

The Effect of the APOS Approach Assisted by GeoGebra on State Islamic Junior High School Students' Spatial Skills in Geometric Transformations

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ABSTRACT

Spatial ability is a crucial component of geometric thinking that supports students' understanding of geometric transformation topics. This study examined the effect of the GeoGebra-assisted Action-Process-Object-Schema (APOS) approach on ninth-grade students' spatial ability in geometric transformations. This study used a quasi-experimental pretest-posttest control-group design with two intact classes at a state Islamic junior high school in Labuhanbatu. The experimental class ($n = 33$) received instruction using the GeoGebra-assisted APOS approach, while the control class ($n = 33$) received conventional instruction. Data were collected using a validated spatial ability essay test covering spatial visualization, mental rotation, and spatial perception. The data were analyzed using the Mann-Whitney U test, N-Gain, and Cohen's d . The results showed a statistically significant difference in posttest spatial ability between the two groups ($U = 1056.0$, $p < 0.001$), with a higher mean score in the experimental class (90.73) than in the control class (69.70). The experimental class achieved a high mean N-Gain of 0.874, whereas the control class achieved a moderate mean N-Gain of 0.601. The Cohen's d value of 2.856 indicated a very large standardized effect. These findings indicate that the GeoGebra-assisted APOS approach was associated with greater improvement in students' spatial ability in geometric transformations than the conventional approach, although the quasi-experimental design does not permit complete control of potential confounding factors.

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1. INTRODUCTION

Mathematics plays a strategic role in the development of human civilization, and geometry holds an important position as the branch most closely related to daily life and

the development of visual and spatial thinking skills [1]. Spatial ability is the capacity to perceive, manipulate, and interpret objects and their relationships in space, both physically and mentally, and it encompasses three main components relevant to learning geometric transformations: spatial visualization, mental rotation, and spatial perception [1]. These abilities can be developed through well-designed learning experiences, as shown in a meta-analysis by Suparman et al. [2] of 33 studies involving 2,739 students, which found that geometry learning supported by dynamic technology such as GeoGebra consistently promotes the development of students' spatial visualization.

However, this potential remains a challenge in Indonesian mathematics education. The 2022 Program for International Student Assessment (PISA) reported that Indonesia ranked 71st among 81 participating countries in mathematics, with a mean score of 366 compared with the OECD average of 472 [3]. These results provide a broader context regarding challenges in mathematics learning in Indonesia; however, PISA mathematics literacy does not directly measure students' spatial ability. Therefore, the PISA results should be interpreted as contextual evidence rather than direct evidence of students' spatial difficulties. Previous studies have also reported weaknesses in students' visual-spatial thinking when learning geometric transformations through conventional instructional approaches [4]–[7].

This weakness is most evident in geometric transformations, which include translation, reflection, rotation, and dilation, and require students to mentally visualize changes in the position, orientation, and size of objects [8]. Several studies report that MTs students struggle to visualize transformations without visual aids and to understand the relationships between transformation processes [9]. Most students get stuck at the Action stage in APOS theory and fail to achieve conceptual understanding because of limitations in mental visualization [10]. Preliminary observations by the researcher among ninth-grade students at a public MTs in Rantauparapat indicated that students tended to recall and apply transformation formulas procedurally but had difficulty visualizing the resulting positions of geometric objects when pictorial representations were not provided. These observations provided context for identifying the research problem and were not treated as the quantitative data analyzed in this study.

From a cognitive psychology perspective, this phenomenon can be explained through the APOS (Action-Process-Object-Schema) theory, which states that mathematical understanding develops through four sequential stages of internalization: Action, Process, Object, and Schema [11]. Instruction that follows the APOS stages should ideally be supported by media that provide students with visual experiences and direct exploration. GeoGebra, as dynamic mathematics software that enables interactive geometric exploration through real-time visualization and multiple representations [12], [13], [14], has been shown to effectively enhance students' engagement and conceptual understanding in learning geometric transformations [15], [16] as well as their mathematical spatial abilities [17], [18].

The APOS framework is particularly relevant to the three spatial components measured in this study. The Action and Process stages can support spatial visualization by allowing students to observe and mentally organize changes in geometric figures. The

dynamic manipulation of figures in GeoGebra can also support mental rotation by enabling students to examine changes in orientation from different perspectives. Furthermore, the Object and Schema stages can support spatial perception by helping students recognize relationships among positions, orientations, and properties of transformed objects. Thus, integrating APOS and GeoGebra provides a theoretical basis for developing the spatial visualization, mental rotation, and spatial perception assessed in this study.

However, Ref. [19] states that most studies on GeoGebra in geometry instruction have not integrated its use with a structured cognitive framework such as the APOS theory, so the process of internalization from the Action stage to subsequent stages does not always occur effectively [20]. Febrianti et al. [21] have shown that combining GeoGebra with innovative approaches can improve students' spatial abilities. However, they did not use APOS theory as a cognitive framework, while Baye et al. [22] demonstrated the effectiveness of integrating GeoGebra and APOS in conceptual understanding of calculus; this has not yet been applied to spatial abilities in geometric transformations at the MTs level. This research gap serves as the starting point for this study, given that, theoretically, the integration of the APOS approach and GeoGebra holds great potential for supporting mathematics learning: in the Action stage, GeoGebra provides an interactive environment for concretely manipulating transformation objects; in the Process stage, its dynamic visualizations help students identify patterns and internalize procedural concepts; and in the Object and Schema stages, the exploration of transformation compositions allows students to integrate various concepts into a comprehensive understanding [23], [24], [25].

This study is novel in examining the integration of the APOS approach and GeoGebra to develop MTs students' spatial ability in geometric transformations. This area has received limited attention compared with studies focusing separately on GeoGebra, APOS, or other learning outcomes.

Based on this description, this study aims to determine the effect of the GeoGebra-assisted APOS approach on the spatial abilities of MTs students in the topic of geometric transformations, to describe the extent of the improvement in students' spatial abilities through N-Gain analysis, and to determine the level of effectiveness of this approach compared to the conventional approach through the calculation of Cohen's d effect size.

2. METHOD

This study used a quasi-experimental pretest-posttest control group design [26]. This design was selected because the research subjects were already organized into naturally formed classes, making individual randomization impractical. The study involved an experimental group and a control group. Both groups were administered a pretest before the intervention. The experimental group received instruction using the APOS approach with GeoGebra support, whereas the control group received conventional instruction. After the intervention, both groups were administered a posttest to examine differences in students' spatial ability following the instructional treatment [27].

The study was conducted at a public Islamic junior high school (MTs Negeri) in Labuhanbatu Regency during the second semester of the 2025/2026 academic year. The study population consisted of all ninth-grade students. The researchers selected the sample

using cluster random sampling at the class level. The researchers selected two existing ninth-grade classes as the research sample: one class of 33 students assigned as the experimental group and another class of 33 students assigned as the control group. The selection and assignment were conducted at the class level because students were already organized into intact classes, so the researchers did not randomize students individually.

The independent variable was the instructional approach: the experimental class received the GeoGebra-assisted APOS approach, while the control class received conventional instruction. The dependent variable was students' spatial ability in geometric transformations. The GeoGebra-assisted APOS approach was implemented through four stages. In the Action stage, students directly manipulated geometric objects using GeoGebra features such as Translate Object, Reflect about Line, and Rotate Object around Point. In the Process stage, students discussed patterns and generalizations derived from their actions. In the Object stage, students explored the properties of geometric transformations. In the Schema stage, students integrated concepts from different types of transformations into a coherent conceptual structure.

The study was conducted in two meetings, with each meeting lasting 60 minutes. The experimental class received the APOS approach assisted by GeoGebra, while the control class received conventional instruction. The pretest was administered before the instructional intervention, and the posttest was administered after all instructional sessions had been completed.

In this study, conventional instruction referred to the instructional practices the teacher routinely used in the control class. The learning activities primarily involved teacher explanations, presentation of worked examples, question-and-answer activities, and individual student exercises. The control class did not receive the APOS approach assisted by GeoGebra.

The research instrument was an essay-type spatial ability test consisting of four items measuring 10 indicators grouped into three components of spatial ability: spatial visualization, mental rotation, and spatial perception [28]. The instrument was developed based on the spatial ability indicators and the geometric transformation material addressed in the study. The maximum raw score was 17, and the raw scores were converted to a 0–100 scale. Two mathematics education experts validated the instrument for content and construct validity, and the researchers pilot-tested it with 33 students not included in the research sample. The researchers then examined its reliability using Cronbach's alpha coefficient before using the instrument as the pretest and posttest.

Students' responses were scored using a scoring rubric based on the indicators assessed in each item. The rubric considered the accuracy and completeness of students' responses. The maximum raw score was 17 and was converted to a 0–100 scale using the following formula:

$$\text{Converted Score} = \frac{\text{Obtained Raw Score}}{17} \times 100 \quad 1)$$

Based on the research objectives, the research hypotheses were formulated to examine differences in students' spatial ability between the experimental and control groups and differences in the improvement of spatial ability following the instructional intervention. The first hypothesis was: H0₁: there is no significant difference in students' posttest spatial ability between the group receiving the APOS approach assisted by GeoGebra and the group receiving conventional instruction. H1₁: There is a significant difference in students' posttest spatial ability between the two groups. The second hypothesis was: H0₂: there is no significant difference in the improvement of students' spatial ability based on N-Gain between the experimental and control groups. H1₂: There is a significant difference in the improvement of students' spatial ability based on N-Gain between the experimental and control groups. All hypothesis tests were conducted using two-tailed tests at a significance level of $\alpha = 0.05$.

Data analysis began with descriptive statistics to summarize the pretest and posttest scores of both groups. Prerequisite analyses included the Shapiro-Wilk normality test and Levene's test for homogeneity of variances. Because most data were not normally distributed, the Mann-Whitney U test was used as the primary nonparametric test to examine initial equivalence and differences in posttest spatial ability between the experimental and control groups. An independent samples t-test was also included as a supplementary robustness analysis [30]. The improvement in students' spatial ability was analyzed using N-Gain based on Hake's formula [31]. The magnitude of the practical effect was examined using Cohen's d effect size according to Cohen's criteria [32]. All inferential hypothesis tests used two-tailed tests with a significance level of $\alpha = 0.05$ [33], [34].

3. RESULTS AND DISCUSSION

3.1. Results

Pretest and posttest data on spatial ability were obtained from 33 students in the experimental class and 33 students in the control class, with an ideal maximum score of 17 converted to a scale of 0–100. Descriptive statistics for both groups are presented in Table 1.

Table 1. Descriptive Statistics of Pretest and Posttest Scores for Spatial Ability

Group	N	Pretest Mean	Posttest Mean	Difference
Experimental	33	26.02	90.73	64.71
Control	33	24.06	69.70	45.64

Table 1 shows that both groups had relatively low and comparable initial spatial abilities before the treatment (the mean pretest difference was only 1.96 points). After the intervention, both groups showed improvement, with a larger mean increase in the experimental class (64.71 points) than in the control class (45.64 points). This difference initially indicates greater improvement in the experimental class following GeoGebra-assisted APOS instruction. Based on the item-by-item scores, the most notable improvement in the experimental class occurred on the item measuring spatial visualization of dilation concepts (from 0.85 to 4.49 out of a maximum score of 5). The

improvement pattern was also distributed across the three spatial ability components. These descriptive findings provide a basis for further inferential analysis.

Before hypothesis testing, we conducted prerequisite analyses, including the Shapiro-Wilk normality test and Levene's test for homogeneity. The results of the normality test showed that three of the four data groups (experimental pretest: $W = 0.884$, $p = 0.002$; experimental posttest: $W = 0.903$, $p = 0.006$; control pretest: $W = 0.894$, $p = 0.004$) were not normally distributed, whereas only the control posttest data met the normality assumption ($W = 0.944$, $p = 0.086$). A skew in pretest data toward low scores is common in spatial ability measures among students who have not yet received explicit instruction on the tested material. Because the assumption of normality was not met for the majority of the data sets, the initial equivalence test and subsequent hypothesis tests used the nonparametric Mann-Whitney U test, with the independent samples t-test included as a supplementary analysis, given that the relatively large sample size ($n = 33$ per group) makes the t-test relatively robust to mild violations of normality [30]. The homogeneity test showed $p = 0.090$ for the pretest and $p = 0.110$ for the posttest; both were > 0.05 , indicating homogeneous variance in spatial ability data across both groups before and after the intervention.

The Mann-Whitney U test for initial ability yielded $p = 0.815$ ($p > 0.05$), further supported by the independent-samples t-test ($t = 0.479$; $df = 64$; $p = 0.633$). These results support comparing the two groups under similar initial conditions. However, because the study used a quasi-experimental design with intact classes and no individual randomization, initial equivalence does not eliminate all potential confounding factors and should not be interpreted as guaranteeing that subsequent posttest differences were caused solely by the intervention [35].

Regarding the variability of the data, the standard deviation (SD) of the pretest scores was 18.77 for the experimental class and 14.13 for the control class, whereas on the posttest, the SD for the experimental class decreased to 5.70 and that for the control class to 8.72. These decreases indicate lower score dispersion at posttest in both groups, with the experimental class showing the smaller posttest SD. This pattern describes the observed variability in the sample and should not be interpreted as evidence that the intervention was equally effective for all students. Table 2 presents the results of the tests for the three research hypotheses.

Table 2. Summary of Hypothesis Test Results

No.	Research Question	Statistical Test	Results	Decision
1	Differences in posttest spatial ability between the experimental and control groups	Mann-Whitney U; Independent Samples t-Test	$U = 1056.0$; $t = 11.602$; $df = 64$; $p < 0.001$	H0 rejected, H1 accepted
2	Magnitude of the increase in spatial ability	N-Gain; Mann-Whitney U	Experimental $g = 0.874$ (High); Control $g = 0.601$ (Moderate); $U = 1065.5$; $p < 0.001$	H0 rejected, H1 accepted
3	Standardized effect size	Cohen's d	$d = 2.856$ (Very Large)	Very large effect

3.2. Discussion

The first hypothesis test showed a statistically significant difference in posttest spatial ability between the two groups. The Mann-Whitney U test indicated $p < 0.001$, and the supplementary independent-samples t-test also yielded a statistically significant result ($t = 11.602$; $df = 64$; $p < 0.001$). The experimental class had a higher posttest mean (90.73) than the control class (69.70). These results indicate greater posttest performance in the experimental class following the GeoGebra-assisted APOS instruction. From a theoretical perspective, this pattern aligns with the APOS framework [11] and GeoGebra's potential to provide dynamic visual representations of geometric transformations. However, the present study did not assess students' APOS stages individually. Therefore, the interpretation that students moved from Action toward Process, Object, and Schema should be understood as a theoretical explanation of the observed learning pattern rather than as a directly observed cognitive transition. GeoGebra may have helped students visualize changes in geometric figures and explore transformation properties, but the study design does not allow the separate contribution of APOS and GeoGebra to be determined.

The N-Gain analysis showed that the experimental class achieved a mean N-Gain of 0.874, categorized as high according to Hake's criteria [31], whereas the control class achieved a mean N-Gain of 0.601, categorized as moderate. The difference in N-Gain between the two groups was statistically significant (Mann-Whitney U = 1065.5; $p < 0.001$). The finding that 100% of students in the experimental class were classified in the high N-Gain category is noteworthy and should be interpreted cautiously. Because this result is based on category membership rather than a direct assessment of individual cognitive processes, it does not by itself demonstrate that all students benefited equally from the intervention. Consider the distribution of individual N-Gain scores and their variability alongside the mean and category frequencies.

The Cohen's d effect size of 2.856 is substantially above the conventional threshold for a large effect ($d \geq 0.8$) [32]. Given its magnitude, this estimate warrants cautious interpretation rather than being treated simply as evidence of an exceptionally powerful strategy. Several factors may have contributed to the large standardized difference, including the small sample size (33 students per group), the short two-meeting intervention, the degree of contrast between the instructional conditions, the alignment between the assessment and the intervention, possible ceiling effects in the posttest scores, the structure of the scoring procedure, and the consistency of implementation. In addition, because the study did not include APOS-only or GeoGebra-only groups, the observed effect cannot be attributed separately to APOS, GeoGebra, or their combination. Further studies comparing these components directly would help clarify their relative contributions. The effect size should therefore be interpreted as an estimate of the standardized difference between the two instructional groups in this specific study context.

In practical terms, the findings suggest that GeoGebra-assisted APOS instruction may be considered when teaching geometric transformations that require students to visualize changes in position, orientation, and shape. The findings should not be generalized to solid geometry, other plane-geometry topics, or other learning contexts

without further empirical testing. Future studies could examine whether similar patterns are observed across other geometry topics and instructional settings.

This study has several limitations. First, the quasi-experimental design, with two naturally formed classes and no individual randomization, cannot fully eliminate potential confounding variables. The pretest results support comparison under similar initial conditions, but they do not remove all threats to internal validity. Second, the sample consisted of only 33 students per group from a single school, which limits the generalizability of the findings. Third, the intervention lasted only two 60-minute meetings, so the study provides no evidence of long-term retention; longitudinal studies or delayed posttests are therefore recommended. Fourth, the study did not include separate APOS-only and GeoGebra-only conditions, so it cannot isolate the relative contribution of each component. Future research could use a factorial or multi-group design to distinguish the effects of APOS, GeoGebra, and their combination.

4. CONCLUSION

Based on the results and discussion, the GeoGebra-assisted APOS group showed higher posttest spatial ability than the conventional-instruction group, with a statistically significant between-group difference (Mann-Whitney U, $p < 0.001$). The experimental group also showed a high mean N-Gain (0.874), compared with a moderate mean N-Gain in the control group (0.601), while the estimated standardized effect size was very large (Cohen's $d = 2.856$). These findings indicate a large observed difference in spatial ability outcomes between the two instructional conditions for geometric transformations in the sampled MTs students. However, the quasi-experimental design, small single-school sample, short intervention, and absence of APOS-only and GeoGebra-only comparison groups limit causal and broader generalization. Future research should examine retention through longitudinal or delayed-posttest designs and consider factorial or multi-group designs that can separate the contributions of APOS and GeoGebra.

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