions (Pedersen & Haavold, 2023; Gómez-Chacón et al., 2024). However, inquiry activities alone may not adequately support students in understanding complex three-dimensional objects. Concrete manipulatives complement inquiry by transforming abstract spatial concepts into observable representations that students can explore, manipulate, and discuss directly, thereby strengthening geometric reasoning and mathematics achievement (Ponte et al., 2023); Gilligan-Lee et al., 2023). Furthermore, opportunities to manipulate physical objects encourage flexible mathematical thinking by enabling students to examine multiple solution strategies rather than relying on routine procedures (Wang & Star, 2023). Collectively, these theoretical and empirical perspectives suggest that integrating inquiry-based learning with concrete manipulatives provides a strong pedagogical foundation for supporting elementary students' spatial visualization and conceptual understanding in geometry.

Preliminary observations conducted at SDN Kauman revealed that geometry instruction remained predominantly teacher-centered, with limited use of concrete learning media to facilitate students' understanding of three-dimensional objects. Consequently, students had few opportunities to actively observe, manipulate, and discuss cube structures during mathematics lessons. Among 29 sixth-grade students, 19 students (66%) demonstrated low-to-moderate learning interest, while 18 students (62%) did not achieve the school's minimum mastery criterion in geometry. Classroom observations further showed that many students experienced difficulty identifying cube nets, interpreting objects from different viewpoints, and mentally visualizing hidden cube faces. These findings indicate that students encountered challenges not only in mastering geometric concepts but also in developing spatial visualization through meaningful learning experiences. Limited opportunities to interact directly with three-dimensional objects appeared to constrain students' ability to construct accurate spatial representations, which may have contributed to both low learning interest and unsatisfactory mathematics achievement. Collectively, these classroom conditions demonstrate that existing instructional practices have not yet adequately supported the development of elementary students' spatial visualization, establishing a clear empirical basis for further investigation.

Previous studies have demonstrated that inquiry-based learning, concrete manipulatives, and spatial visualization interventions can improve students' mathematics learning and geometric reasoning (Medina Herrera et al., 2024; Harris et al., 2023; Ponte et al., 2023). However, existing evidence remains fragmented because these instructional approaches have largely been examined independently rather than as an integrated pedagogical framework. Furthermore, prior research has predominantly emphasized cognitive achievement, whereas affective outcomes, such as learning interest, and students' classroom responses have received comparatively limited attention despite their important roles in fostering engagement and meaningful mathematics learning. Research on spatial visualization has also focused primarily on general geometric reasoning or mental rotation, with relatively little attention given to cube spatial visualization, which requires learners to interpret multiple viewpoints and mentally reconstruct three-dimensional structures. Consequently, robust empirical evidence explaining how structured inquiry supported by concrete manipulatives simultaneously influences elementary students' spatial visualization, learning interest, and mathematics achievement remains limited. Addressing these gaps is expected to strengthen the empirical foundation for designing more effective geometry instruction in elementary mathematics.

Responding to these theoretical, practical, and empirical gaps, this study investigated the effects of inquiry-based learning supported by colorful cube manipulatives on sixth-grade students' learning interest, cube spatial visualization, mathematics achievement, and classroom responses through a quasi-experimental design. By examining cognitive and affective learning outcomes within an integrated instructional framework, the study provides empirical evidence on the pedagogical value of combining structured inquiry with concrete manipulatives in elementary geometry learning. The findings contribute to current mathematics education literature by strengthening understanding of how inquiry-supported concrete learning experiences can foster students' spatial visualization while simultaneously promoting learning interest and mathematics achievement, thereby offering practical implications for designing more meaningful and student-centered geometry instruction.

Accordingly, this study investigated the effects of inquiry-based learning supported by colorful cube manipulatives on sixth-grade students' learning interest, cube spatial visualization, mathematics achievement, and classroom responses through a quasi-experimental design. By simultaneously examining cognitive and affective learning outcomes within an integrated instructional framework, the study contributes empirical evidence on how structured inquiry supported by concrete manipulatives enhances elementary geometry learning. The findings also provide practical insights for designing more engaging, meaningful, and student-centered mathematics instruction.

METHOD

Research Design and Participants

This study employed a quantitative quasi-experimental design using the Matching Only Pretest–Posttest Control Group Design to examine the effects of inquiry-based learning supported by colorful cube manipulatives on sixth-grade students' learning interest and cube spatial visualization achievement (Buckler & Moore, 2023; Creswell & Creswell, 2023). A quasi-experimental approach was selected because random assignment of students was not feasible, as the participating schools maintained intact classroom organization throughout the academic year. To minimize selection bias and improve baseline comparability, a matching procedure was implemented by comparing students' previous mathematics achievement and pretest scores before the intervention.

The study was conducted from January to April 2026 at SDN 1 Jepangrejo and SDN Kauman, two public elementary schools in Blora Regency, Central Java, Indonesia. Participants comprised 58 sixth-grade students, including 29 students in the experimental group and 29 students in the control group. Purposive sampling was adopted because both schools implemented the Merdeka Curriculum, possessed comparable accreditation status, teacher qualifications, class size, learning facilities, and socio-demographic characteristics, while random assignment of students was impractical. Initial equivalence between the two groups was examined using an independent-samples *t*-test on the pretest scores, confirming no statistically significant difference before treatment ($p > .05$), thereby indicating comparable baseline achievement. Table 1 summarizes the demographic and educational characteristics of the participants in both research groups, as well as the matching criteria used to establish baseline comparability prior to the intervention.

Table 1. Demographic and Educational Characteristics of the Research Participants

Characteristic	Experimental Group	Control Group
School	SDN 1 Jepangrejo	SDN Kauman
Number of Students	29	29
Grade	VI	VI
Sampling Technique	Purposive	Purposive
Curriculum	Merdeka Curriculum	Merdeka Curriculum
Teacher Qualification	Bachelor's Degree	Bachelor's Degree
Matching Basis	Previous mathematics achievement + Pretest	Previous mathematics achievement + Pretest

Table 1 indicates that the experimental and control groups shared comparable demographic and educational characteristics, confirming the appropriateness of the matching procedure and the equivalence of both groups before the intervention. The overall flow of the research design and experimental procedures is presented in Figure 1.

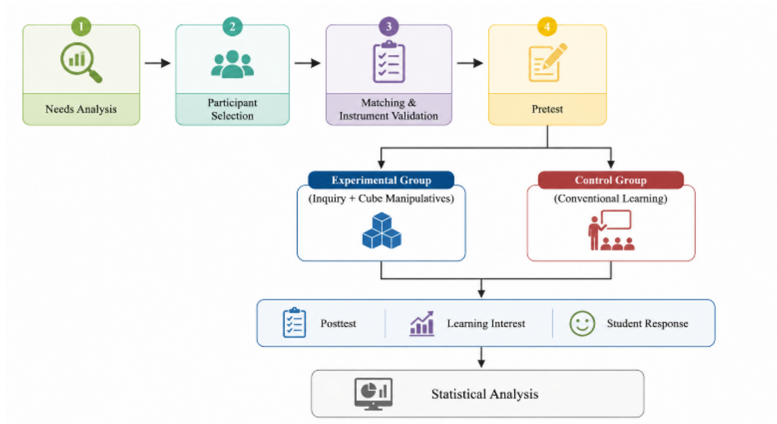

Figure 1. Research Framework

Research Instruments

Data were collected using an achievement test, a learning-interest questionnaire, a student-response questionnaire, classroom observations, structured interviews, documentation, and field notes. Multiple instruments were employed to obtain comprehensive evidence regarding students' cognitive achievement, affective outcomes, and the implementation of inquiry-based learning, following recommendations for educational research (Mertens, 2023; Yusrina et al., 2026). Table 2 presents the research instruments, the variables measured, their primary indicators, participants, and the corresponding data-analysis techniques used in this study.

Table 2. Research Instruments and Data Analysis Procedures

Instrument	Variable	Main Indicator	Participants	Data Analysis
Achievement Test	Cube Spatial Visualization	Cube identification, spatial perspectives, cube nets, spatial reasoning	Experimental & Control	Paired-samples *t*-test, Independent-samples *t*-test, N-Gain, Cohen's *d*
Learning-Interest Questionnaire	Learning Interest	Enjoyment, attention, participation, engagement	Experimental & Control	Independent-samples *t*-test
Student-Response Questionnaire	Student Response	Satisfaction, usefulness, motivation, interaction	Experimental	Descriptive percentage
Observation Sheet	Learning Implementation	Six inquiry learning stages	Experimental	Descriptive analysis
Structured Interview	Initial Classroom Condition	Teacher perceptions	Teacher	Narrative analysis
Documentation	Supporting Evidence	Attendance records, lesson plans, classroom photographs	School	Narrative analysis

As summarized in Table 2, different instruments were employed to capture complementary aspects of the study, enabling comprehensive evaluation of students' learning achievement, learning interest, classroom responses, and the implementation of the instructional intervention.

Instrument Validation

To ensure measurement quality, all research instruments were reviewed by two mathematics education experts before classroom implementation, following established procedures for educational instrument development (Mertens, 2023). Content validity was established through expert judgment, whereas achievement-test items were examined using Pearson Product–Moment correlation, item discrimination, and difficulty index analyses. Internal consistency of the achievement test and questionnaires was evaluated using Cronbach's alpha. Similar validation procedures have been widely adopted in recent mathematics education studies (Boadu et al., 2026; Yusrina et al., 2026; Adawiah et al., 2026). All instruments satisfied the predetermined validity and reliability criteria before being administered in the main study.

The results of the instrument validation and reliability analysis are summarized in Table 3.

Table 3. Instrument Validation and Reliability Results

Instrument	Content Validity	Item Validity	Validation Result	Reliability (Cronbach's α)	Interpretation
Achievement Test	Expert judgment (2 mathematics education experts)	Pearson Product–Moment	All items valid	0.88	Good
Learning-Interest Questionnaire	Expert judgment (2 mathematics education experts)	Pearson Product–Moment	All items valid	0.91	Excellent
Student-Response Questionnaire	Expert judgment (2 mathematics education experts)	Pearson Product–Moment	All items valid	0.89	Good

Table 3 demonstrates that all research instruments fulfilled the required validity and reliability criteria, confirming their suitability for measuring the variables investigated in this study before the intervention was implemented.

Intervention Procedure

The instructional intervention was implemented over six instructional meetings (2 × 35 minutes per meeting). Students in the experimental group participated in inquiry-based learning assisted by colorful cube manipulatives, whereas students in the control group received conventional teacher-centered instruction covering identical learning objectives, instructional duration, and assessment procedures. The inquiry activities were adapted from established inquiry-learning procedures and integrated with concrete manipulatives to facilitate students' exploration and understanding of three-dimensional cube concepts (Campillo-Ferrer & Miralles-Martínez, 2023; Siller & Ahmad, 2024). Table 4 summarizes the instructional stages implemented in the experimental group, together with the corresponding learning activities and the use of colorful cube manipulatives.

Table 4. Inquiry-Based Learning Activities Using Colorful Cube Manipulatives

Inquiry Stage	Learning Activities	Cube Manipulative Activities
Orientation	Observe cube structures and identify learning objectives	Observe colorful cube models
Problem Formulation	Formulate investigation questions related to cube structures	Identify cube arrangements and perspectives
Hypothesis Formulation	Predict possible solutions based on prior knowledge	Construct cube models
Data Collection	Explore and investigate cube problems collaboratively	Rotate, assemble, and compare cube models
Hypothesis Testing	Verify predictions using inquiry activities	Analyze visible and hidden cube faces
Conclusion	Present findings and reflect on learning outcomes	Explain spatial reasoning using cube models

As presented in Table 4, each inquiry stage was systematically supported by concrete manipulative activities, enabling students to observe, manipulate, investigate, and communicate spatial concepts throughout the learning process. The overall sequence of data collection throughout the intervention is described in the following section.

Data Collection Procedure

Data collection was conducted systematically from January to April 2026 following the sequence of the quasi-experimental design. The process began with classroom observations and teacher interviews to identify students' initial learning conditions, followed by instrument validation before classroom implementation. Subsequently, both groups completed the pretest prior to the intervention. After six instructional meetings, students completed the posttest and learning-interest questionnaire, while the experimental group additionally completed the student-response questionnaire. Documentation and field notes were collected throughout the study to support data interpretation and verify the implementation of the learning activities (Kuzu & Taşdelen, 2026; Carolina et al., 2026). The sequence of data collection and implementation procedures adopted in this study is illustrated in Figure 2.

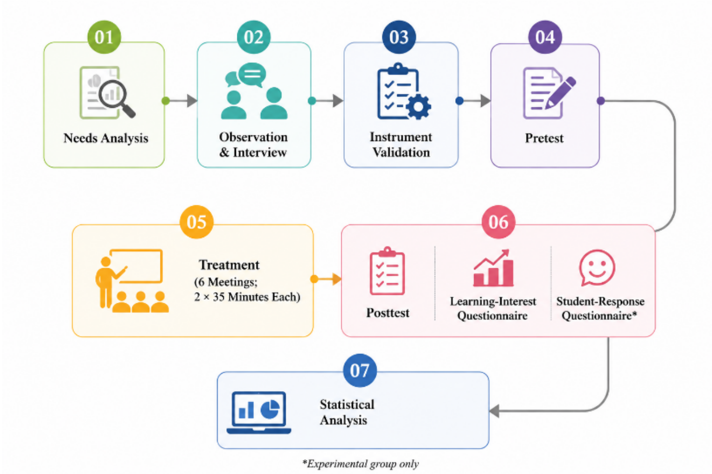

Figure 2. Research Procedure and Data Collection Process

As shown in Figure 2, the study followed a systematic sequence beginning with the identification of students' initial learning conditions through observations and interviews, followed by instrument validation, pretesting, classroom intervention, posttesting, questionnaire administration, and statistical analysis. This structured procedure ensured consistency in data collection and strengthened the validity of the research findings.

Data Analysis

Data analysis was conducted to evaluate the effects of inquiry-based learning assisted by colorful cube manipulatives on students' learning interest, cube spatial visualization achievement, and classroom responses. Statistical analyses were performed following commonly accepted procedures for quantitative educational research using descriptive and inferential statistics (Creswell & Creswell, 2023; Field, 2024). Table 5 summarizes the statistical analyses performed to address each research objective and evaluate the effectiveness of the instructional intervention.

Table 5. Statistical Analysis Procedures

Research Objective	Data	Statistical Analysis
Initial group equivalence	Pretest scores	Independent-samples *t*-test
Data normality	All variables	Shapiro–Wilk test
Homogeneity of variance	All variables	Levene's test
Within-group improvement	Pretest and posttest	Paired-samples *t*-test
Between-group comparison	Posttest scores	Independent-samples *t*-test
Learning improvement	Pretest and posttest	Normalized Gain (N-Gain)
Practical significance	Posttest scores	Cohen's *d* (with Hedges' correction)

As presented in Table 5, the statistical analyses were conducted sequentially to verify the assumptions of parametric testing, compare learning outcomes within and between groups, evaluate learning improvement, and determine the practical significance of the intervention. Statistical analyses were conducted at a significance level of $\alpha = .05$. Before hypothesis testing, the assumptions of normality and homogeneity were examined using the Shapiro–Wilk and Levene's tests, respectively. Differences in learning interest and achievement between the experimental and control groups were analyzed using independent-samples *t*-tests, whereas within-group improvements from pretest to posttest were examined using paired-samples *t*-tests. Students' learning improvement was further evaluated using normalized gain (N-Gain), categorized as low (< 0.30), moderate (0.30–0.69), and high (≥ 0.70). The magnitude of the intervention effect was determined using Cohen's *d*, with values of 0.20, 0.50, and 0.80 representing small, medium, and large effect sizes, respectively (Field, 2024).

RESULTS

Students' Learning Interest

Higher learning-interest scores were observed among students receiving inquiry-based learning assisted by colorful cube manipulatives than among those receiving conventional instruction. Table 6 presents the descriptive statistics of learning-interest scores for the experimental and control groups.

Table 6. Descriptive Statistics of Students' Learning Interest

Group	*n*	Minimum	Maximum	Mean	SD
Experimental	29	74	113	93.48	10.10
Control	29	38	72	53.86	8.21

Experimental-group students achieved a substantially higher mean learning-interest score (M = 93.48, SD = 10.10) than control-group students (M = 53.86, SD = 8.21), corresponding to a mean difference of 39.62 points. Slightly greater score variability was observed in the experimental group, whereas the control group exhibited a more homogeneous distribution of relatively low learning-interest scores. Descriptive findings indicate higher levels of learning interest among students receiving inquiry-based learning assisted by colorful cube manipulatives prior to inferential statistical analysis. Learning-interest scores were further classified into five categories to describe the distribution of students across different levels of learning interest. Table 7 summarizes the frequency distribution for both groups.

Table 7. Distribution of Students' Learning-Interest Categories

Category	Score Range	Experimental *n* (%)	Control *n* (%)
Very High	121–150	0 (0.0)	0 (0.0)
High	91–120	16 (55.2)	0 (0.0)
Moderate	61–90	13 (44.8)	7 (24.1)
Low	31–60	0 (0.0)	22 (75.9)
Very Low	≤30	0 (0.0)	0 (0.0)
Total		**29 (100)**	**29 (100)**

Higher learning-interest categories predominated in the experimental group, with 55.2% of students classified in the high category and the remaining 44.8% in the moderate category. In contrast, 75.9% of students in the control group remained in the low category, while only 24.1% reached the moderate category. No students in either group were classified in the very high or very low categories. Overall, the category distribution consistently supports the descriptive statistics, indicating higher levels of learning interest among students receiving inquiry-based learning assisted by colorful cube manipulatives.

Students' Learning Achievement

Higher posttest cube spatial visualization achievement was observed among students receiving inquiry-based learning assisted by colorful cube manipulatives than among those receiving conventional instruction. Table 8 summarizes the descriptive statistics of achievement scores obtained before and after the intervention.

Table 8. Descriptive Statistics of Cube Spatial Visualization Achievement

Group	Pretest Mean	Posttest Mean	Mean Difference (Posttest − Pretest)
Experimental	46.15	85.63	39.48
Control	45.75	67.34	21.59

Experimental-group students demonstrated substantially greater improvement in cube spatial visualization achievement than control-group students. As presented in Table 8, mean achievement increased from 46.15 to 85.63 in the experimental group, whereas the control group improved from 45.75 to 67.34. Comparable pretest performance indicated similar baseline achievement, while higher posttest achievement reflected stronger cube spatial visualization following inquiry-based learning assisted by colorful cube manipulatives. Learning mastery was subsequently examined using the minimum mastery criterion of 70. Table 9 presents the proportion of students achieving mastery before and after the intervention.

Table 9. Learning Mastery Before and After the Intervention

Achievement Status	Pretest *n* (%)	Posttest *n* (%)
Mastery (≥70)	0 (0.0)	38 (65.5)
Non-mastery (<70)	58 (100.0)	20 (34.5)

Learning mastery improved substantially following the intervention. No students achieved the mastery criterion before instruction, whereas 65.5% reached mastery after completing the learning activities. Normalized gain scores were further calculated to evaluate the magnitude of learning improvement. Table 10 summarizes the distribution of N-Gain categories.

Table 10. Distribution of N-Gain Categories

Category	Frequency	Percentage
High	10	17.2
Moderate	41	70.7
Low	7	12.1

Moderate and high learning improvement was achieved by 87.9% of the students, indicating substantial improvement in cube spatial visualization achievement throughout the intervention period. Distributional assumptions were examined before inferential statistical analysis. Table 11 summarizes the results of the normality and homogeneity tests.

Table 11. Assumption Tests for Cube Spatial Visualization Achievement

Test	Result
Shapiro–Wilk	All $p > .05$
Levene's Test	$p = .301$

Normality and homogeneity assumptions were satisfied, supporting the use of parametric statistical analyses. Group differences in posttest achievement were subsequently examined using an independent-samples *t*-test. Table 12 summarizes the hypothesis-testing results.

Table 12. Independent-Samples *t*-Test for Cube Spatial Visualization Achievement

Mean Difference	*t*	*df*	*p*	Cohen's *d*
15.574	13.479	56	< .001	3.540

Posttest achievement differed significantly between groups ($t(56) = 13.479$, $p < .001$), with a very large practical effect ($d = 3.540$). Students receiving inquiry-based learning assisted by colorful cube manipulatives achieved substantially higher cube spatial visualization scores than those receiving conventional instruction.

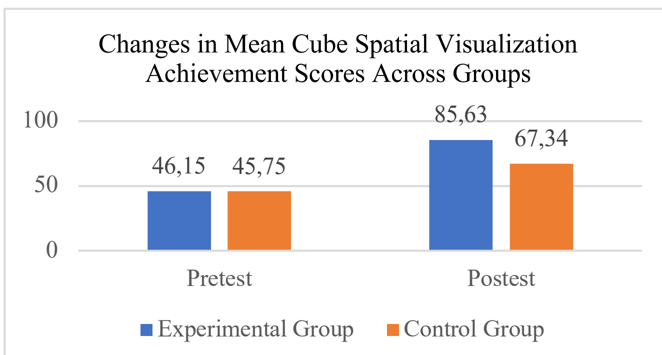

Figure 3. Changes in Mean Cube Spatial Visualization Achievement

Figure 3 illustrates a greater increase in mean cube spatial visualization achievement from pretest to posttest among students receiving inquiry-based learning than among those receiving conventional instruction.

Students' Responses Toward Inquiry-Based Learning

Positive student responses were observed following the implementation of inquiry-based learning assisted by colorful cube manipulatives. Table 13 summarizes students' perceptions of the instructional model based on the response questionnaire completed by the experimental group.

Table 13. Students' Responses Toward Inquiry-Based Learning

Indicator	Percentage (%)	Category
Learning Motivation	85.34	Very Positive
Learning Interest	84.62	Very Positive
Ease of Understanding	83.91	Very Positive
Classroom Participation	82.74	Very Positive
Overall Mean	84.25	Very Positive

Student responses indicated a highly positive perception of inquiry-based learning assisted by colorful cube manipulatives, with an overall mean score of 84.25%, categorized as very positive. High ratings across all indicators suggest that students perceived the instructional approach as engaging, understandable, and supportive of active participation during cube spatial visualization learning. To provide an integrated overview of the study outcomes, Table 14 summarizes the principal findings corresponding to each research objective.

Table 14. Summary of Research Findings

Variable	Statistical Analysis	Main Finding	Effect Size
Learning Interest	Independent-samples *t*-test	Significant difference ($p < .001$)	Cohen's $d = 4.31$
Cube Spatial Visualization Achievement	Independent-samples *t*-test	Significant difference ($p < .001$)	Cohen's $d = 3.54$
Learning Improvement	N-Gain analysis	Experimental group demonstrated higher learning improvement than the control group	
Student Responses	Descriptive analysis	Mean response = 84.25% (Very Positive)	

Overall, the findings consistently support the effectiveness of inquiry-based learning assisted by colorful cube manipulatives in enhancing sixth-grade students' mathematics learning outcomes. Compared with conventional instruction, the intervention was associated with higher learning interest, stronger cube spatial visualization achievement, greater learning improvement, and highly positive student responses. Collectively, these findings demonstrate that integrating systematic inquiry activities with concrete educational manipulatives provides meaningful support for learning three-dimensional geometry in elementary mathematics.

DISCUSSION

Higher learning interest observed among students receiving inquiry-based learning assisted by colorful cube manipulatives can be interpreted as the result of sustained cognitive engagement throughout the learning process. Active participation in observing cube structures, formulating problems, generating hypotheses, manipulating concrete models, testing predictions, and communicating findings encouraged students to construct mathematical understanding through direct exploration rather than passive reception of information. Such learning experiences likely increased students' curiosity, autonomy, and confidence because abstract spatial concepts became more accessible through meaningful interaction with tangible objects. Inquiry activities therefore created an instructional environment in which students were continuously involved in questioning, investigating, and reflecting, thereby promoting stronger interest in mathematics beyond simple exposure to instructional media.

Comparable evidence has been reported in recent mathematics education research. Debrenti, (2024) demonstrated that active learning experiences enhance students' motivation, collaboration, communication, and problem-solving by increasing meaningful participation during mathematical activities, while (Saccardo et al., 2024) emphasized that tangible learning tools become more effective when integrated with emotionally supportive learning environments. Findings of the present study extend these perspectives by demonstrating that colorful cube manipulatives alone are insufficient to stimulate learning interest unless they are systematically embedded within a structured inquiry process. Rather than functioning merely as visual teaching aids, the manipulatives became cognitive tools that enabled students to explore, verify, discuss, and communicate spatial relationships, thereby creating meaningful learning experiences that strengthened both engagement and sustained interest in elementary mathematics.

Improved cube spatial visualization achievement can be attributed to the integration of inquiry-based learning with colorful cube manipulatives, which transformed abstract three-dimensional concepts into concrete learning experiences. Direct manipulation of cube models enabled students to observe spatial relationships, identify cube nets, recognize visible and hidden faces, and verify their own predictions through systematic investigation. Such learning experiences promoted active knowledge construction and strengthened spatial reasoning because mathematical ideas were explored through observation, experimentation, and reflection rather than memorization. Increased learning achievement therefore reflects not only students' understanding of cube geometry but also their ability to mentally visualize and manipulate three-dimensional objects during problem-solving activities.

Comparable findings have been reported in recent mathematics education research. Schenck & Nathan, (2024) demonstrated that embodied interaction with concrete manipulatives significantly improves students' spatial reasoning by connecting physical actions with abstract mathematical representations, while (Thom et al., 2024) emphasized that inquiry-oriented mathematics instruction enhances conceptual understanding through exploration, evidence-based reasoning, and collaborative discussion. Consistent with (Manunure & Leung, 2024), active engagement in mathematical investigation facilitates deeper conceptual understanding than conventional teacher-centered instruction. Findings of the present study extend previous research by demonstrating that combining structured inquiry learning with colorful cube manipulatives simultaneously strengthens spatial visualization and conceptual understanding in elementary geometry, providing empirical evidence that carefully integrated pedagogical strategies are more effective than using inquiry activities or concrete manipulatives independently.

Positive student responses, increased learning interest, and substantial learning improvement indicate that cognitive and affective outcomes developed simultaneously throughout the inquiry-based learning process. Active exploration using colorful cube manipulatives encouraged students to participate more confidently in mathematical investigations, while continuous interaction with concrete objects and collaborative inquiry sustained motivation and facilitated deeper conceptual understanding. Stronger engagement therefore contributed not only to greater enthusiasm for learning but also to improved cube spatial visualization achievement, suggesting that affective involvement functioned as an important catalyst for cognitive development. Comparable conclusions were reported by (Saccardo et al., 2024), who emphasized that emotionally engaging learning environments strengthen students' motivation and conceptual understanding, whereas (Simpson et al., 2024) highlighted that meaningful classroom participation enhances both academic performance and long-term learning engagement. Findings of the present study extend previous evidence by demonstrating that integrating inquiry-based learning with colorful cube manipulatives simultaneously promotes students' interest, positive learning experiences, and learning improvement, thereby supporting a more holistic approach to elementary mathematics instruction.

Consistent improvements in learning interest, cube spatial visualization achievement, learning improvement, and positive student responses demonstrate that integrating inquiry-based learning with colorful cube manipulatives provides a comprehensive instructional approach for elementary mathematics. Previous studies have shown that inquiry-based learning promotes active knowledge construction and conceptual understanding, whereas concrete manipulatives facilitate students' spatial reasoning and mathematical visualization (Schenck & Nathan, 2024; Thom et al., 2024;Manunure & Leung, 2024). Existing evidence, however, has generally examined these instructional components separately or focused primarily on either cognitive or affective outcomes. Findings of the present study extend previous research by demonstrating that structured inquiry activities and colorful cube manipulatives operate synergistically to enhance students' cognitive achievement, learning interest, learning improvement, and classroom engagement within a single instructional framework. Such evidence contributes to mathematics education theory by reinforcing constructivist perspectives that meaningful mathematical understanding emerges through active investigation supported by concrete representations, while also providing empirical evidence that integrating inquiry pedagogy with educational manipulatives offers a more holistic strategy for improving elementary students' spatial visualization learning.

Successful implementation of inquiry-based learning assisted by colorful cube manipulatives highlights its potential as an effective instructional strategy for strengthening elementary mathematics education under the Merdeka Curriculum. Integration of systematic inquiry activities with concrete manipulatives encourages active participation, mathematical reasoning, collaboration, and conceptual understanding while supporting the development of students' spatial visualization skills through meaningful learning experiences. Comparable recommendations have been proposed by (Bufasi et al., 2024), who emphasized the importance of learner-centered instructional approaches for improving mathematical competencies, and by (Pinilla, 2024), who argued that curriculum implementation should integrate innovative pedagogical strategies with authentic learning resources to foster deeper conceptual learning. Practical implications of the present study therefore extend beyond improved academic achievement by providing teachers with an empirically supported instructional framework that simultaneously promotes students' engagement, spatial reasoning, and meaningful mathematical understanding, thereby offering a feasible model for enhancing geometry instruction in elementary classrooms.

Several limitations should be considered when interpreting the findings of this study. Implementation of the intervention was limited to two elementary schools and focused exclusively on cube spatial visualization, which may restrict the generalizability of the findings to other mathematical topics and educational contexts. Although the matching procedure ensured comparable baseline characteristics between the experimental and control groups, future studies should provide more comprehensive group-specific reporting for all outcome measures, including descriptive statistics, learning mastery, and learning improvement, to strengthen the transparency and interpretability of comparative analyses. Broader investigations involving larger samples, diverse school settings, extended intervention periods, and longitudinal designs are recommended to examine the sustainability of inquiry-based learning assisted by educational manipulatives across different mathematical domains and student populations.

CONCLUSION

Inquiry-based learning assisted by colorful cube manipulatives was associated with higher learning interest, stronger cube spatial visualization achievement, greater learning improvement, and highly positive student responses than conventional instruction among sixth-grade elementary students. Integration of structured inquiry activities with concrete educational manipulatives provided meaningful learning experiences that promoted active participation, strengthened spatial reasoning, and facilitated conceptual understanding of three-dimensional geometry. Collectively, these findings indicate that combining inquiry pedagogy with colorful cube manipulatives represents a promising instructional approach for supporting both cognitive and affective learning outcomes in elementary mathematics.

Practical contributions of the study extend beyond improved academic performance by providing teachers with an empirically supported instructional framework that aligns with the principles of the Merdeka Curriculum and encourages active mathematical exploration through concrete learning experiences. Future research should involve larger and more diverse samples, investigate the long-term retention of spatial visualization skills, examine the effectiveness of the instructional approach across different mathematical topics, and provide more comprehensive group-specific reporting of learning outcomes to strengthen the transparency and generalizability of comparative findings.

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ACKNOWLEDGEMENT

The authors sincerely thank the principals, teachers, and sixth-grade students of SDN 1 Jepangrejo and SDN Kauman for their cooperation and participation in this study. Appreciation is also extended to the academic supervisors and all parties who assisted in providing literature, research data, instructional materials, and constructive feedback during the preparation and writing of this article.

AUTHOR CONTRIBUTION STATEMENT

DCA conceptualized the study, developed the research methodology and instruments, collected and analyzed the data, interpreted the findings, and prepared the initial manuscript. DA also revised the manuscript and approved the final version for publication.

AI DISCLOSURE STATEMENT

The author used OpenAI's ChatGPT during the preparation of this work to assist with language refinement, organization, and academic presentation. After using the tool, the author thoroughly reviewed, verified, and edited the content as needed and takes full responsibility for the accuracy, integrity, and final content of the publication.

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