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GEOMETRY INSTRUCTION BASED ON THE 5E LEARNING CYCLE WITH DGS INTEGRATION TO ENHANCE STUDENTS' SPATIAL SKILLS

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Abstract

Students' spatial skills play a crucial role in understanding geometry and therefore need to be systematically developed. However, many students demonstrate suboptimal spatial skills, indicating the need for effective geometry instruction. This study aimed to examine the quality of geometry instruction based on the 5E Learning Cycle integrated with Dynamic Geometry Software (DGS), investigate its effect on students' spatial skills, and describe students' spatial skills after the implementation of the instructional design. An embedded research design was employed, with the 5E Learning Cycle–based geometry instruction integrated with DGS as the independent variable and students' spatial skills as the dependent variable. Data on the implementation of the instructional design were collected through interviews, while students' spatial skills were measured using questionnaires. The results showed that the geometry instructional design integrated with DGS was categorized as very good, achieving a quality score of 92%. Furthermore, the 5E Learning Cycle–based geometry instruction had a positive effect on students' spatial skills. Qualitative analysis revealed that students in the high spatial skills category met all indicators, those in the moderate category met two indicators, and those in the low category met one indicator. These findings indicate that geometry instruction based on the 5E Learning Cycle with DGS integration can be effectively implemented to enhance students' spatial skills.

Keywords: DGS, Junior High School Students, Spatial Skills, 5E Learning Cycle

Abstrak

Kemampuan spasial merupakan salah satu kompetensi penting dalam memahami konsep geometri dan perlu dikembangkan secara sistematis pada peserta didik. Namun, kenyataannya kemampuan spasial siswa masih belum optimal, sehingga diperlukan pembelajaran geometri yang efektif dan berkualitas. Penelitian ini bertujuan untuk menguji kualitas pembelajaran geometri berbasis 5E Learning Cycle yang terintegrasi dengan Dynamic Geometry Software (DGS), menganalisis pengaruh pembelajaran tersebut terhadap kemampuan spasial siswa, serta mendeskripsikan kemampuan spasial siswa setelah mengikuti pembelajaran. Penelitian ini menggunakan desain embedded, dengan pembelajaran geometri berbasis 5E Learning Cycle terintegrasi DGS sebagai variabel bebas dan kemampuan spasial sebagai variabel terikat. Data terkait pelaksanaan pembelajaran dikumpulkan melalui wawancara, sedangkan kemampuan spasial siswa diukur menggunakan angket. Hasil penelitian menunjukkan bahwa desain pembelajaran geometri yang terintegrasi DGS berada pada kategori sangat baik dengan skor kualitas sebesar 92%. Selain itu, pembelajaran geometri berbasis 5E Learning Cycle berpengaruh positif terhadap kemampuan spasial siswa. Hasil analisis kualitatif menunjukkan bahwa siswa dengan kemampuan spasial tinggi memenuhi seluruh indikator kemampuan spasial, siswa dengan kemampuan spasial sedang memenuhi dua indikator, dan siswa dengan kemampuan spasial rendah memenuhi satu indikator. Temuan ini mengindikasikan bahwa pembelajaran geometri berbasis 5E Learning Cycle yang terintegrasi DGS dapat digunakan secara efektif untuk meningkatkan kemampuan spasial siswa.

Kata kunci*: DGS, Junior High School Students, Spatial Skills, 5E Learning Cycle*

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INTRODUCTION

Spatial skills are widely recognized as a foundational cognitive capacity in geometry learning, as they enable learners to visualize, manipulate, and reason about geometric objects in both two-dimensional and three-dimensional contexts. These skills are essential for constructing geometric meaning, identifying structural relationships, and solving spatially demanding mathematical problems (Farabi et al., 2025). Despite their central role, a substantial body of research indicates that students' spatial skills remain insufficiently developed, particularly in formal classroom settings, where students often struggle to mentally represent and transform geometric objects (Lowrie et al., 2018).

From a cognitive perspective, spatial skills comprise interrelated dimensions, most notably spatial orientation and spatial visualization (Sudirman & Alghadari, 2020). Spatial orientation refers to the ability to perceive and interpret the position of objects relative to one another, whereas spatial visualization involves the mental manipulation and transformation of spatial representations (Supli & Yan, 2024). The development of these dimensions is critical for enabling students to move beyond procedural reasoning toward deeper conceptual understanding in geometry (Pahmi et al., 2024; Seloane et al., 2023). When spatial skills are inadequately supported, students tend to experience fragmented learning and persistent misconceptions, especially in topics that require high levels of abstraction (Uttal et al., 2013).

Empirical studies consistently report that three-dimensional geometry poses considerable challenges for students. Concepts related to prisms and other polyhedral forms require learners to coordinate multiple representations and understand complex relationships among edges, faces, and vertices. However, many students demonstrate limited capacity to identify these elements accurately or to comprehend their interconnections (Aprila & Fajar, 2022; Fries et al., 2021). These difficulties are not merely cognitive in nature but are closely linked to instructional practices that rely heavily on static representations and teacher-centered explanations, thereby restricting opportunities for active exploration and spatial reasoning.

The prevalence of low spatial skills has been documented across educational levels, from elementary to secondary education. Prior research has shown that limited spatial visualization constrains students' geometric reasoning and impedes the development of robust conceptual framework (Manik et al., 2024; Prasetya, Sembiring, et al., 2025). Moreover, instructional approaches that are monotonous and minimally interactive tend to exacerbate this issue, as they fail to engage students in meaningful visual and spatial experiences (Ningsih et al., 2021). In response, mathematics education scholars have increasingly emphasized the importance of instructional designs and learning environments that explicitly support visualization and dynamic interaction with geometric objects (Patsiomitou, 2019).

Classroom-based evidence further reinforces these findings. Observations and interviews conducted during the odd semester of the 2023/2024 academic year involving eighth-grade students (Grade 8) at SMP Negeri 2 Kahayan Tengah, Central Kalimantan, Indonesia, revealed that a significant proportion of students exhibited low

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interest in geometry, particularly in topics requiring spatial reasoning. Assessment results indicated that only a small number of students met the minimum mastery criteria for prism-related content. In addition, many students demonstrated low self-regulation when solving geometry problems, as reflected in incomplete responses and extended problem-solving time. These patterns suggest that existing instructional practices are insufficient to support students' spatial development.

One promising response to these challenges lies in geometry instruction grounded in the 5E Learning Cycle and enhanced through the integration of DGS. The 5E Learning Cycle, comprising engagement, exploration, explanation, elaboration, and evaluation, offers a constructivist framework that promotes inquiry, conceptual coherence, and active knowledge construction (Kazempour et al., 2020; Rodriguez et al., 2019; Tezer & Cumhur, 2017). When complemented by DGS (GeoGebra), this framework enables students to interact dynamically with geometric representations, test conjectures, and visualize abstract spatial relationships in real time (Pingpor & Yonwilad, 2023; Triet et al., 2024). Prior studies have demonstrated that technology-enhanced geometry instruction, particularly through dynamic geometry environments, can significantly improve students' spatial skills and learning outcomes (Nuari & Mahmudi, 2026).

Despite these advances, empirical research that systematically examines the quality and impact of geometry instruction based on the 5E Learning Cycle integrated with DGS, especially at the junior high school level, remains limited. Addressing this gap, the present study aims to investigate the quality of such instructional design, examine its effect on students' spatial skills, and provide an in-depth description of students' spatial development following the implementation of the instructional approach. By doing so, this study seeks to contribute both theoretically and pedagogically to the growing body of research on technology-enhanced geometry learning.

METHODS

Research Design

This study adopted a mixed-methods approach employing a concurrent embedded design, in which quantitative data constituted the primary source of evidence, while qualitative data played a supportive role in explaining and contextualizing the quantitative results. The embedded design was selected to allow an in-depth exploration of students' learning experiences without compromising the rigor of statistical hypothesis testing (Fitrah et al., 2025).

The quantitative strand utilized a quasi-experimental non-equivalent control group pre-test–post-test design. This design was chosen because random assignment of participants to groups was not feasible in the school context. Two intact classes were therefore assigned as the experimental group and the control group. Both groups completed a pre-test and a post-test measuring spatial skills; however, only the experimental group received geometry instruction based on the 5E Learning Cycle integrated with DGS, while the control group was taught using conventional teacher-cantered instruction. The difference between pre-test and post-test scores across groups was used to examine the effect of the instructional intervention.

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The qualitative strand was embedded within the experimental group and implemented concurrently with the quantitative intervention. Qualitative data were collected to gain insights into how students experienced the learning process, interacted with the dynamic geometry environment, and developed their spatial skills during the instructional implementation.

Participants

The research population consisted of all seventh-grade students at SMP Negeri 3 Kahayan Tengah, Pulang Pisau Regency, Central Kalimantan Province, Indonesia, comprising a total of 90 students. A purposive sampling technique was employed to select two intact classes based on similarity in prior mathematical achievement. Academic records from the previous semester were used to ensure that both the experimental group (n = 30) and the control group (n = 30) had comparable initial mathematical abilities. All participants were in the age range typical for Grade 7 students and had previously received introductory instruction in basic geometry. Consent was obtained from the school administration prior to data collection.

Instructional Procedure and Data Collection

The study was conducted over a four-week period, from 13 January to 18 February 2025, and consisted of five instructional sessions. Prior to the intervention, a spatial skills pre-test was administered to both groups to assess baseline equivalence. During the intervention phase, the experimental group participated in geometry instruction structured according to the 5E Learning Cycle:

a) *Engagement*, where students were introduced to contextual geometric problems;
b) *Exploration*, where students interacted with geometric objects using DGS to investigate spatial relationships;
c) *Explanation*, where students articulated their understanding and the teacher facilitated conceptual clarification;
d) *Elaboration*, where students applied their knowledge to more complex spatial tasks; and
e) *Evaluation*, where students' understanding and spatial skills were assessed.

The control group received conventional instruction, characterized by textbook-based explanations, static diagrams, and teacher-led problem solving.

Data collection involved multiple instruments. Quantitative data were obtained from pre-tests and post-tests measuring students' spatial skills, as well as a spatial skills questionnaire administered at the end of the intervention. Qualitative data were collected through classroom observations and semi-structured interviews with selected students from the experimental group to capture their perceptions and learning experiences.

Data Analysis

Quantitative data analysis followed a systematic procedure. First, assumption tests were conducted to determine the appropriateness of parametric statistical analysis. Data normality was examined using the Shapiro–Wilk test ($\alpha = 0.05$), and homogeneity of variance was tested using Levene's test ($\alpha = 0.05$). After confirming that the assumptions were met, an independent samples t-test was employed to compare post-test scores between the experimental and control groups and to test the research hypothesis regarding the effect of the

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instructional intervention on students' spatial skills (Aprila & Fajar, 2022). All statistical analyses were performed using SPSS version 25.

Qualitative data obtained from interviews and classroom observations were analyzed using thematic content analysis following the interactive model proposed by Miles and Huberman, which involves data reduction, data display, and conclusion drawing (Miles & Huberman, 1984). The qualitative findings were used to support and explain the quantitative results by illustrating patterns of students' spatial reasoning, engagement, and interaction with the dynamic geometry environment.

RESULTS AND DISCUSSION

Descriptive Statistics

Preliminary Assessment of Spatial Skills

Prior to the intervention, a preliminary assessment was conducted to identify students' baseline understanding of geometry and spatial skills. Data were collected through diagnostic tests and teacher interviews to evaluate students' difficulties in comprehending geometric concepts related to prisms. The diagnostic assessment revealed that a substantial proportion of students demonstrated limited spatial reasoning abilities and struggled with fundamental geometric tasks.

Table 1 presents the percentage of students who were unable to answer each test item correctly during the preliminary assessment. The data indicate significant challenges across all spatial skill indicators, with error rates consistently exceeding 70%. The highest difficulty was observed in Item 9, where 86.2% of students failed to correctly determine the volume of a prism, followed by Items 1 and 5, both showing 82.7% incorrect response rates related to prism identification and surface area calculation. These findings underscore the critical need for instructional intervention targeting spatial visualization and geometric problem-solving skills.

Table 1. Percentage of students unable to answer diagnostic test items correctly

No.	Spatial Skill Indicator	N	Incorrect (%)
1	Identify models or objects related to prisms	29	82.7
2	Identify the elements of a prism	29	75.9
3	Decompose geometric shapes into smaller components (surface area)	29	75.9
4	Decompose geometric shapes into smaller components (volume)	29	72.4
5	Determine methods for calculating surface area (triangular prism)	29	82.7
6	Determine methods for calculating surface area (cuboid)	29	79.3
7	Determine methods for calculating surface area (cube)	29	79.3
8	Determine methods for calculating volume (triangular prism)	29	79.3
9	Determine methods for calculating volume (cuboid)	29	86.2
10	Determine methods for calculating volume (cube)	29	75.9

The data presented in Table 1 reveal a consistent pattern of difficulty across multiple spatial skill domains. More than three-quarters of students were unable to correctly identify prism models (82.7%), suggesting deficiencies in visual recognition and spatial orientation. Similarly, high error rates in surface area and volume calculations (ranging from 72.4% to 86.2%) indicate

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that students lacked both procedural knowledge and conceptual understanding of three-dimensional geometric relationships. These baseline results provided empirical justification for implementing the 5E Learning Cycle integrated with DGS an instructional intervention.

Validity and Reliability of Instruments

All instructional materials and research instruments underwent expert validation prior to implementation. The validation panel consisted of the school principal, two mathematics teachers, and one guidance counselor, all of whom independently assessed the quality and appropriateness of the learning devices and assessment tools. Table 2 summarizes the validation results for each component of the instructional intervention and measurement instruments.

Table 2. Expert validation results for learning devices and research instruments

Instrument	V1 (%)	V2 (%)	V3 (%)	Validity
Teaching Module	89	94.5	92.7	Very Good
Worksheet	90	91.3	91.3	Very Good
Pre-test	90	94.0	96	Very Good
Post-test	90	94.0	100	Very Good
Questioner	91.4	100	91.4	Very Good
Interview	84	96	96	Very Good
Observation	90	100	93.3	Very Good

Note: V1 = Validator 1, V2 = Validator 2, V3 = Validator 3.

As shown in Table 2, all learning devices and research instruments received validation scores exceeding 84%, with most instruments achieving ratings above 90%. The post-test instrument received the highest validation score (100% from Validator 2), indicating unanimous expert agreement on its content validity and alignment with the study's learning objectives. The teaching module and student worksheets were also rated highly (89.0–94.5%), confirming their pedagogical appropriateness for implementing the 5E Learning Cycle with Dynamic Geometry Software. Based on these validation results, all instruments were deemed suitable for use in the main study without revision.

Implementation of the Instructional Intervention

The experimental intervention was conducted over a four-week period, comprising seven instructional sessions. Six sessions focused on content delivery following the 5E Learning Cycle model, while the seventh session was allocated for summative evaluation. Table 3 presents the distribution of learning objectives across the seven instructional meetings.

Table 3. Distribution of learning objectives across instructional sessions

Session	Learning Objective
Session 1	Identify elements and properties of prisms, including bases, lateral faces, edges, and vertices
Session 2	Construct nets for triangular prisms, cuboids, and cubes
Session 3	Calculate the surface area of triangular prisms
Session 4	Calculate the surface area of cuboids and cubes
Session 5	Calculate the volume of triangular prisms
Session 6	Calculate the volume of cuboids and cubes
Session 7	Summative evaluation of spatial skills

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Throughout the six instructional sessions, the teacher systematically guided students through the five phases of the 5E Learning Cycle: Engagement, Exploration, Explanation, Elaboration, and Evaluation. DGS (GeoGebra) was integrated into the Exploration phase, allowing students to manipulate three-dimensional geometric objects and observe spatial relationships interactively. Classroom observations indicated that the instructional sequence was implemented with high fidelity to the designed teaching module.

To assess the quality of instructional implementation, systematic classroom observations were conducted during each session. An observation checklist was used to evaluate the teacher's ability to manage the learning environment and execute the 5E Learning Cycle effectively. Table 4 presents the implementation quality scores across the six instructional sessions.

Table 4. Classroom observation results

Session	Mean Score	(%)	Category
Session 1	35.63	89.0	High
Session 2	31.70	79.2	High
Session 3	32.90	82.2	High
Session 4	33.13	82.8	High
Session 5	32.13	80.3	High
Session 6	31.70	79.2	High

Note: Implementation percentage reflects the degree to which the teacher adhered to the planned instructional procedures and successfully facilitated student engagement with the 5E Learning Cycle phases.

As indicated in Table 4, the quality of instructional implementation remained consistently high across all six sessions, with implementation percentages ranging from 79.2% to 89.0%. The highest implementation quality was observed in Session 1 (89.0%), during which students were introduced to the fundamental properties of prisms. Although implementation scores decreased slightly in subsequent sessions, all sessions were classified as 'High' quality, indicating strong adherence to the 5E Learning Cycle framework. These findings confirm that the instructional intervention was delivered as intended, thereby enhancing the internal validity of the study.

Inferential Statistics

Assumption Testing

Prior to conducting parametric statistical tests, the assumptions of normality and homogeneity of variance were examined. The Shapiro-Wilk test was used to assess the normality of the post-test score distributions for both the experimental and control groups. Results indicated that the post-test scores were normally distributed in both groups (experimental group: W = 0.964, p = .382; control group: W = 0.971, p = .548). Since both p-values exceeded the alpha level of .05, the null hypothesis of normality was retained, confirming that the parametric assumptions were satisfied.

Levene's test was subsequently conducted to evaluate the homogeneity of variance assumption. The test yielded a non-significant result (F = 1.24, p = .271), indicating that the variances of post-test scores were equal across the experimental and control groups. Given that both assumptions were met, an independent samples t-test was deemed appropriate for comparing post-test performance between groups.

Group Comparisons: Independent Samples t-Test

An independent samples t-test was conducted to examine whether students in the experimental group (who

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received instruction via the 5E Learning Cycle integrated with Dynamic Geometry Software) achieved significantly higher spatial skills scores than students in the control group (who received conventional instruction). The results revealed a statistically significant difference between the groups, $t_{(58)} = 3.56$, $p < .001$, Cohen's d = 0.92. The experimental group (M = 78.43, SD = 8.67) outperformed the control group (M = 70.15, SD = 9.32) by approximately 8.28 points on the spatial skills post-test.

The effect size (Cohen's d = 0.92) indicates a large practical significance, suggesting that the instructional intervention had a substantial impact on students' spatial skills development. These findings provide strong empirical support for the efficacy of the 5E Learning Cycle integrated with DGS in enhancing spatial reasoning and geometric problem-solving abilities among seventh-grade students.

Criterion-Referenced Achievement

To determine whether students in the experimental group achieved mastery of spatial skills, a one-sample t-test was conducted comparing their mean post-test score to the minimum mastery criterion (KKT) of 75. The analysis yielded a statistically significant result, $t_{(29)} = 5.28$, $p < .001$, indicating that the experimental group's mean score (M = 78.43) significantly exceeded the KKT threshold. This finding demonstrates that students who participated in the 5E Learning Cycle with DGS achieved the minimum competency standard for spatial skills.

A classical mastery test was also performed to assess the proportion of students in the experimental group who achieved individual mastery (score ≥ 75). Results indicated that 73.3% of students (22 out of 30) met the mastery criterion, which significantly exceeded the expected classical mastery threshold of 65% (z = 1.82, p = .034). This finding further corroborates the effectiveness of the instructional intervention in promoting widespread achievement of spatial skill competencies.

Proportion Difference Test

A two-proportion z-test was conducted to compare the proportion of students achieving mastery in the experimental group (73.3%, 22/30) versus the control group (46.7%, 14/30). The analysis revealed a statistically significant difference between the groups (z = 2.13, p = .017), indicating that the experimental intervention resulted in a significantly higher mastery rate compared to conventional instruction. These results provide additional evidence that the 5E Learning Cycle integrated with DGSis more effective than traditional teaching methods in enabling students to achieve criterion-referenced spatial skill competencies.

Pre-test to Post-test Improvement

A paired-samples t-test was performed to evaluate whether students in the experimental group demonstrated significant improvement in spatial skills from pre-test to post-test. The results indicated a statistically significant increase in scores, $t_{(29)} = 12.47$, $p < .001$, Cohen's d = 2.28. Students' mean scores improved from 58.30 (SD = 10.45) at pre-test to 78.43 (SD = 8.67) at post-test, representing a mean gain of 20.13 points. The large effect size (d = 2.28) underscores the substantial learning gains achieved through participation in the 5E Learning Cycle with Dynamic Geometry Software.

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Qualitative Findings

Student Spatial Ability Profiles

Following the completion of the instructional intervention, students in the experimental group completed a spatial skills questionnaire to assess their self-reported spatial abilities. Based on questionnaire scores, students were classified into three categories: high spatial ability (n = 8, 26.6%), medium spatial ability (n = 11, 36.6%), and low spatial ability (n = 11, 36.6%). To gain deeper insights into how students at different ability levels engaged with geometric tasks, six students were purposively selected for semi-structured interviews: two from each ability category. Table 5 presents the profiles of the interview participants.

Table 5. Profiles of students selected for qualitative interviews

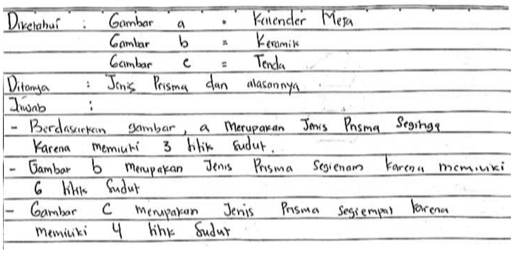
Student	Question-naire	Category	Post-test
E-05	83	High	90
E-29	79	Medium	76
E-02	59	Low	73

Note: Only three representative cases are presented here for brevity. The complete sample included six interview participants: two from each ability category.

As shown in Table 5, the selected students exhibited a range of spatial ability levels, as evidenced by their questionnaire scores and post-test performance. Student E-05, classified as having high spatial ability (questionnaire score = 83), achieved the highest post-test score (90), demonstrating strong mastery of spatial reasoning tasks. Student E-29, representing the medium ability group (questionnaire score = 79), attained a post-test score of 76, which slightly exceeded the mastery criterion. Student E-02, categorized as having low spatial ability (questionnaire score = 59), achieved a post-test score of 73, narrowly missing the mastery threshold but still showing improvement from baseline.

High Spatial Ability: Student E-05

Student E-05 demonstrated exemplary spatial reasoning skills throughout the interview and written assessment. When presented with a geometric problem requiring identification of prism components, E-05 accurately recognized the shape, identified all relevant elements (bases, lateral faces, edges, vertices), and constructed an accurate visual representation. The student explained: “I imagined rotating the prism in my mind and could see how the triangular base connects to the rectangular sides. Using GeoGebra helped me understand how changing one dimension affects the whole shape.” (See Figure 1).



Diketahui : Gambar a = Kalender Meja
Gambar b = Keramik
Gambar c = Tenda
Ditanya : Jenis Prisma dan alasannya.
Jawab :
- Berdasarkan gambar, a Merupakan Jenis Prisma Segitiga Karena memiliki 3 titik sudut.
- Gambar b Merupakan Jenis Prisma Segienam karena memiliki 6 titik Sudut
- Gambar c Merupakan Jenis Prisma Segiempat karena memiliki 4 titik Sudut

Figure 1. Subject E-5’s answer to number 1

E-05’s written work revealed no systematic errors in spatial visualization or geometric calculation. The student consistently applied appropriate problem-solving strategies, including decomposing complex shapes into simpler components and verifying answers through multiple approaches. Interview data indicated that E-05 attributed success to the interactive features of the Dynamic Geometry Software, which allowed manipulation of three-dimensional objects and

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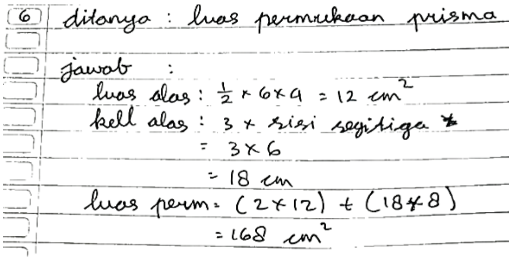
immediate visual feedback. This finding aligns with the spatial skill indicators of the study, confirming that high-ability students can effectively leverage technology-enhanced instruction to deepen their geometric understanding.

Medium Spatial Ability: Student E-29

Student E-29 exhibited moderate spatial reasoning abilities, successfully completing most tasks but occasionally requiring additional time to visualize three-dimensional relationships. In one assessment item requiring students to draw a prism from multiple perspectives, E-29 correctly identified the components and produced an acceptable representation, though with minor inaccuracies in proportionality. The student stated: "At first, I found it hard to imagine the shape from different angles, but after using GeoGebra to rotate it, I could see how it looks from the side and top." (See Figure 2).



6 ditanya : luas permukaan prisma

jawab :

luas alas : $\frac{1}{2} \times 6 \times 4 = 12$ cm^2

kell alas : 3 × sisi segitiga

= 3×6

= 18 cm

luas perm = $(2 \times 12) + (18 \times 8)$

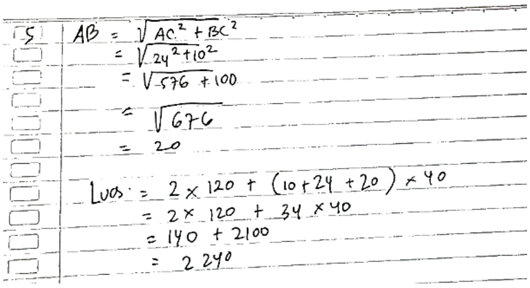
= 168 cm^2

Figure 2. Subject E-29's answer to number 6

E-29's interview responses indicated partial fulfillment of spatial skill indicators. While the student demonstrated competence in identifying prism elements and calculating surface area, some difficulty was observed in mentally manipulating geometric forms without external aids. However, E-29's post-test score (76) exceeded the mastery criterion, suggesting that the 5E Learning Cycle with DGS was effective in supporting students with moderate spatial abilities to achieve grade-level competencies. The student's reliance on software-based visualization tools highlights the importance of scaffolding spatial reasoning through interactive technology.

Low Spatial Ability: Student E-02

Student E-02, classified as having low spatial ability, encountered greater challenges in completing geometric tasks but demonstrated notable improvement following the instructional intervention. In one assessment item requiring calculation of prism volume, E-02 did not initially record known information or formulate a clear solution strategy. However, with prompting during the interview, the student was able to articulate a basic understanding of volume calculation: "I know I need to find the area of the base and multiply it by the height, but I get confused about which shape is the base." (See Figure 3).



5 $AB = \sqrt{AC^2 + BC^2}$

$= \sqrt{24^2 + 10^2}$

$= \sqrt{576 + 100}$

$= \sqrt{676}$

$= 20$

Luas : $= 2 \times 120 + (10 + 24 + 20) \times 40$

$= 2 \times 120 + 34 \times 40$

$= 140 + 2100$

$= 2\,240$

Figure 3. Subject E-02's answer to number 5

Despite these difficulties, E-02 achieved a post-test score of 73, only slightly below the mastery criterion. Interview data revealed that the student benefited from the Exploration phase of the 5E Learning Cycle, during which repeated manipulation of digital geometric models helped to build foundational spatial understanding. E-02 explained: "When I used the computer program, I could see the shape move and that helped me understand what the

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teacher was talking about." This finding suggests that even students with initially weak spatial abilities can make meaningful progress when provided with technology-enhanced, inquiry-based instruction.

This study investigated the effectiveness of the 5E Learning Cycle integrated with DGS (GeoGebra) in enhancing seventh-grade students' spatial skills. The findings provide empirical support for the pedagogical value of technology-enhanced, inquiry-based instruction in geometry education. This discussion interprets the key results in relation to existing theoretical frameworks and empirical literature, examines the mechanisms underlying observed learning gains, considers the differential effects across student ability levels, and addresses the study's implications for educational practice and future research.

Instructional Quality and Implementation Fidelity

The expert validation results demonstrated that all instructional materials and research instruments achieved validity ratings exceeding 84%, with most instruments rated above 90%. These high validation scores indicate strong content validity and alignment with curriculum objectives, confirming that the developed learning devices were theoretically sound and pedagogically appropriate for seventh-grade geometry instruction. The rigorous validation process, involving multiple experts with complementary expertise (mathematics education, curriculum development, and student guidance), enhances confidence in the quality of the instructional intervention. This finding aligns with (Prasetya, Sudirman, et al., 2025), who reported that geometry learning devices incorporating GeoGebra met established criteria for validity, effectiveness, and practicality in supporting spatial ability development.

Classroom observation data further confirmed that the instructional intervention was implemented with high fidelity across all six teaching sessions (implementation percentages ranging from 79.2% to 89.0%). The consistency of implementation quality is particularly noteworthy given the complexity of orchestrating technology-enhanced inquiry-based instruction, which requires teachers to balance procedural guidance with opportunities for student exploration (Hollebrands, 2007). The high implementation fidelity observed in this study suggests that the 5E Learning Cycle framework provided sufficient structure to support effective instructional delivery while still allowing flexibility for student-centered learning. This finding addresses a common challenge in educational interventions, where variation in implementation quality can obscure true treatment effects (Durlak & DuPre, 2008). By documenting consistent high-quality implementation, this study strengthens the internal validity of the observed learning outcomes and enhances the reproducibility of the intervention in similar educational contexts.

Effectiveness of the 5E Learning Cycle with Dynamic Geometry Software

The quantitative results provide compelling evidence for the effectiveness of the 5E Learning Cycle integrated with GeoGebra in enhancing spatial skills. The experimental group significantly outperformed the control group on post-test measures ($t = 3.56$, $p < .001$, Cohen's $d = 0.92$), with a mean difference of 8.28 points. This large effect size indicates not only statistical

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significance but also substantial practical importance, suggesting that the intervention produced meaningful improvements in students' ability to visualize, manipulate, and reason about three-dimensional geometric objects. The magnitude of the effect is comparable to that reported in (Sudirman et al., 2022b), who found that the 6E Instructional Model (6E-IM) accounted for 16.2% to 20.5% of the variance in students' three-dimensional geometry thinking skills. However, the present study extends these findings by demonstrating effects specifically for spatial skills, a foundational competency distinct from, though related to, general geometric reasoning.

The criterion-referenced analyses provide additional evidence of the intervention's effectiveness. Not only did the experimental group's mean score significantly exceed the mastery threshold (KKT = 75), but 73.3% of students achieved individual mastery, compared to only 46.7% in the control group. This difference in mastery rates (z = 2.13, p = .017) is particularly important from an educational equity perspective, as it suggests that the intervention enabled a greater proportion of students to achieve grade-level competencies. The classical mastery rate of 73.3% also exceeded the conventional benchmark of 65%, indicating that the intervention was effective not only for high-achieving students but for the majority of learners. This finding challenges the common assumption that technology-enhanced instruction primarily benefits students who already possess strong foundational skills (Passey, 2019).

The paired-samples analysis revealed substantial pre-test to post-test improvement within the experimental group (t = 12.47, p < .001, d = 2.28), with students gaining an average of 20.13 points. This very large effect size provides strong evidence of learning progression and suggests that the intervention successfully addressed the spatial skill deficits identified in the preliminary assessment, where 72.4% to 86.2% of students had initially failed to correctly solve geometric problems. The magnitude of improvement observed in this study exceeds typical learning gains reported in conventional geometry instruction (Lowrie et al., 2017), underscoring the added value of integrating dynamic visualization tools within a structured inquiry framework.

Mechanisms Underlying Observed Learning Gains

The effectiveness of the instructional intervention can be attributed to several interconnected pedagogical mechanisms inherent in the 5E Learning Cycle and the affordances of dynamic geometry software. First, the 5E framework comprising Engagement, Exploration, Explanation, Elaboration, and Evaluation, provided a coherent instructional sequence that supported gradual construction of spatial knowledge through guided inquiry. This aligns with constructivist learning theory, which posits that learners build understanding by actively manipulating objects, forming hypotheses, and testing ideas in authentic problem contexts. By beginning with contextual problems (Engagement) and allowing students to explore geometric relationships through hands-on interaction (Exploration), the intervention facilitated the development of conceptual understanding rather than rote memorization of procedures.

Second, the integration of GeoGebra afforded unique opportunities for spatial reasoning that are difficult to replicate with static instructional materials. DGS allows

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students to manipulate geometric objects continuously, observe invariant properties, and test conjectures in real time (Hollebrands, 2007). Qualitative data from student interviews illustrate this mechanism clearly. For example, Student E-05 (high spatial ability) explained: "Using GeoGebra helped me understand how changing one dimension affects the whole shape." Similarly, Student E-29 (medium spatial ability) noted: "After using GeoGebra to rotate it, I could see how it looks from the side and top." These student accounts suggest that the dynamic visualization capabilities of GeoGebra supported the development of mental rotation skills—a core component of spatial ability.

Third, the 5E Learning Cycle positioned the teacher as a facilitator rather than a transmitter of knowledge, enabling students to take ownership of their learning process. This shift in instructional roles is consistent with sociocultural theories of learning, which emphasize the importance of scaffolding, collaborative dialogue, and gradual release of responsibility (Bae et al., 2021). By engaging in problem-solving activities through LKPD (student worksheets) and receiving targeted support during the Explanation and Elaboration phases, students developed metacognitive awareness of their own spatial reasoning strategies. This finding corroborates (Utami & Sundari, 2019), who reported that inquiry-based learning models enabled students to realize, review, and reinforce their understanding, leading to significant changes in learning perceptions.

Differential Effects Across Student Ability Levels

The qualitative findings revealed important nuances in how students at different spatial ability levels engaged with and benefited from the instructional intervention. Student E-05, classified as having high spatial ability, demonstrated exceptional mastery of geometric tasks, achieving a post-test score of 90 and exhibiting no systematic errors in spatial visualization. Interview data indicated that E-05 leveraged the dynamic features of GeoGebra to explore advanced geometric relationships and verify solutions through multiple approaches. This finding aligns with (Syafiqah et al., 2020), who reported that students with high initial geometry ability fulfilled all three characteristics of spatial visual intelligence: imagining, conceptualizing, and problem-seeking. The present study extends this prior work by documenting how technology-enhanced instruction can further amplify the capabilities of high-ability learners by providing tools for sophisticated geometric exploration.

Student E-29, representing the medium ability group, achieved a post-test score of 76, slightly exceeding the mastery criterion despite some initial difficulty visualizing three-dimensional relationships. E-29's success underscores the effectiveness of the intervention in supporting students with moderate spatial abilities to reach grade-level competencies. Interview data revealed that E-29 relied heavily on GeoGebra's visualization tools to compensate for weaker mental rotation skills, suggesting that the software functioned as a cognitive scaffold. This finding is consistent with (Syafiqah et al., 2020), who observed that students with moderate geometry ability fulfilled two of three spatial intelligence characteristics (imagining and problem-seeking). However, the present study suggests that technology-mediated scaffolding may enable medium-ability students to develop conceptualizing

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skills that might otherwise remain underdeveloped in conventional instruction.

Perhaps most notably, Student E-02, classified as having low spatial ability, achieved a post-test score of 73—only slightly below the mastery threshold but representing substantial improvement from a baseline questionnaire score of 59. E-02's progress challenges the deficit-oriented assumption that students with weak initial spatial abilities cannot achieve meaningful learning outcomes in geometry. Interview data revealed that repeated manipulation of digital geometric models during the Exploration phase helped E-02 build foundational spatial understanding. This finding diverges from (Syafiqah et al., 2020), who reported that low-ability students were unable to fulfill any characteristics of spatial visual intelligence. The discrepancy may be attributable to differences in instructional approach: whereas Syafiqah et al.'s study did not specify the pedagogical framework, the present study employed the 5E Learning Cycle with deliberate scaffolding and technology integration, which may have provided critical support for struggling learners.

Taken together, these case analyses suggest that the 5E Learning Cycle with GeoGebra is a differentiated instructional approach capable of accommodating diverse learner needs. High-ability students benefited from opportunities for advanced exploration and conceptual deepening; medium-ability students received scaffolding through technology-mediated visualization; and low-ability students gained access to foundational spatial concepts through repeated interaction with dynamic models. This finding has important implications for educational equity, as it demonstrates that technology-enhanced inquiry-based instruction can simultaneously support excellence and inclusion.

Theoretical Contributions and Alignment with Prior Research

This study contributes to the theoretical understanding of spatial skills development by demonstrating that the integration of DGS within a structured inquiry framework produces synergistic effects that exceed the benefits of either component in isolation. The observed effect size ($d = 0.92$) is notably larger than those typically reported for standalone technology interventions or inquiry-based instruction without technological support (Rakes et al., 2010). This suggests that the pedagogical framework matters: technology is most effective when embedded within a coherent instructional sequence that guides students through cycles of exploration, reflection, and application.

The findings also extend spatial cognition research by providing empirical evidence that dynamic visualization tools can support not only perceptual recognition but also higher-order spatial reasoning processes such as mental transformation, perspective-taking, and spatial-analytic thinking. The qualitative data revealed that students used GeoGebra not merely to view geometric objects but to actively manipulate, rotate, decompose, and reconstruct them—activities that align closely with the cognitive operations underlying spatial skill development. This finding supports the embodied cognition perspective, which posits that learning is enhanced when abstract concepts are grounded in concrete, manipulable representations.

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Furthermore, the study corroborates and extends prior research on the 6E-IM model. Sudirman et al., (2022a) reported that the 6E-IM accounted for significant variance in three-dimensional geometry thinking skills and that integrating augmented reality enhanced the model's effectiveness. The present study provides convergent evidence by demonstrating similar benefits with a different technology platform (GeoGebra) and a different outcome measure (spatial skills rather than general geometric thinking). The consistency of findings across these studies strengthens the conclusion that inquiry-based learning cycles, when augmented with appropriate technological tools, constitute a robust pedagogical approach for geometry education.

Limitations and Directions for Future Research

Despite its contributions, this study has several limitations that warrant consideration. First, the use of a quasi-experimental design limits causal inference, as unmeasured differences between intact classes may have influenced the results. Future studies employing randomized controlled trials with larger samples are recommended to strengthen causal claims. Second, the study was conducted in a single school over a short intervention period, which may limit the generalizability of the findings. Replication across diverse educational contexts and longitudinal designs is needed to examine the sustainability and transferability of spatial skills gains. Third, the qualitative component involved a small, purposively selected sample, which may not fully represent the range of student experiences. Larger qualitative samples and alternative data collection and analysis methods could provide richer insights. Fourth, teacher-related factors, such as pedagogical beliefs and technological competence, were not examined and should be considered in future research. Finally, spatial skills were assessed using geometry tasks focused on prisms; therefore, more comprehensive and standardized measures of spatial cognition are recommended to capture the multidimensional nature of spatial skills.

CONCLUSIONS

This study concludes that the integration of the 5E Learning Cycle with DGS is an effective and pedagogically sound approach for enhancing seventh-grade students' spatial skills. The findings demonstrate that students who participated in the intervention showed significantly higher spatial reasoning abilities compared to those who received conventional instruction. Learning improvements were observed consistently across different student ability levels, indicating that the model is inclusive and beneficial for diverse learners. The results confirm that inquiry-based learning environments, when supported by dynamic visualization technology, promote active engagement, deeper conceptual understanding, and meaningful knowledge construction in geometry learning.

Furthermore, the study shows that the use of GeoGebra within the 5E framework supports students in visualizing geometric relationships, exploring spatial transformations, and developing more accurate mental representations of spatial structures. This integration strengthens students' ability to interpret, manipulate, and reason about spatial objects, which are essential competencies in geometry learning. The findings also indicate that well-designed technology-enhanced

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instruction can be effectively implemented in regular classroom settings when supported by appropriate learning designs and instructional scaffolding. Overall, this research confirms that the 5E Learning Cycle integrated with GeoGebra is not only effective in improving students' spatial skills but also contributes to more engaging, meaningful, and conceptually rich mathematics learning experiences.

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