



The effect of geoboard media on elementary students' learning outcomes in plane geometry

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Abstract

Background: Elementary students frequently encounter difficulties understanding abstract geometric concepts, particularly when instruction relies on verbal explanations and memorization. Concrete manipulatives, such as geoboards, offer opportunities to explore geometric properties through hands-on learning.

Aims: This study aims to examine changes in second-grade students' mathematics learning outcomes following geoboard-assisted instruction in plane geometry.

Method: A quantitative pre-experimental study employing a one-group pretest-posttest design involved 17 second-grade students at MI Fathul Huda Singkut, Indonesia, selected through total sampling. Data were collected using achievement tests and analyzed through descriptive statistics and the Wilcoxon Signed-Rank Test.

Results: The mean achievement score increased from 69.12 to 93.18, while learning mastery improved from 52.94% to 100%. The Wilcoxon test revealed a statistically significant pretest-posttest difference ($Z = -2.925$, $p = 0.003$), with a large effect size ($r = 0.731$).

Conclusion: Geoboard-assisted instruction was associated with significant improvements in students' mathematics achievement. However, the absence of a control group and limited sample size prevent causal conclusions, highlighting the need for further controlled investigations.

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INTRODUCTION

Geometry is an important component of elementary mathematics education because it develops students' ability to recognize, describe, classify, and interpret spatial relationships and two-dimensional shapes. However, geometry learning remains challenging for young learners because many geometric concepts involve abstract properties and relationships that are difficult to understand through verbal explanations and memorization alone. At the elementary level, students need opportunities to encounter geometric concepts through concrete and visually accessible learning experiences that can help them connect geometric properties with observable objects and representations (Schoenfeld, 2016). Among the various mathematical domains, geometry plays a particularly important role because it enables students to recognize, classify, and interpret spatial relationships encountered in everyday life. Early geometry learning, especially the study of plane figures, contributes significantly to the development of visual reasoning, spatial awareness, and conceptual understanding, which subsequently support students in learning more advanced mathematical concepts (Szabo et al., 2020). Despite its importance, geometry can be challenging for elementary school students, particularly when learning involves abstract geometric concepts. The abstract nature of geometric concepts may hinder young learners from fully understanding the properties, relationships, and classifications of two-dimensional shapes. Students may experience difficulties in distinguishing geometric figures, identifying their attributes, and applying these concepts to real-life situations (Rojas & Benakli, 2020). These learning difficulties may be influenced,

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in part, by instructional approaches that emphasize memorization rather than conceptual understanding. In such learning contexts, students may be able to recall the names of geometric shapes without fully understanding their defining characteristics or mathematical relationships (Su et al., 2016). One factor that may contribute to these learning difficulties is the limited use of instructional media that facilitate meaningful mathematical experiences. In some elementary mathematics classrooms, instruction may rely substantially on teacher explanations and textbook-based learning, which can provide students with fewer opportunities to manipulate mathematical objects directly (Çelik & Özdemir, 2020). Such teacher-centered practices may provide fewer opportunities for student engagement and active knowledge construction. From a constructivist perspective, meaningful mathematical understanding is developed through learners' active engagement in constructing knowledge, including through interaction with concrete objects and relevant learning experiences, rather than through the passive reception of information alone (Dolapcioglu & Doğanay, 2022).

The use of manipulatives and hands-on learning materials has received increasing attention in mathematics education, particularly for supporting students' engagement with concrete representations of mathematical concepts. A recent study involving elementary school students found that manipulative materials supported students in exploring and constructing geometric figures while distinguishing shapes based on their properties. More broadly, a 2023 scoping review of 102 studies on physical manipulatives in pre-primary and primary education found that such materials have been widely investigated as part of educational interventions, including in mathematics learning. These findings suggest that physical manipulatives can provide opportunities for students to explore geometric structures, examine mathematical relationships, and connect concrete representations with mathematical ideas. However, the contribution of manipulatives may depend on how they are integrated into instructional activities and connected to the intended mathematical concepts (Dolapcioglu & Doğanay, 2022; Ariani, 2015). These learning experiences may be particularly relevant for younger learners because their development of mathematical understanding can benefit from opportunities to connect concrete representations with abstract concepts. This perspective is consistent with theories of cognitive and mathematical development that emphasize the role of concrete representations in supporting children's transition toward more abstract forms of reasoning.

In Indonesia, similar challenges were identified during preliminary observations at MI Fathul Huda Singkut. The observations focused on second-grade mathematics learning and examined students' performance in learning plane figures, classroom instructional practices, and the use of instructional media. The preliminary findings indicated that several students experienced difficulties in recognizing geometric shapes, describing their properties, and relating geometric concepts to objects in their surrounding environment. The observation also indicated that classroom instruction relied predominantly on lecture-based activities, with limited use of instructional media. These observations provided the initial contextual basis for examining the use of geoboard media in plane-geometry learning. However, because the preliminary observation was exploratory and was not designed as a formal assessment, the findings are treated as contextual information rather than as evidence of the effectiveness of a particular instructional approach.

Addressing these instructional conditions may require learning activities that provide students with opportunities to connect abstract mathematical ideas with concrete representations. One such medium is the geoboard, a manipulative learning tool consisting of a board with evenly spaced pegs on which students use elastic bands to construct geometric figures. Through direct manipulation, students can construct and examine two-dimensional shapes, compare their properties, and explore relationships among geometric figures. In this sense, geoboard activities provide a concrete environment in which students can engage with geometric representations through construction and observation. The potential contribution of geoboard-assisted learning can be explained through Bruner's theory of representation, which describes learning as involving enactive, iconic, and symbolic modes of representation. From this perspective, physically constructing geometric figures may provide enactive experiences that can subsequently be connected with visual and symbolic representations. Thus, Bruner's framework provides a theoretical rationale for examining whether geoboard activities may support students' learning of plane geometry, rather than constituting evidence that the medium is inherently effective.

The use of geoboards can also be considered from a constructivist perspective, in which learners develop knowledge through active interaction with learning environments. In geoboard activities, students are given opportunities to construct geometric figures, observe their properties, and compare different representations. These activities may support students' exploration of geometric concepts by allowing them to work directly with mathematical objects. The present study therefore focuses primarily on students' learning outcomes, while potential changes in engagement, mathematical communication, or other learning processes are considered theoretical possibilities rather than measured outcomes.

Geoboard activities can further be related to selected principles of Realistic Mathematics Education (RME), particularly the use of meaningful contexts, students' active exploration of mathematical ideas, and guided movement from concrete or informal representations toward more formal mathematical understanding. In the present context, students construct plane figures using elastic bands and then examine and discuss their characteristics. Such activities provide a concrete representation through which students can explore geometric ideas before relating these observations to formal descriptions of shapes and their properties. The connection with RME therefore lies not simply in the use of a manipulative, but in the way the geoboard is incorporated into guided mathematical exploration and the development of more formal representations. (Fauzan et al., 2024). Within this framework, geoboard activities encourage learners to investigate geometric patterns, formulate conjectures, and verify their own mathematical ideas through concrete manipulation. Such learning experiences are expected to strengthen conceptual understanding while simultaneously improving students' mathematics achievement (Cobb et al., 2008). Within this framework, geoboard activities provide opportunities for learners to investigate geometric patterns, formulate conjectures, and examine their mathematical ideas through concrete manipulation. These learning experiences may support students' learning of plane geometry and, consequently, may be reflected in their mathematics achievement as measured by the learning outcomes assessed in this study (Cahyani & Setyawati, 2017; Kholil & Zulfiani, 2020). Such evidence is expected to contribute to the growing body of research on mathematics manipulatives while providing practical recommendations for teachers seeking more effective instructional strategies.

The use of manipulative learning media has become one of the most prominent instructional strategies for improving mathematics learning in elementary education. Manipulatives enable students to interact directly with mathematical objects, allowing abstract concepts to be represented in concrete forms that are easier to observe, explore, and understand (Majid, 2019). Previous research consistently demonstrates that hands-on learning environments promote students' conceptual understanding, mathematical reasoning, problem-solving skills, and overall academic achievement. These findings are particularly relevant to geometry learning, where visualization and spatial reasoning constitute essential cognitive processes (Pratiwi & Imami, 2022). Among various mathematical manipulatives, the geoboard has received increasing attention because of its ability to facilitate the exploration of geometric concepts through active learning. By arranging elastic bands on a pegboard, students can construct, compare, and modify various plane figures while simultaneously identifying their properties, such as sides, vertices, angles, and symmetry. This interactive process encourages students to discover mathematical relationships independently rather than merely memorizing geometric definitions. Recent empirical studies have shown that geoboard-assisted instruction significantly improves students' conceptual understanding of geometry, reduces misconceptions regarding two-dimensional shapes, and increases learning motivation. Moreover, integrating geoboard activities with student-centered instructional approaches provides opportunities for collaborative learning and mathematical discussion, which further enhance conceptual development. The effectiveness of geoboard-based learning becomes even more meaningful when implemented within the framework of Realistic Mathematics Education (RME). Freudenthal's perspective emphasizes that mathematics should be viewed as a human activity in which learners actively construct knowledge from meaningful experiences rather than passively receiving information. In RME classrooms, students are encouraged to explore contextual problems, formulate strategies, and progressively develop formal mathematical understanding through guided reinvention. Geoboard media naturally supports these principles because students physically manipulate geometric figures while connecting mathematical concepts to tangible

experiences. Consequently, learning activities become more engaging, contextualized, and cognitively meaningful.

Previous studies have also reported positive effects of geoboard implementation across different educational contexts. Research has demonstrated improvements not only in students' learning outcomes but also in conceptual understanding, mathematical communication, spatial visualization, classroom participation, and learning motivation. These findings indicate that geoboards function not merely as instructional aids but as pedagogical tools that facilitate active knowledge construction. Nevertheless, the reported magnitude of learning improvement varies considerably depending on educational level, instructional design, learning objectives, participant characteristics, and classroom context. Such inconsistencies suggest that the effectiveness of geoboard media may be influenced by contextual factors that require further empirical investigation. Although previous studies consistently support the educational benefits of geoboard media, several important research gaps remain.

First, most existing investigations have focused on upper elementary students, whereas empirical evidence involving lower-grade students, particularly second-grade learners, remains relatively limited. Considering that younger learners are still within the concrete operational stage of cognitive development, the effectiveness of manipulative media may differ substantially from that observed among older students. Second, previous studies have generally examined conceptual understanding, mathematical reasoning, or students' engagement, while fewer studies have specifically investigated improvements in overall mathematics learning outcomes using a pre-experimental design. Moreover, many existing studies were conducted in public elementary schools, with limited attention given to Islamic primary schools (Madrasah Ibtidaiyah), whose instructional environments and student characteristics may differ from those of general elementary schools. Third, despite increasing interest in manipulative-based mathematics instruction, relatively few studies have examined geoboard implementation within authentic classroom settings characterized by limited instructional media and teacher-centered learning practices. Consequently, further evidence is needed to determine whether geoboard-based learning remains effective under these educational conditions. Addressing these gaps is expected to enrich the literature on elementary mathematics education while providing practical implications for improving geometry instruction in diverse educational contexts.

Based on the identified research gaps, this study aims to examine the effect of geoboard media on elementary students' learning outcomes in plane figures using a pre-experimental research design. Specifically, the study investigates whether the implementation of geoboard-based learning significantly improves second-grade students' mathematics achievement at MI Fathul Huda Singkut. The findings are expected to contribute to the growing body of research on manipulative-based mathematics instruction by providing empirical evidence regarding the effectiveness of geoboard media in facilitating geometry learning among lower elementary students. Furthermore, the study is expected to offer practical recommendations for elementary school teachers in selecting instructional media that promote meaningful, interactive, and conceptually rich mathematics learning experiences.

LITERATURE REVIEW

Geometry constitutes an essential domain of elementary mathematics education because it provides a foundation for understanding spatial relationships, geometric structures, and the characteristics of two-dimensional figures. Learning plane geometry requires students to develop the ability to recognize shapes, identify their defining attributes, and establish relationships between geometric representations and everyday objects. Nevertheless, young learners frequently encounter conceptual difficulties when geometric knowledge is presented primarily through abstract explanations and procedural memorization. Such difficulties may become particularly evident when students are expected to distinguish geometric figures based on their properties rather than their visual appearance alone (Andini & Cahyaningsih, 2024). The development of meaningful geometric understanding therefore requires instructional experiences that connect mathematical concepts

with accessible visual and physical representations. Concrete learning materials can provide opportunities for students to examine mathematical relationships through direct observation and manipulation. Carbonneau et al. (2013) demonstrated that concrete manipulatives can support mathematics learning, although their educational contribution depends on instructional conditions and implementation strategies. From this perspective, effective geometry instruction should integrate conceptual explanation with opportunities for active mathematical exploration. This instructional orientation is particularly relevant to lower elementary students, whose mathematical reasoning continues to develop through interactions with concrete representations. Consequently, the selection of appropriate instructional media becomes an important consideration in supporting students' achievement in plane geometry.

Geoboard media represent a form of physical mathematical manipulative that enables students to construct and investigate geometric figures using elastic bands arranged around pegs on a board. Unlike instructional approaches that depend exclusively on verbal descriptions or printed illustrations, geoboard activities allow learners to modify geometric representations through direct physical interaction. Students can construct squares, rectangles, triangles, and parallelograms while examining differences in their sides, vertices, and overall configurations. These activities provide opportunities to investigate geometric properties through observable representations rather than relying solely on memorized definitions. The pedagogical relevance of such experiences can be interpreted through Bruner's theory of representation, which distinguishes enactive, iconic, and symbolic modes of learning (Jinzhi & Xuejun, 2024). Within this framework, manipulating elastic bands constitutes an enactive experience that can be connected to visual recognition and subsequent mathematical descriptions. Geoboard activities may therefore provide an instructional bridge between students' concrete experiences and their emerging understanding of abstract geometric concepts. Constructivist learning theory also emphasizes the importance of learners' active participation in developing mathematical knowledge through meaningful interactions with learning environments (Liangshi, 2024). Accordingly, the educational contribution of geoboard media depends not merely on the availability of physical materials but also on how teachers organize exploration, questioning, and conceptual discussion. These theoretical perspectives provide a rationale for investigating geoboard-assisted instruction as a potential approach to supporting elementary students' mathematics learning outcomes.

The integration of geoboard media into mathematics instruction can also be understood through the principles of Realistic Mathematics Education (RME), which emphasize meaningful mathematical activity and the progressive development of formal understanding. RME encourages learners to explore mathematical relationships through accessible situations and representations before developing more formal conceptual interpretations (Cobb et al., 2008). In plane geometry instruction, students may begin by constructing familiar shapes and subsequently examining the mathematical properties that distinguish one figure from another. Such learning experiences create opportunities for students to connect physical representations with geometric terminology, classification, and mathematical reasoning. Fauzan et al. (2024) highlighted the relevance of RME for strengthening mathematical literacy and numeracy in elementary education. Although RME and geoboard-assisted instruction represent distinct pedagogical considerations, they share an emphasis on active exploration and the meaningful construction of mathematical knowledge. Teachers can facilitate these processes by asking students to compare geometric figures, explain their observations, and justify their classifications. Through guided interaction, students may gradually recognize that geometric concepts concern structural properties rather than visual resemblance alone. However, meaningful learning cannot be attributed automatically to the use of manipulatives because instructional guidance and alignment with learning objectives remain necessary. Therefore,

geoboard-assisted learning should be examined as an instructional arrangement that combines concrete representation, student exploration, and teacher-facilitated conceptual development.

Previous educational research provides a basis for considering the potential contribution of manipulative-based instruction to mathematics achievement. In their meta-analysis, Carbonneau et al. (2013) identified beneficial effects of concrete manipulatives on mathematical learning while emphasizing variation across instructional conditions. These findings suggest that physical representations can support mathematical understanding when students are guided to connect manipulative activities with the concepts being taught. Research on authentic mathematics learning has similarly emphasized the value of instructional experiences that encourage active inquiry and meaningful engagement with mathematical ideas (Dolapcioglu & Doğanay, 2022). Within geometry education, these principles are relevant because students must coordinate visual recognition with an understanding of geometric attributes and relationships. The use of geoboards provides opportunities to examine such relationships by constructing, transforming, and comparing two-dimensional figures. Nevertheless, evidence concerning concrete manipulatives in mathematics education should not be interpreted as establishing equivalent learning benefits across all materials, student populations, or instructional contexts. Differences in learners' developmental characteristics, classroom practices, instructional duration, and assessment procedures may influence observed achievement patterns. Furthermore, findings concerning mathematical engagement or conceptual understanding cannot automatically be generalized to overall achievement measured through standardized classroom assessments. These considerations indicate the importance of evaluating geoboard-assisted instruction through clearly defined learning outcomes and contextually appropriate empirical procedures.

Despite the theoretical relevance of concrete manipulatives, further investigation is warranted regarding geoboard-assisted learning among students in the early grades of elementary education. Existing literature provides broader support for manipulative-based mathematics instruction, but its applicability to second-grade plane geometry learning within Indonesian Islamic elementary schools requires context-specific examination. This concern is particularly relevant in classrooms where instructional activities have predominantly emphasized teacher explanations and where access to interactive mathematical media may be limited. The present study addresses this contextual need by examining mathematics achievement before and after geoboard-assisted instruction among second-grade students at MI Fathul Huda Singkut. The instructional activities focus on constructing plane figures, recognizing geometric attributes, classifying shapes, and relating geometric representations to familiar objects. Mathematics learning outcomes are operationalized through students' achievement scores obtained from assessments administered before and after the instructional activities. The investigation draws on Bruner's representational framework, constructivist learning theory, and selected RME principles to explain the pedagogical rationale for using geoboards. However, these perspectives function as theoretical foundations rather than independently tested mechanisms of learning improvement. Because the research employs a one-group pretest-posttest design, its findings can establish whether achievement scores changed significantly but cannot isolate the causal contribution of geoboard media. Accordingly, the study seeks to provide preliminary empirical evidence concerning changes in lower-elementary students' plane geometry achievement following geoboard-assisted mathematics instruction.

METHOD

Research Design

This study employed a quantitative approach using a pre-experimental research design, specifically the one-group pretest–posttest design, to investigate changes in elementary students' mathematics learning outcomes following geoboard-assisted instruction in plane geometry. This design involved measuring students' mathematics achievement before and after the implementation of geoboard-based learning activities within the same group of participants. The pretest was administered to establish students' initial achievement levels, whereas the posttest was conducted after the instructional intervention to identify subsequent changes in their performance. This research design was selected because the investigation was conducted in an existing classroom setting where random assignment and the establishment of a separate control group were not feasible. According to Creswell and Creswell (2017), pre-experimental designs can provide preliminary evidence regarding changes in educational outcomes following instructional interventions. Similarly, Fraenkel and Wallen (1990) explain that pretest–posttest comparisons enable researchers to examine differences in participants' performance across two measurement periods. Nevertheless, the absence of a control group limits the ability to attribute observed changes exclusively to the intervention. Therefore, the present study focused on identifying statistically significant differences in mathematics achievement before and after geoboard-assisted instruction rather than establishing a definitive causal relationship.

Participant

The participants consisted of 17 second-grade students enrolled at MI Fathul Huda Singkut, Indonesia, during the 2025/2026 academic year. The study involved both male and female students who had previously received introductory mathematics instruction and were beginning to study plane geometric figures as part of the elementary mathematics curriculum. A total sampling technique was employed because the target population comprised a relatively small number of students within a single classroom. Accordingly, all 17 students were included as research participants, ensuring that the entire accessible classroom population was represented in the investigation. Total sampling is appropriate for small and clearly defined populations because it enables researchers to include all eligible members rather than selecting only a subset (Etikan & Bala, 2017). The selection of second-grade students was consistent with the study's objective of examining geoboard-assisted mathematics learning among lower-elementary learners. All participants received the same instructional content, learning duration, classroom facilities, and assessment procedures to maintain consistency throughout the intervention.

Research Instrument and Data Collection

Data were collected using mathematics achievement tests, structured classroom observations, and supporting documentation. The primary research instrument consisted of pretest and posttest achievement tests developed to measure students' mathematics learning outcomes in plane geometry. The assessment items were aligned with the instructional objectives, including identifying two-dimensional geometric figures, recognizing their properties, classifying shapes, and relating geometric concepts to objects encountered in everyday life. The pretest was administered before the implementation of geoboard-assisted instruction to assess students' initial mathematics achievement, while the posttest was conducted after the instructional activities to evaluate their subsequent performance. Both assessments focused on the learning indicators addressed during the instructional intervention, enabling comparisons between students' achievement before and after the learning activities. In addition to achievement tests, classroom observations were conducted using a structured observation sheet to document students' participation during geoboard-assisted learning. The observation indicators included students' involvement in constructing geometric

figures, attention to instructional guidance, interaction during learning activities, and completion of assigned tasks. Supporting documentation, including classroom photographs and instructional records, was also collected to provide contextual information about the implementation process. However, observation and documentation data were treated as supplementary information rather than primary outcome variables. Consequently, students' pretest and posttest achievement scores constituted the principal dataset used to examine changes in mathematics learning outcomes following the instructional intervention.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical procedures to examine differences in students' mathematics achievement before and after geoboard-assisted instruction. Descriptive statistics were employed to summarize students' pretest and posttest performance through mean scores, highest and lowest scores, and the percentages of students achieving the predetermined Minimum Mastery Criterion (KKM) of 75. These descriptive measures provided an overview of students' mathematics achievement at both measurement periods. To determine whether the differences between paired achievement scores were statistically significant, the Wilcoxon Signed-Rank Test was employed as a non-parametric statistical procedure. This test was selected because the study involved paired observations obtained from the same 17 students and a relatively small sample size. Statistical significance was evaluated using a two-tailed significance level of $\alpha = .05$, with differences considered statistically significant when the resulting p-value was below .05. The analysis also examined positive ranks, negative ranks, and tied observations to describe the direction of individual achievement changes between the pretest and posttest. Furthermore, the magnitude of the observed difference was quantified using the Wilcoxon effect-size formula, $r = |Z|/\sqrt{N}$, where Z represents the standardized Wilcoxon test statistic and N denotes the number of non-zero paired differences. With 16 non-zero differences, the reported test statistic of $Z = -2.925$ yielded an effect size of approximately $r = .73$. The descriptive statistics, significance test, and effect-size estimate were interpreted collectively to characterize achievement changes while acknowledging that the one-group pretest–posttest design could not establish a definitive causal effect of geoboard media.

Research Procedure

The research procedure was implemented through sequential classroom activities involving preliminary assessment, geoboard-assisted instruction, classroom observation, post-intervention assessment, and supporting documentation. Initially, all 17 participants completed a pretest to determine their mathematics achievement in plane geometry before receiving the instructional intervention. Following the preliminary assessment, the teacher implemented geoboard-assisted learning using a square pegboard and elastic bands that enabled students to construct various two-dimensional geometric figures. During the instructional sessions, students were encouraged to construct squares, rectangles, triangles, and parallelograms, identify their geometric properties, compare similarities and differences among figures, and associate geometric concepts with familiar objects. The teacher facilitated learning by providing instructional guidance, encouraging mathematical discussion, and offering feedback while students explored geometric representations. Throughout the intervention, classroom observations were undertaken to document students' participation, attention to instructions, interactions, and completion of learning activities. These observations served as supplementary evidence describing the instructional implementation rather than as independent measures of mathematical achievement. After completing the geoboard-assisted learning activities, students participated in a posttest covering the mathematical indicators addressed during the intervention. Classroom photographs and learning records were collected as supporting documentation, while consistent instructional content, learning duration, assessment procedures, and classroom facilities were maintained across participants. Finally, students' pretest and posttest achievement scores were analyzed using descriptive statistics and the Wilcoxon Signed-

Rank Test to determine the magnitude and statistical significance of the observed changes in mathematics learning outcomes.

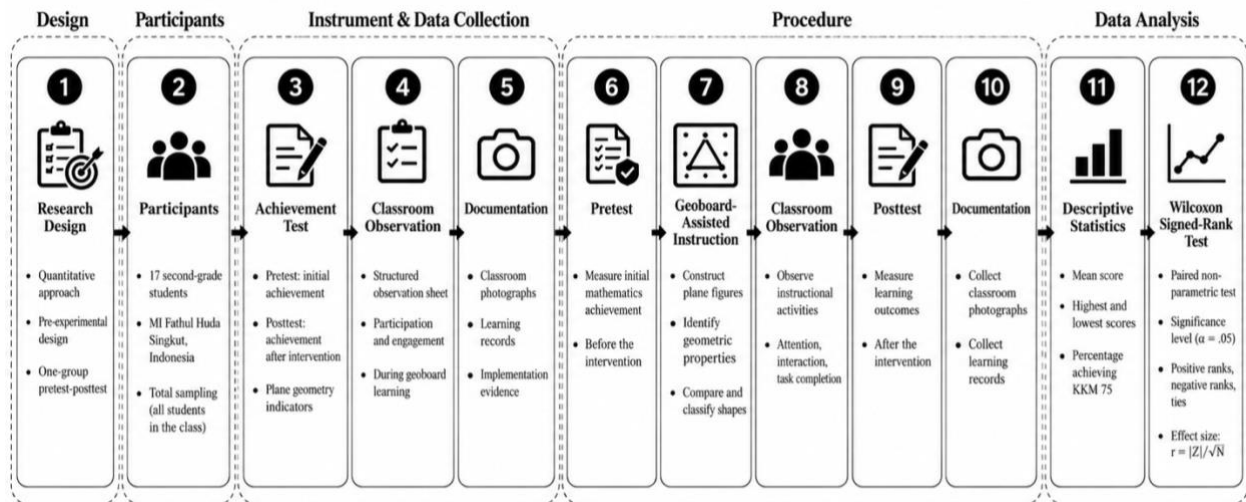


Figure 1. Research Method Flow

RESULTS AND DISCUSSION

Results

Students' Learning Outcomes Before and After the Geoboard Intervention

The comparison of students' mathematics achievement before and after the instructional intervention was conducted to examine changes in their performance following the use of geoboard media. A pretest was administered to assess students' achievement in plane geometry before the geoboard-based learning activities, while a posttest was administered after the instructional activities to assess their subsequent achievement. The pretest and posttest scores were then compared to identify whether a statistically significant difference occurred between the two measurements (Liburd & Jen, 2021). The comparison between the two assessments provides evidence of changes in students' mathematics achievement scores following the geoboard-based learning activities. The pretest and posttest results were therefore examined to determine the extent and statistical significance of the observed changes in students' performance in plane geometry (Alabdulaziz et al., 2021). According to Creswell and Creswell, a pretest-posttest design enables researchers to examine changes in students' academic performance by comparing measurements obtained before and after an educational intervention. In the present study, the pretest and posttest scores were compared to identify changes in students' mathematics achievement following the geoboard-based learning activities, without attributing the observed changes exclusively to the instructional treatment (Field, 2024). The pretest results indicate that students entered the learning process with relatively diverse levels of mathematical understanding. Table 1 presents the descriptive statistics of students' learning outcomes before the implementation of geoboard media.

Table 1. Pretest Results of Students' Mathematics Learning Outcomes

Indicator	Result
Number of students	17
Students achieving KKM	9 (52.94%)
Students below KKM	8 (47.06%)
Highest score	100
Lowest score	25
Mean score	69.12

As presented in Table 1, only 9 out of 17 students (52.94%) achieved the minimum mastery criterion (KKM), while the remaining 8 students (47.06%) failed to reach the expected level of competency. The average pretest score was 69.12, which remained below the established KKM of 75. Although several students demonstrated excellent performance by obtaining a perfect score of 100, two students achieved only 25. The pretest scores ranged from 25 to 100, indicating variation in students' initial achievement in plane geometry. Based on the mastery criterion used in the study, 47.06% of students did not reach the required level of mastery in the pretest. These results indicate that some students had not yet achieved the expected level of performance in plane geometry prior to the instructional intervention (Andini & Cahyaningsih, 2024; Huang, 2017). The pretest results indicate that some students had not yet achieved the expected level of performance in plane geometry prior to the instructional activities. However, the aggregate pretest scores do not provide sufficient evidence to determine specific difficulties in recognizing geometric figures, distinguishing their characteristics, or identifying particular properties of two-dimensional shapes. Such interpretations would require item-level or domain-level analysis of students' responses.

During the instructional activities, students learned plane geometry using geoboard media. The learning activities involved constructing various plane figures with elastic bands attached to the pegboard, identifying the names of the figures, observing their properties, comparing similarities and differences among shapes, and relating geometric representations to objects in everyday contexts. These activities constituted the instructional procedures through which the pretest and posttest measurements were conducted (Furner & Marinas, 2007). Rather than receiving information passively through teacher explanations, students became active participants in constructing mathematical knowledge through direct exploration. Such learning activities are closely aligned with constructivist learning theory, which views knowledge as something actively constructed by learners through meaningful interaction with learning materials rather than passively transmitted by teachers (Žakelj & Klančar, 2022). Following the completion of the instructional intervention, students completed the posttest to evaluate their learning outcomes after participating in geoboard-based learning. The descriptive statistics of the posttest are presented in Table 2.

Table 2. Posttest Results of Students' Mathematics Learning Outcomes

Indicator	Result
Number of students	17
Students achieving KKM	17 (100%)
Students below KKM	0
Highest score	100
Lowest score	80
Mean score	93.18

The posttest results showed higher mathematics achievement scores than those observed in the pretest. As presented in Table 2, all seventeen students (100%) achieved the minimum mastery criterion in the posttest. The mean score increased from 69.12 in the pretest to 93.18 in the posttest, representing a mean increase of 24.06 points. The minimum score also increased from 25 in the pretest to 80 in the posttest. These descriptive results indicate an overall increase in the group-level achievement scores between the two assessments. However, the change in the minimum score alone does not establish that each individual student improved; individual-level changes are examined through the paired analysis presented in the subsequent section (Kearns & Fuchs, 2013; Yeager et al., 2019).

The posttest scores were higher than the pretest scores, indicating an overall increase in students' mathematics achievement following the geoboard-based learning activities. The observed pretest–posttest difference was subsequently examined using the Wilcoxon Signed-Rank Test to determine whether the change in students' scores was statistically significant. The interpretation of

how geoboard activities may support students' learning of plane geometry is discussed in relation to relevant theoretical and empirical literature in the Discussion section (Carbonneau et al., 2013). Similarly, recent studies in mathematics education have consistently demonstrated that hands-on learning environments increase students' engagement, conceptual understanding, and retention of mathematical knowledge. To obtain a clearer overview of students' learning progress, the descriptive statistics of the pretest and posttest were compared, as presented in Table 3.

Table 3. Comparison of Pretest and Posttest Results

Indicator	Pretest	Posttest
Mean score	69.12	93.18
Highest score	100	100
Lowest score	25	80
Number of students	17	17
Learning mastery	52.94%	100%

Table 3 presents the descriptive comparison of students' mathematics achievement scores before and after the geoboard-based learning activities. The mean score increased by 24.06 points, from 69.12 in the pretest to 93.18 in the posttest. The minimum score also increased from 25 to 80, while all seventeen students achieved the minimum mastery criterion in the posttest. These descriptive statistics indicate an overall increase in group-level achievement between the two assessments. However, the aggregate statistics do not establish whether learning gains were distributed across particular subgroups of students; such conclusions require analysis of individual pretest–posttest score changes. (Zohar & Dori, 2003). Moreover, the percentage of students achieving the minimum mastery criterion increased from 52.94% in the pretest to 100% in the posttest. This descriptive change indicates an increase in the proportion of students who reached the required level of mastery in plane geometry between the two assessments. However, this change should not be interpreted as evidence of reduced learning disparities because no variance, achievement-gap, or subgroup analysis was conducted in the present study.

The observed pretest–posttest changes are further discussed in relation to relevant theoretical perspectives on mathematics learning in the Discussion section. In particular, Bruner's theory of cognitive representation provides a theoretical framework for considering how concrete learning experiences may be connected with subsequent iconic and symbolic representations. This theoretical interpretation is presented separately from the empirical results and does not constitute evidence of a causal effect of geoboard media (Helena & Perbowo, 2026; Peng et al., 2024). The geoboard provided opportunities for students to manipulate geometric figures physically, thereby facilitating conceptual understanding that may not be achieved through conventional lecture-based instruction alone. Furthermore, Freudenthal argues that mathematics learning becomes more meaningful when students actively construct mathematical ideas through exploration and contextual experiences, a principle that is strongly reflected in geoboard-assisted learning activities (Romero et al., 2024). Although the descriptive statistics indicate an increase in students' mathematics achievement scores, an inferential analysis was conducted to determine whether the difference between the pretest and posttest scores was statistically significant. The distribution of the paired differences between the pretest and posttest scores was first assessed using the Shapiro–Wilk test. The normality assessment yielded a Shapiro–Wilk statistic of $W = -2.925$ with a p -value = 0.003. Based on the normality assessment, the Wilcoxon Signed-Rank Test was selected as the non-parametric procedure for comparing the paired pretest and posttest scores. The results are presented in Table 4.

Table 4. Wilcoxon Signed-Rank Test Results

Statistic	Result
Negative ranks	4
Positive ranks	12
Ties	1
Z value	-2.925
Asymp. Sig. (2-tailed)	0.003

The Wilcoxon Signed-Rank Test identified 12 positive ranks, indicating that most students obtained higher scores after participating in geoboard-based learning (Okoye & Hosseini, 2024). Meanwhile, 4 negative ranks and 1 tied score were identified, suggesting that only a small number of students demonstrated unchanged or slightly lower performance. More importantly, the statistical analysis produced an Asymp. Sig. (2-tailed) value of 0.003, which is substantially lower than the predetermined significance level of 0.05. Therefore, the null hypothesis was rejected, confirming that the difference between pretest and posttest scores was statistically significant. According to Field (2024), a significance value below 0.05 in the Wilcoxon Signed-Rank Test indicates that the observed differences are unlikely to occur by chance, thereby providing strong evidence of the effectiveness of the instructional intervention (Kesgin & İlayda, 2025).

Overall, the descriptive and inferential findings indicate an increase in students' mathematics achievement scores between the pretest and posttest. The mean score increased from 69.12 to 93.18, the minimum score increased from 25 to 80, and the proportion of students achieving the minimum mastery criterion increased from 52.94% to 100%. The Wilcoxon Signed-Rank Test also indicated a statistically significant difference between the paired pretest and posttest scores ($Z = -2.925$, $p = 0.003$), with an effect size of $r = 0.731$. These findings describe a statistically significant pretest–posttest change following the geoboard-based learning activities. However, because the study employed a one-group pretest–posttest design without a control group, the findings do not isolate a causal treatment effect or establish that the observed change was attributable exclusively to geoboard media. The broader educational implications of the findings and their relationship to relevant theories and previous empirical studies are discussed in the following section.

Discussion

The findings of this study indicate that students' mathematics achievement scores differed significantly between the pretest and posttest following the geoboard-based learning activities. The descriptive and inferential analyses showed higher group-level achievement in the posttest, with the Wilcoxon Signed-Rank Test indicating a statistically significant pretest–posttest difference ($Z = -2.925$, $p = 0.003$; $r = 0.731$). These results provide evidence of a statistically significant change in students' mathematics achievement within the study period. However, because the study employed a one-group pretest–posttest design with 17 students and no control group, the observed change cannot be interpreted as a statistically established causal effect of geoboard media. Rather, the findings provide preliminary contextual evidence of changes in achievement following geoboard-assisted learning (Puspita, 2024). The mean score increased from 69.12 in the pretest to 93.18 in the posttest, representing an improvement of 24.06 points, while the percentage of students achieving the Minimum Mastery Criterion (KKM) increased from 52.94% to 100%. These findings suggest that geoboard media effectively facilitated students' understanding of geometric concepts while reducing learning difficulties commonly encountered in elementary mathematics classrooms (Andini & Cahyaningsih, 2024). To strengthen the interpretation of the findings, inferential statistical analysis was conducted using the Wilcoxon Signed-Rank Test. The results are presented in Table 5 and Table 6.

Table 5. Wilcoxon Signed-Rank Test (Ranks)

Category	N	Mean Rank	Sum of Ranks
Negative Ranks (Posttest < Pretest)	4	2.88	11.50
Positive Ranks (Posttest > Pretest)	12	10.38	124.50
Ties (Posttest = Pretest)	1	–	–
Total	17		

Table 6. Wilcoxon Signed-Rank Test Statistics

Test Statistic	Value
Z	-2.925
Asymp. Sig. (2-tailed)	0.003

As shown in Table 5, 12 students obtained higher scores in the posttest than in the pretest, whereas only 4 students experienced lower scores and 1 student maintained the same score. More importantly, the sum of positive ranks (124.50) was substantially greater than the sum of negative ranks (11.50), indicating that the dominant pattern among participants was academic improvement after the implementation of geoboard media. Furthermore, Table 6 shows that the Wilcoxon Signed-Rank Test produced a Z value of -2.925 with an Asymp. Sig. (2-tailed) value of 0.003. Since the probability value is lower than the significance level of 0.05, the null hypothesis is rejected, indicating that the improvement in students' learning outcomes was statistically significant. According to Field, the Wilcoxon Signed-Rank Test is an appropriate non-parametric procedure for comparing two related measurements when sample sizes are relatively small and data do not necessarily satisfy normality assumptions (Chumnaul et al., 2026; Field, 2024). Therefore, the statistical evidence confirms that the observed learning gains were unlikely to have occurred by chance.

The significant improvement observed in this study can be explained by the pedagogical characteristics of geoboard media. Unlike conventional lecture-based instruction, which often requires students to memorize geometric definitions, geoboard-based learning provides opportunities for learners to construct geometric figures physically using elastic bands and pegboards. Through this process, students actively identify sides, vertices, angles, and similarities among different plane figures. Such direct interaction transforms abstract mathematical concepts into observable and manipulable objects, making them easier for young learners to understand. Consequently, students are able to build stronger conceptual understanding rather than relying solely on procedural memorization. These findings are highly consistent with Bruner's Theory of Representation, which states that meaningful learning develops through three sequential stages: enactive, iconic, and symbolic representation (Helena & Perbowo, 2026; Jinzhi & Xuejun, 2024). During the implementation of geoboard media, students first manipulated geometric figures directly (enactive representation), then observed visual patterns created on the geoboard (iconic representation), and finally understood mathematical terminology and geometric properties symbolically. This instructional sequence enables learners to bridge concrete experiences with abstract mathematical reasoning. Because elementary school students are still developing higher-order abstract thinking, learning experiences that begin with concrete manipulation are particularly effective in facilitating conceptual understanding (Sibiya et al., 2025).

The findings also support the principles of constructivist learning theory, which emphasize that knowledge is actively constructed through learners' interactions with their environment. During geoboard-assisted instruction, students did not simply receive explanations from the teacher; instead, they actively explored geometric relationships, formulated ideas, discussed their observations with peers, and verified mathematical concepts independently ('Constructivism Learning Theory in Education', 2023; Liangshi, 2024). Such student-centered learning activities encourage meaningful knowledge construction and improve long-term retention of mathematical concepts. This explanation is consistent with the view of Fosnot, who argues that conceptual

understanding develops most effectively when learners actively participate in constructing knowledge through authentic learning experiences (Berlin et al., 2024). Furthermore, the present findings strongly support the philosophy of Realistic Mathematics Education (RME) proposed by Freudenthal. RME views mathematics as a human activity in which learners gradually reinvent mathematical concepts through meaningful exploration rather than memorizing formulas or definitions (Santos et al., 2024). The learning activities implemented in this study closely reflected these principles (Romero et al., 2024). Students explored geometric figures by constructing them on the geoboard, comparing their characteristics, identifying similarities and differences, and connecting geometric concepts with familiar objects found in everyday life. Consequently, mathematics became a meaningful activity rather than merely an abstract school subject. Such instructional experiences are believed to strengthen conceptual understanding because students develop mathematical knowledge through personal exploration instead of passive reception. Another important finding concerns the improvement of learning equity within the classroom. Although several students had already achieved satisfactory scores during the pretest, substantial progress was primarily observed among students who initially demonstrated relatively weak understanding of plane geometry. This conclusion is reflected by the increase in the minimum score from 25 during the pretest to 80 in the posttest. Such improvement indicates that geoboard media does not only benefit high-achieving students but also provides meaningful learning opportunities for lower-achieving learners. This finding is particularly important because one of the primary objectives of elementary mathematics instruction is ensuring that all students acquire sufficient conceptual understanding regardless of their initial academic ability.

The results of this study are also consistent with previous empirical investigations concerning manipulative-based mathematics instruction. Carbonneau, Marley, and Selig (2013), through a comprehensive meta-analysis, concluded that concrete manipulatives produce positive effects on students' mathematics achievement, especially when integrated into inquiry-based instructional activities. Likewise, Lavayette et al. reported that geoboard media significantly improved elementary students' understanding of plane geometry while reducing misconceptions regarding geometric properties (Lavayette et al., 2026). Similarly, Novitasari et al. found that the implementation of Realistic Mathematics Education promoted greater conceptual understanding, classroom participation, and mathematical communication among elementary school students. Compared with these previous studies, the present research contributes additional empirical evidence by demonstrating that geoboard media is also highly effective for second-grade students in an Indonesian Islamic elementary school using a pre-experimental design (Novitasari et al., 2025). This contribution expands the existing literature because relatively few studies have specifically investigated the effectiveness of geoboard media among lower elementary learners.

From a practical perspective, the findings suggest that geoboard media can serve as an effective alternative instructional resource for elementary mathematics teachers. The media are inexpensive, reusable, and relatively easy to construct using simple classroom materials. More importantly, geoboards encourage students to become active participants in the learning process through exploration, collaboration, and discussion (Popescu & Țîrlea, 2022). Therefore, mathematics teachers should consider integrating manipulative media into geometry instruction to enhance conceptual understanding, increase student engagement, and reduce dependence on rote memorization. Schools and curriculum developers may also benefit from incorporating concrete mathematical manipulatives into regular classroom practice, particularly in lower elementary grades where students require tangible learning experiences (Brookhart, 2023).

Despite these findings, several limitations should be acknowledged. First, the study employed a pre-experimental one-group pretest–posttest design without a control or comparison group. Therefore, the statistically significant pretest–posttest difference and the estimated effect size cannot

be interpreted as evidence of a causal effect of geoboard media, because alternative explanations such as maturation, testing effects, history, and regression to the mean cannot be ruled out. Second, the sample consisted of only 17 students from a single school, which limits the transferability and generalizability of the findings to other populations and educational settings. Third, the intervention focused exclusively on plane geometry and was implemented over a relatively short instructional period, limiting conclusions about other mathematical topics and longer-term learning outcomes. In addition, the study did not include a delayed posttest, so the retention of the observed achievement changes could not be examined.

Future research should employ quasi-experimental or randomized experimental designs with appropriate control or comparison groups, larger samples, and participants from multiple schools. Such studies should report effect-size estimates alongside statistical significance and, where feasible, include delayed posttests to examine the retention of learning outcomes over time. Research across different mathematical topics and educational contexts would also help determine the extent to which the observed pretest–posttest changes are consistent across settings. These methodological improvements would provide stronger evidence for evaluating the causal contribution and longer-term educational implications of geoboard-assisted learning.

Table 5. Wilcoxon Signed-Rank Test (Ranks)

Category	N	Mean Rank	Sum of Ranks
Negative Ranks (Posttest < Pretest)	4	2.88	11.50
Positive Ranks (Posttest > Pretest)	12	10.38	124.50
Ties (Posttest = Pretest)	1	–	–
Total	17		

The Wilcoxon Signed-Rank Test provides a more comprehensive understanding of individual changes in students' mathematics achievement following the implementation of geoboard media. As shown in Table 6, twelve students demonstrated positive ranks, indicating that their posttest scores were higher than their pretest scores (Okoye & Hosseini, 2024). In contrast, four students showed negative ranks, suggesting slightly lower posttest scores than pretest scores, while one student obtained identical scores in both assessments. More importantly, the sum of positive ranks (124.50) was considerably greater than the sum of negative ranks (11.50), indicating that the dominant trend among participants was an improvement in mathematics achievement after the instructional intervention. This finding demonstrates that the learning gains were experienced by the majority of students rather than by only a small number of high-performing individuals (Kesgin & İlayda, 2025).

The distribution of ranks also suggests that geoboard-assisted learning was effective in supporting students with different initial levels of mathematical ability. Students who initially experienced difficulties in understanding plane geometry generally showed meaningful progress after participating in the learning activities. This pattern indicates that the instructional intervention promoted more equitable learning outcomes by reducing achievement disparities within the classroom. Such findings are consistent with constructivist perspectives, which emphasize that active engagement with concrete learning materials enables learners to construct mathematical understanding more effectively than passive instructional approaches.

Table 7. Wilcoxon Signed-Rank Test Statistics

Test Statistic	Value
Z	-2.925
Asymp. Sig. (2-tailed)	0.003

The statistical significance of the observed improvement is confirmed by the Wilcoxon Signed-Rank Test presented in Table 7. The analysis produced a Z value of -2.925 and an Asymp. Sig. (2-tailed) value of 0.003. Because the probability value is substantially lower than the predetermined significance level of 0.05, the null hypothesis is rejected, indicating that there was a statistically

significant difference between students' pretest and posttest scores. According to Field (2024), the Wilcoxon Signed-Rank Test is an appropriate non-parametric statistical procedure for comparing paired observations when the sample size is relatively small or when the assumption of normality cannot be fully satisfied (Kesgin & İlayda, 2025; Okoye & Hosseini, 2024). Therefore, the statistical evidence strongly suggests that the improvement observed in this study resulted from the implementation of geoboard-assisted learning rather than random variation.

The combination of descriptive and inferential findings strengthens the overall conclusion of this study. The increase in the mean score from 69.12 to 93.18, the improvement in learning mastery from 52.94% to 100%, the dominance of positive ranks over negative ranks, and the statistically significant Wilcoxon result collectively demonstrate that geoboard media substantially enhanced students' understanding of plane geometry. These findings support previous research indicating that manipulative-based mathematics instruction enables learners to visualize abstract mathematical concepts, promotes active participation, and facilitates meaningful conceptual understanding (Carbonneau et al., 2013; Jinzhi & Xuejun, 2024). Consequently, geoboard media can be regarded as an effective instructional strategy for improving mathematics learning outcomes among lower elementary school students. Overall, the present study provides compelling evidence that geoboard media constitute an effective instructional strategy for improving elementary students' mathematics learning outcomes. The combination of substantial descriptive improvement, statistically significant Wilcoxon Signed-Rank Test results ($Z = -2.925$, $p = 0.003$), and strong theoretical support from Bruner's Theory of Representation, Constructivism, and Realistic Mathematics Education demonstrates that geoboard-assisted instruction successfully transforms abstract geometric concepts into meaningful learning experiences. Consequently, geoboard media can be recommended as an effective pedagogical tool for promoting active, engaging, and conceptually rich mathematics learning in elementary schools.

Implications

The findings of this study provide theoretical and practical implications for improving elementary mathematics instruction through geoboard-assisted learning. The observed increase in students' mean achievement scores from 69.12 to 93.18 suggests that geoboard media may support mathematics learning outcomes in plane geometry. Theoretically, these findings align with Bruner's theory of representation, constructivist learning principles, and Realistic Mathematics Education, which emphasize meaningful learning through concrete experiences and active exploration. Pedagogically, geoboard activities offer opportunities for students to construct geometric figures, identify their properties, and connect abstract mathematical concepts with tangible representations. For teachers, geoboards represent an accessible and affordable instructional resource that may encourage student participation and conceptual understanding. Schools may therefore consider integrating manipulative-based learning into elementary mathematics instruction and providing appropriate teacher training. Nevertheless, the small sample size and absence of a control group limit causal interpretation and generalizability. Consequently, further controlled studies are required to establish the effectiveness of geoboard-assisted instruction across different educational contexts.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting its findings. First, the one-group pretest–posttest design without a control group limits the ability to establish a causal relationship between geoboard-assisted instruction and mathematics achievement. Second, the small sample of 17 students from a single elementary school restricts the generalizability of the results. Third, the study focused exclusively on plane geometry, limiting its applicability to other mathematical topics. Additionally, the absence of a delayed posttest prevented an assessment of long-term knowledge retention. The study also did not independently measure students' spatial

reasoning, motivation, or conceptual understanding. Future research should employ quasi-experimental or randomized controlled designs to strengthen causal evidence. Larger samples involving multiple schools are recommended to improve the generalizability of findings. Longitudinal investigations should examine whether learning improvements are sustained over time. Further studies could also explore the influence of geoboard media on students' mathematical reasoning and problem-solving abilities. Comparative investigations involving physical geoboards, digital manipulatives, and conventional instruction would provide additional pedagogical insights. These approaches could strengthen the evidence base for geoboard-assisted mathematics instruction across diverse elementary educational settings.

CONCLUSION

This study examined changes in elementary students' mathematics achievement in plane geometry before and after geoboard-based learning activities using a pre-experimental one-group pretest-posttest design involving 17 second-grade students at MI Fathul Huda Singkut. The descriptive findings showed that the mean achievement score increased from 69.12 in the pretest to 93.18 in the posttest, while the proportion of students achieving the minimum mastery criterion increased from 52.94% to 100%. The Wilcoxon Signed-Rank Test indicated a statistically significant difference between the paired pretest and posttest scores ($Z = -2.925$, $p = 0.003$), with an effect size of $r = 0.731$. These findings indicate a statistically significant change in students' mathematics achievement following the geoboard-based learning activities. The findings can be interpreted in relation to Bruner's Theory of Representation, Constructivist Learning Theory, and principles of Realistic Mathematics Education, which emphasize the role of concrete and meaningful learning experiences in mathematical learning. However, these theoretical perspectives were not directly tested in the present study and therefore should be regarded as interpretive frameworks rather than empirical evidence supporting the theories. Similarly, the observed pretest-posttest change cannot be interpreted as a causal effect of geoboard media because the study did not include a control group and involved a relatively small sample from a single school. The contribution of this study is therefore best understood as preliminary contextual evidence from a lower-elementary Islamic school in Indonesia. The findings provide empirical information about changes in students' mathematics achievement following geoboard-assisted learning activities in the specific classroom context examined. They should not be generalized to other schools, grade levels, or national contexts without further comparative evidence. From a practical perspective, geoboard media may be considered a potentially useful instructional option for plane-geometry learning, particularly where teachers seek to incorporate concrete representations into classroom activities. However, the present findings are insufficient to establish the superiority or causal effectiveness of geoboard-based instruction. Further evaluation using controlled or comparative designs is warranted before broader instructional recommendations are made. Future research should employ quasi-experimental or randomized experimental designs with appropriate control or comparison groups, larger and multisite samples, and direct estimation of effect sizes. Studies incorporating delayed posttests would also be valuable for examining whether observed achievement changes are retained over time. Such designs would provide stronger evidence regarding the causal contribution of geoboard-assisted learning and its potential effects across different educational settings and mathematical topics.

AUTHOR CONTRIBUTIONS STATEMENT

Nur Shinta Kurnia contributed to the research conceptualization, methodology development, instructional implementation, data collection, statistical analysis, interpretation of findings, and preparation of the original manuscript. Elce Purwandari contributed to research supervision, methodological refinement, validation of research instruments, interpretation of results, critical manuscript review, and editorial revisions. Both authors contributed to the intellectual development of the study, reviewed and approved the final manuscript, and agreed to be accountable for its content.

REFERENCES

- Alabdulaziz, M. S., Aldossary, S. M., Alyahya, S. A., & Althubiti, H. M. (2021). The effectiveness of the GeoGebra programme in the development of academic achievement and survival of the learning impact of the mathematics among secondary stage students. *Education and Information Technologies*, 26(3), 2685–2713. <https://doi.org/10.1007/s10639-020-10371-5>
- Andini, I., & Cahyaningsih, U. (2024). An analysis of students' learning difficulties in solving plane geometry problems among seventh-grade students. *International Journal of Advance Research in Mathematics Education*, 2(2), 110–121. <https://doi.org/10.56916/ijr.v2i2.2657>
- Ariani, D. N. (2015). Hubungan antara Technological Pedagogical Content Knowledge dengan Technology Integration Self Efficacy guru matematika di sekolah dasar. *Muallimuna : Jurnal Madrasah Ibtidaiyah*, 1(1), 79–91. <https://doi.org/10.31602/muallimuna.v1i1.277>
- Berlin, E., Yegya-Raman, N., Hollawell, C., Haertter, A., Fosnot, J., Rhodes, S., Seol, S. W., Gentile, M., Li, T., Freedman, G. M., & Taunk, N. K. (2024). Breast reconstruction complications after postmastectomy proton radiation therapy for breast cancer. *Advances in Radiation Oncology*, 9(3), 101385. <https://doi.org/10.1016/j.adro.2023.101385>
- Brookhart, S. M. (2023). *Classroom assessment essentials*. ASCD.
- Cahyani, H., & Setyawati, R. W. (2017). Pentingnya peningkatan kemampuan pemecahan masalah melalui PBL untuk mempersiapkan generasi unggul menghadapi MEA. PRISMA, Prosiding Seminar Nasional Matematika, 151-160.
- Carbonneau, K. J., Marley, S. C., & Selig, J. P. (2013). A meta-analysis of the efficacy of teaching mathematics with concrete manipulatives. *Journal of Educational Psychology*, 105(2), 380–400. <https://doi.org/10.1037/a0031084>
- Çelik, H. C., & Özdemir, F. (2020). Mathematical thinking as a predictor of critical thinking dispositions of pre-service Mathematics teachers. *International Journal of Progressive Education*, 16(4), 81. <https://doi.org/10.29329/ijpe.2020.268.6>
- Chumnaul, J., Sarong, T., & Promruangchot, A. (2026). Parametric versus non-parametric statistics: A case study in traditional and alternative medicine research with the development of SDA4AMR web application. *European Journal of Statistics*, 6, 8–8. <https://doi.org/10.28924/ada/stat.6.8>
- Cobb, P., Zhao, Q., & Visnovska, J. (2008). Learning from and adapting the theory of Realistic Mathematics education. *Éducation et Didactique*, (2-1), Article 2-1. <https://doi.org/10.4000/educationdidactique.276>
- Constructivism Learning Theory in Education: Characteristics, Steps and Learning Models. (2023). *Research in education and rehabilitation*, 6(2), 234-242. <https://doi.org/10.51558/2744-1555.2023.6.2.234> [<https://doi.org/10.51558/2744-1555.2023.6.2.234>]
- Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE Publications.
- Dolapcioglu, S., & Doğanay, A. (2022). Development of critical thinking in mathematics classes via authentic learning: An action research. *International Journal of Mathematical Education in Science and Technology*, 53(6), 1363–1386. <https://doi.org/10.1080/0020739X.2020.1819573>
- Etikan, I., & Bala, K. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal*, 5(6), 62–65. <https://doi.org/10.15406/bbij.2017.05.00149>

- Fauzan, A., Harisman, Y., Yerizon, Y., Suherman, S., Tasman, F., Nisa, S., Sumarwati, S., Hafizatunnisa, H., & Syaputra, H. (2024). Realistic mathematics education (RME) to improve literacy and numeracy skills of elementary school students based on teachers' experience. *Infinity Journal*, 13(2), 301–316. <https://doi.org/10.22460/infinity.v13i2.p301-316>
- Field, A. (2024). *Discovering statistics using IBM SPSS statistics*. SAGE Publications.
- Fraenkel, J. R., & Wallen, N. E. (1990). *How to design and evaluate research in education*. Order Department, McGraw Hill Publishing Co.
- Furner, J. M., & Marinas, C. A. (2007). Geometry sketching software for elementary children: Easy as 1, 2, 3. *Eurasia Journal of Mathematics, Science and Technology Education*, 3(1), 83–91. <https://doi.org/10.12973/ejmste/75376>
- Helena, P., & Perbowo, K. S. (2026). Mathematical representation abilities in Bruner's representation stages: A phenomenological study of high school students. *(JIML) JOURNAL OF INNOVATIVE MATHEMATICS LEARNING*, 9(2), 427–450. <https://doi.org/10.22460/jiml.v9i2.31378>
- Huang, H.-M. E. (2017). Curriculum interventions for area measurement instruction to enhance children's conceptual understanding. *International Journal of Science and Mathematics Education*, 15(7), 1323–1341. <https://doi.org/10.1007/s10763-016-9745-7>
- Jinzhi, H., & Xuejun, B. (2024). Bruner's three models of presentation theory. In *The ECPH Encyclopedia of Psychology* (pp. 167-170). Springer. https://doi.org/10.1007/978-981-97-7874-4_172
- Kearns, D. M., & Fuchs, D. (2013). Does cognitively focused instruction improve the academic performance of low-achieving students? exceptional children, 79(3), 263-290. <https://doi.org/10.1177/001440291307900200>
- Kesgin, T., & İlayda, R. (2025). Revisiting trend stability using Mann-Kendall and Wilcoxon signed-rank tests through innovative method comparisons. *Sustainability*, 17(23), 10454. <https://doi.org/10.3390/su172310454>
- Kholil, M., & Zulfiani, S. (2020). Faktor-faktor kesulitan belajar matematika siswa madrasah ibtidaiyah da'watul falah kecamatan tegaldlimo kabupaten banyuwangi. *EDUCARE Journal of Primary Education*, 1(2), 151–168. <https://doi.org/10.35719/educare.v1i2.14>
- Lavayette, V. R., Rohimah, S. M., & Nurhadi, M. (2026). Pengaruh pendekatan Realistic Mathematics education berbantuan media Scratch untuk meningkatkan kemampuan pemahaman konsep matematis siswa SD. *FONDATIA*, 10(2), 436–447. <https://doi.org/10.36088/fondatia.v10i2.6315>
- Liangshi, Y. (2024). Constructivism learning theory. In *The ECPH Encyclopedia of Psychology* (pp. 311-313). Springer. https://doi.org/10.1007/978-981-97-7874-4_1077
- Liburd, K. K. D., & Jen, H.-Y. (2021). Investigating the effectiveness of using a Technological approach on students' achievement in mathematics-case study of a high school in a caribbean country. *Sustainability*, 13(10), 5586. <https://doi.org/10.3390/su13105586>
- Majid, A. (2019). Implementasi pendekatan matematika realistik dalam pembelajaran matematika di sekolah dasar (SD) atau madrasah ibtidaiyah (MI). *Didaktika: Jurnal Kependidikan*, 8(1), 17–24. <https://doi.org/10.58230/27454312.64>
- Novitasari, D., Soeprianto, H., Kurniati, N., Junaidi, J., Tyaningsih, R. Y., & Agustina, A. (2025). Empowering elementary teachers: Digital mathematics learning resource training center for enhanced classroom instruction. *Rengganis Jurnal Pengabdian Masyarakat*, 5(1), 192–201. <https://doi.org/10.29303/rengganis.v5i1.560>
- Okoye, K., & Hosseini, S. (2024). Wilcoxon statistics in R: Signed-rank test and rank-sum test. In K. Okoye & S. Hosseini (Eds), *R Programming: Statistical Data Analysis in Research* (pp. 279-303). Springer Nature. https://doi.org/10.1007/978-981-97-3385-9_13
- Peng, J., Sun, M., Yuan, B., Lim, C. P., van Merriënboer, J. J. G., & Wang, M. (2024). Visible thinking to support online project-based learning: Narrowing the achievement gap between high- and low-achieving students. *Education and Information Technologies*, 29(2), 2329–2363. <https://doi.org/10.1007/s10639-023-11896-1>
- Popescu, A. M., & Țîrlea, M. R. (2022). Theoretical and practical study on value added tax at national and community level (First part). *RAIS Conference Proceedings 2022-2023*, Article 0248.

- Pratiwi, A. F., & Imami, A. I. (2022). Analisis self-efficacy dalam pembelajaran matematika pada siswa smp. *AKSIOMA: Jurnal Matematika dan Pendidikan Matematika*, 13(3), 403–410. <https://doi.org/10.26877/aks.v13i3.13973>
- Puspita, N. A. (2024). The effect of probing prompting learning model with geoboard media on fourth-grade Mathematics learning outcomes. *International Journal of Elementary Education*, 8(4), 726–733. <https://doi.org/10.23887/ijee.v8i4.91665>
- Rojas, E., & Benakli, N. (2020). Mathematical literacy and critical thinking. In J. C. But (Ed.), *Teaching College-Level Disciplinary Literacy: Strategies and Practices in STEM and Professional Studies* (pp. 197–226). Springer International Publishing. https://doi.org/10.1007/978-3-030-39804-0_8
- Romero, A. A., Silva, F. E. R., Espinoza, A. S., Quispe, J. T., Castillo, A. C. L., & Huarcaya, F. D. B. (2024). Hans Freudenthal: Perspectives in Mathematics education and phenomenological analysis. Online Submission.
- Santos, D. F. D., Silva, G. D. S. E., & Miguel, J. C. (2024). Theory OF STUDY activity AND realistic mathematics education: Articulation AND possibilities. *Educação Em Revista*, 40, e39763. <https://doi.org/10.1590/0102-469839763t>
- Schoenfeld, A. H. (2016). Learning to think mathematically: Problem solving, metacognition, and sense making in Mathematics (Reprint). *Journal of Education*, 196(2), 1–38. <https://doi.org/10.1177/002205741619600202>
- Sibiya, M. R., Roux, A., & Kloppers, M. (2025). An introduction of a CIRGON geoboard as a manipulative for teaching geometry in K-12 Mathematics. *Studies in Learning and Teaching*, 6(3), 730–742. <https://doi.org/10.46627/silet.v6i3.585>
- Su, H. F. H., Ricci, F. A., & Mnatsakanian, M. (2016). Mathematical teaching strategies: Pathways to critical thinking and metacognition. *International Journal of Research in Education and Science*, 2(1), 190–200. <https://doi.org/10.21890/ijres.57796> [<https://doi.org/10.21890/ijres.57796>]
- Szabo, Z. K., Körtesi, P., Guncaga, J., Szabo, D., & Neag, R. (2020). Examples of problem-solving strategies in Mathematics education supporting the sustainability of 21st-century skills. *Sustainability*, 12(23), 10113. <https://doi.org/10.3390/su122310113>
- Yeager, D. S., Hanselman, P., Walton, G. M., Murray, J. S., Crosnoe, R., Muller, C., Tipton, E., Schneider, B., Hulleman, C. S., Hinojosa, C. P., Paunesku, D., Romero, C., Flint, K., Roberts, A., Trott, J., Iachan, R., Buontempo, J., Yang, S. M., Carvalho, C. M., ... Dweck, C. S. (2019). A national experiment reveals where a growth mindset improves achievement. *Nature*, 573(7774), 364–369. <https://doi.org/10.1038/s41586-019-1466-y>
- Žakelj, A., & Klančar, A. (2022). The role of visual representations in geometry learning. *European Journal of Educational Research*, 11(3), 1393–1411. <https://doi.org/10.12973/eu-jer.11.3.1393>
- Zohar, A., & Dori, Y. J. (2003). Higher order thinking skills and low-achieving students: Are they mutually exclusive? *journal of the learning sciences*, 12(2), 145–181. https://doi.org/10.1207/S15327809JLS1202_1