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Research Article

GeoGebra-supported contextual learning: Enhancing secondary school students' mathematical communication and representation in transformation geometry

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ABSTRACT

GeoGebra in mathematics learning can potentially be used to help students improve their mathematical communication and representation skills in solving problems. However, limited research has examined the integration of GeoGebra and contextual mathematics learning to improve these skills. The study aims to examine the effectiveness of GeoGebra in contextual mathematics learning on students' mathematical communication and representation skills. Using a quantitative approach with a quasi-experimental design, the study involved 53 ninth-grade students from a junior high school, who were divided into experimental and control groups through purposive sampling. They participated in a five-session GeoGebra-supported contextual learning program. Data collection was conducted through a mathematical representation ability test and a mathematical communication observation sheet. Data were analyzed using descriptive statistics, independent-samples t-tests, and multivariate analysis of covariance to examine the simultaneous effects of the intervention on both dependent variables. The results revealed significant improvements in both mathematical communication and representation skills. The intervention produced a small effect on mathematical communication (Cohen's d = 0.402) and a large effect on mathematical representation (Cohen's d = 1.61), indicating stronger gains in students' ability to construct and translate mathematical representations. The findings demonstrate that dynamic visualization combined with contextual problem-solving provides an effective learning environment for strengthening students' mathematical communication and representation (Antara & Sutama, 2026; Kholid et al., 2024b; Septiani & Kholid, 2023). Unlike previous studies that primarily examined GeoGebra or contextual learning separately, the study provides empirical evidence that integrating dynamic visualization through GeoGebra with contextual learning activities can simultaneously enhance students' mathematical communication and representation skills.

Keywords: GeoGebra, contextual learning, mathematical communication, mathematical representation, dynamic geometry software, transformation geometry

INTRODUCTION

Mathematics plays an important role in everyday life as it functions as a symbolic language that supports precise and effective communication (Rajagukguk et al., 2022). One of the important skills in learning mathematics is mathematical communication (Halawati & Laelasari, 2022). Mathematical communication skills are a key factor for improving students' mathematical thinking skills (Nartani et al., 2015). Mathematical communication skills need to be developed because, as Paridjo and Waluya (2017) asserted, mathematical communication plays a crucial role in conveying, explaining, describing, and understanding mathematical concepts. However, many students still experience difficulties in expressing their mathematical ideas, both verbally and in writing, thus requiring special attention in mathematics learning (Uyen et al., 2021).

In addition to mathematical communication, mathematical representation is also an important skill that must be developed in mathematics learning, because mathematical representation contributes significantly to the teaching and learning of mathematics (Mainali, 2021). Mathematical representation refers to students' ability to describe, express, and transform ideas in the form of mathematical objects that have been previously known from seeing concrete objects (Junita, 2016). Numbers, symbols, tables, pictures, diagrams, graphs, expressions, and mathematical notation are forms of mathematical representation (Rahmawati et al., 2021). Mathematical representation plays an important role in helping students visualize and understand mathematical concepts (Minarni & Napitupulu, 2017). Furthermore, low mathematical representation skills can affect how students understand the mathematical problems they face and how to solve them (Mulyaningsih et al., 2020). Although mathematical representation skills are very important, previous studies found that students in their studies showed relatively low mathematical representation skills due to limited motivation to understand problem statements, lack of collaboration during learning activities, and lack of confidence in expressing mathematical solutions through appropriate representations (Silviani et al., 2021).

One factor contributing to students' weak mathematical communication and representation skills is the limited interactivity of conventional learning. The learning process tends to be teacher-centered (Nuraida & Amam, 2019). As a result, students have fewer opportunities to express ideas through various representations, practice expressing ideas, and discuss their understanding of mathematical concepts. Palinussa (2020) stated that the use of conventional learning models by teachers makes the classroom learning process monotonous, leading to student boredom and decreased motivation to learn. Consequently, students may develop only a limited understanding of mathematical concepts, particularly regarding material considered difficult. To enable students to communicate mathematically with others more effectively, teachers must implement appropriate and efficient learning strategies (Turmuzi et al., 2024).

Contextual learning is one approach that can be applied to improve students' mathematical communication and representation. The student-centered approach bridges everyday life with the learning environment, thereby acquiring practically relevant knowledge and skills (Ahdhianto et al., 2020). Furthermore, students will be motivated to communicate their ideas both orally and in writing. Contextual learning also encourages students to become accustomed to analyzing, applying, and connecting various concepts (Farlina & Rohaeti, 2018). Contextual learning helps students not only strengthen concepts but also improve their mathematical communication and representation (Tupamahu et al., 2023). However, although contextual learning provides meaningful real-world connections, it often lacks technological tools that can help students visualize abstract mathematical concepts dynamically. Consequently, students may still experience difficulties in translating contextual situations into mathematical representations.

In addition to appropriate learning approaches, the implementation of digital technology in mathematics education can also serve as a supporting factor in enhancing students' mathematical communication and representation (Bach et al., 2024). One technology that can be utilized in mathematics learning is GeoGebra. GeoGebra is an interactive mathematics learning software application that facilitates the understanding of mathematical concepts through a proactive, exploratory, and flexible approach, both in face-to-face and distance learning (Ziatdinov & Valles, 2022). Khaq and Febriana (2023) stated GeoGebra helps students develop their mathematical communication skills, especially when applied together with the think-pair-share learning model. Furthermore, Nurzannah et al. (2021) argued GeoGebra has an impact on students' representation skills. Nevertheless, while GeoGebra provides powerful dynamic visualization and interactive exploration, its implementation does not automatically ensure that students can relate mathematical concepts to meaningful real-life contexts. As a result, learning activities may focus primarily on technological exploration without sufficiently connecting mathematical concepts to students' everyday experiences.

Previous research has demonstrated the effectiveness of using GeoGebra in mathematics learning to improve students' understanding of mathematical concepts as well as their mathematical communication and representation skills. Kusumah et al. (2020) stated that the integration of GeoGebra into students' learning significantly improved their mathematical communication skills. Furthermore, Septian et al. (2023) demonstrated that GeoGebra improved students' mathematical representation skills compared to conventional learning. GeoGebra, combined with the project-based learning model, which emphasizes visual precision and accuracy, has been empirically proven to improve the effectiveness of analytical geometry teaching, in line with GeoGebra's proven ability to improve understanding, communication, and mathematical representation (Kholid et al., 2022). These studies consistently indicate that GeoGebra is effective in supporting mathematical learning. However, most previous studies have focused on the impact of GeoGebra as a technological tool or its integration with specific learning models, while relatively little attention has been given to its integration with contextual learning approaches. Similarly, studies on contextual learning have generally emphasized meaningful learning experiences but have rarely incorporated dynamic visualization technologies that can strengthen students' communication and representation processes.

From a constructivist perspective, mathematical understanding develops when students actively construct knowledge through interaction with meaningful learning experiences (Suryawati & Osman, 2018). Contextual learning provides authentic situations that encourage students to discuss, interpret, and explain mathematical ideas based on real-life problems, allowing learners to connect new knowledge with prior experiences and construct understanding through social interaction and reflection (Dewi et al., 2021; Suryawati & Osman, 2018). These processes support the development of mathematical communication because students are required to express mathematical reasoning using appropriate language, representations, and explanations. Meanwhile, GeoGebra provides dynamic visualizations that enable students to explore mathematical relationships, manipulate objects, and connect visual, symbolic, and verbal forms of representation (Ziatdinov & Valles, 2022). Such dynamic geometry environments (DGEs) facilitate the transformation and coordination of multiple representations, which are essential for developing students' mathematical representation and communication skills (Bach et al., 2024). Therefore, the integration of contextual learning and GeoGebra is expected to create a complementary learning environment in which contextual problems provide meaning and relevance, while dynamic visualization supports exploration and representation. Through the combination, students are encouraged not only to represent mathematical ideas in multiple forms but also to communicate their reasoning more effectively. Based on the conceptual rationale, GeoGebra-supported contextual learning is expected to enhance both mathematical communication and mathematical representation skills simultaneously.

Therefore, there remains a research gap regarding how the integration of GeoGebra and contextual learning can simultaneously support students' mathematical communication and representation skills. Although previous studies have demonstrated the effectiveness of GeoGebra in improving these skills, most have focused on GeoGebra as a technological tool or its integration with other learning models, while studies on contextual learning have rarely incorporated dynamic visualization technologies. Consequently, research specifically examining the integration of GeoGebra and contextual learning, particularly in transformation geometry learning at the junior secondary level, remains limited. The combination is theoretically important because contextual learning provides meaningful real-life situations that encourage students to communicate mathematical ideas, while GeoGebra offers dynamic visualizations that help students construct and connect multiple mathematical representations. Therefore, the study aims to examine the effectiveness of GeoGebra-supported contextual mathematics learning in improving students' mathematical communication and representation skills. Specifically, the study investigates whether the integration of GeoGebra and contextual learning leads to better mathematical communication and representation outcomes compared to conventional learning. To achieve the objective, the study is guided by the following research questions:

(1) does GeoGebra-supported contextual mathematics learning significantly improve students' mathematical communication skills?;

(2) does GeoGebra-supported contextual mathematics learning significantly improve students' mathematical representation skills?;

(3) are there significant differences in mathematical communication and representation skills between students who learn through GeoGebra-supported contextual learning and those who learn through conventional instruction?; and

(4) does GeoGebra-supported contextual mathematics learning have a significant simultaneous effect on students' mathematical communication and representation skills after controlling for their initial abilities?

Hypothesis

Several previous studies have applied a contextual approach to improve students' mathematical communication and mathematical representation, such as Tupamahu et al. (2023). Furthermore, several previous studies have also integrated GeoGebra to improve students' mathematical communication and mathematical representation (Kholid et al., 2022; Kusumah et al., 2020; Septian et al., 2023). Although several previous studies have demonstrated effectiveness, it is hypothesized that the integration of GeoGebra with contextual learning can enhance mathematical communication and representation. Therefore, the hypothesis of the study is that the implementation of GeoGebra in contextual mathematics learning significantly improves students' mathematical communication and representation.

State of the Art

Several studies related to mathematical communication and representation were reviewed and grouped into three main categories:

(1) research on the correlation between mathematical communication and representation and contextual learning,

(2) research on the relationship between contextual learning and technology or media to improve mathematical communication and representation, and

(3) research on technology and media for mathematical learning to improve mathematical communication and representation.

The first group includes research on the correlation between mathematical communication and representation and contextual learning, suggesting several important points:

(1) ethnomathematics-based contextual learning has a positive effect on mathematical communication skills (Rizqi & Hawa, 2023);

(2) contextual learning can be used as an additional mathematics learning method to significantly improve students' mathematical communication skills (Uyen et al., 2021);

(3) metacognitive-based contextual learning is effective in improving mathematical communication skills (Ahdhianto et al., 2020);

(4) Kolaka City-based contextual learning is effective in improving students' mathematical communication skills (Rustam & Handayani, 2017);

(5) contextual learning provides greater benefits in improving mathematical communication (Hutapea et al., 2019);

(6) Think-talk-write-based contextual learning affects students' mathematical representations (Waluya et al., 2018);

(7) a contextual approach through student worksheets can improve students' mathematical representation skills in visual, verbal, and symbolic aspects (Nursanti, 2019); and

(8) contextual learning with an outdoor approach has an effect on improving and achieving students' mathematical representation (Priyadi et al., 2021).

The second group comprises research on the relationship between contextual learning and technology or media to improve mathematical communication and representation, indicating the following findings:

(1) contextual learning assisted by Moodle improves mathematical communication skills (Susanto et al., 2022);

(2) contextual learning assisted by interactive media articulate storyline 3 has an influence in improving mathematical communication skills (Ratnaningsih et al., 2024);

(3) learning tools based on a contextual approach can improve mathematical communication skills (Yerizon et al., 2020);

(4) digital books based on a contextual approach can improve mathematical communication skills (Lestari, 2022);

(5) the REACT strategy assisted by GeoGebra software has a significant effect on students' mathematical representation skills (Nurzannah et al., 2021); and

(6) think pair share with autographs has a significant effect on students' mathematical representation skills (Ragelia Sinaga et al., 2018).

The third research group focuses on technology and media for mathematics learning to improve mathematical communication and representation. The studies indicate the following results:

(1) GeoGebra has been shown to improve mathematical communication skills (Diaz-Nunja et al., 2018);

(2) the use of GeoGebra can improve mathematical communication skills (Kusumah et al., 2020);

(3) interactive technology is effective in improving mathematical communication skills (Pasani & Amelia, 2025);

(4) virtual escape rooms can improve mathematical communication (Luque-Sánchez & Montejo-Gámez, 2023);

(5) mathematics learning with the brain-based learning approach with autograph can develop mathematical communication skills (Triana et al., 2019);

(6) technology in learning is proven to be effective in improving mathematical communication skills (Suharti et al., 2024);

(7) DGEs are able to improve mathematical representation (Bach et al., 2024); and

(8) interactive learning videos are effective in improving mathematical representation skills (Sriyanti et al., 2024).

Following the review of studies related to mathematical communication and mathematical representation, several research focuses which can be further investigated were identified:

(1) GeoGebra-based contextual learning to improve mathematical communication and representation,

(2) factors that influence students' mathematical communication and representation in digital contextual learning, and

(3) development of GeoGebra-based learning media to improve mathematical communication and representation.

Our research this year is focused on GeoGebra-based contextual learning to improve mathematical communication and representation. **Figure 1** illustrates the previous research we have conducted and the future research we have planned.

METHOD

Research Design

The study employed a quantitative approach with a quasi-experimental design to examine the effectiveness of GeoGebra in contextual mathematics learning to improve mathematical communication and representation skills. The research design involved two groups, one experimental group (GE) and one control group (GC). Therefore, GE will receive contextual mathematics learning integrated with GeoGebra, while GC will be taught using conventional methods. The quantitative approach was selected because the study is related to measuring, testing, or analyzing relationships between variables objectively and measurably (Creswell & Creswell, 2018). To minimize the influence of external variables, both groups were taught the same transformation geometry content, used the same learning objectives, received instruction over the same period, and were assessed using identical instruments. In addition, pre-test scores were analyzed to ensure that the GE and GC had comparable initial abilities before the treatment. **Table 1** depicts the outline of a quasi-experimental research design.

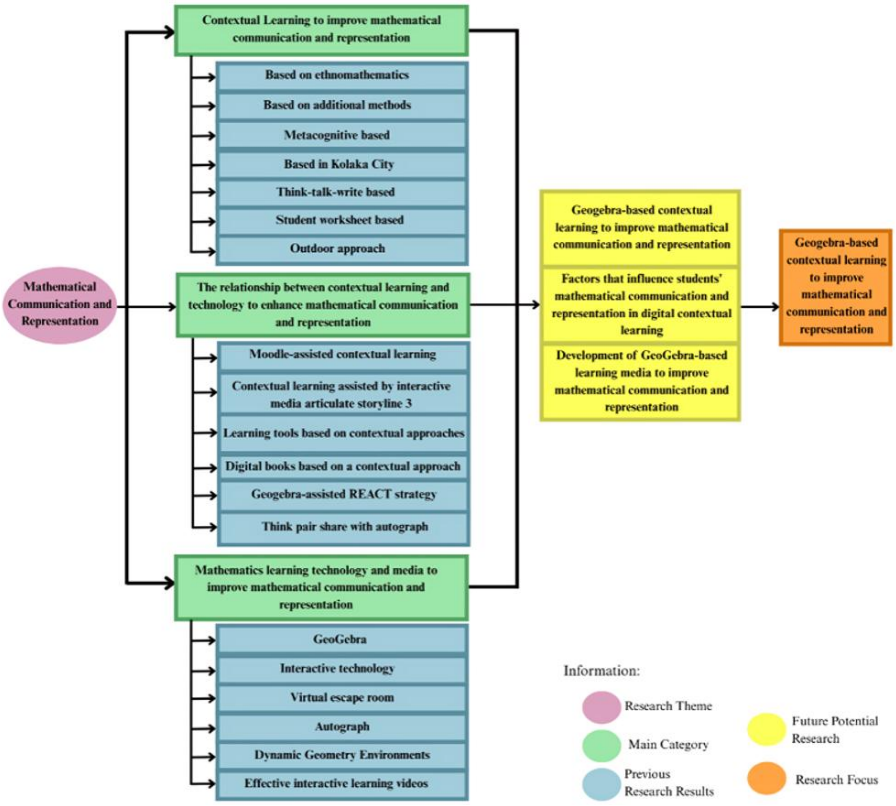


Figure 1. State of the art (created by the authors)

Table 1. Outline of a quasi-experimental research design

Group	Treatment		
GE	Pre-test	Using GeoGebra	Post-test
GC	Pre-test	Without GeoGebra	Post-test

Table 2. Research sample in ninth grade

Class	Gender		Number of students	Group
	Male	Female		
IX A	13	13	26	GE
IX B	13	14	27	GC
Total	26	27	53	

Population, Sampling, and Samples

The study population included all ninth-grade students at a school in Indonesia, consisting of four classes with 101 students. The school was selected purposively because it had adequate technological facilities to support GeoGebra implementation and had experience integrating digital learning media into mathematics instruction. Ninth-grade students were selected as the target group because they had already received material relevant to the research topic and were considered capable of providing data in accordance with the research objectives. Purposive sampling was used to select two classes with relatively similar academic achievement based on previous mathematics scores and teacher recommendations. One class was randomly assigned to the GE and the other to the GC. Class IX A, consisting of 26 students, served as the GE while class IX B, comprising 26 students served as the GC. **Table 2** depicts the sample distribution.

Data Collection

Data were collected over five learning sessions through pre-tests, post-tests, and classroom observations. Before the instructional intervention, all students completed a pre-test to measure their initial mathematical representation skills. The GE then participated in GeoGebra-supported contextual mathematics learning, while the GC received conventional teacher-centered instruction. To minimize teacher effects, the same mathematics teacher taught both the GE and GC. Prior to the intervention, the teacher was briefed on the instructional procedures and learning materials to ensure consistency in implementation across the study. After the learning intervention was completed, a post-test was administered to assess students' mathematical representation skills. In addition, data on students' mathematical communication skills were collected through classroom observations conducted during students' presentations. During these activities, students were asked to present their solutions and explain their reasoning in front of the class, while the observation sheet was completed by an observer who was a mathematics teacher. The observer assessed students' mathematical communication skills based on the predetermined indicators throughout the presentation activities.

Learning Procedures

The GE participated in GeoGebra-supported contextual mathematics learning on transformation geometry topics. Each learning session lasted approximately 2 lesson hours (70 minutes). Students worked collaboratively in small groups using GeoGebra activities prepared by the researcher and integrated into student worksheets. Through these activities, students explored concepts of translation, reflection, rotation, and dilation by manipulating geometric objects dynamically in GeoGebra and connecting the concepts to contextual problems (Sukowati & Sutama, 2026; Uula et al., 2024). Students were required to complete the student worksheets while discussing their observations and findings within their groups. At the end of each session, groups presented their solutions and conclusions both orally and by demonstrating the GeoGebra constructions they had created. These presentations were designed to encourage students to communicate mathematical ideas, explain solution strategies, and represent mathematical concepts using visual, symbolic, and verbal forms. In contrast, the GC learned the same material through conventional teacher-centered instruction involving explanation, examples, and individual exercises without GeoGebra.

Instruments

The instruments used to collect data in the study were a mathematical communication observation sheet and a mathematical representation ability test in the transformation material. These instruments were designed to examine students' mathematical communication and mathematical representation skills. In designing the mathematical communication ability observation sheet, questions were developed based on the view of Uyen et al. (2021) who stated that there are three aspects assessed in mathematical communication, namely mathematical vocabulary, representation, and explanation. Then, these three aspects were further developed by Kholid et al. (2024a) to include five aspects:

(1) being able to understand problems;

(2) being able to change problems into mathematical language;

(3) understanding how to represent a problem;

(4) being able to represent problems;

(5) understanding how to explain answers; and

(6) being able to provide explanations of answers orally and in writing.

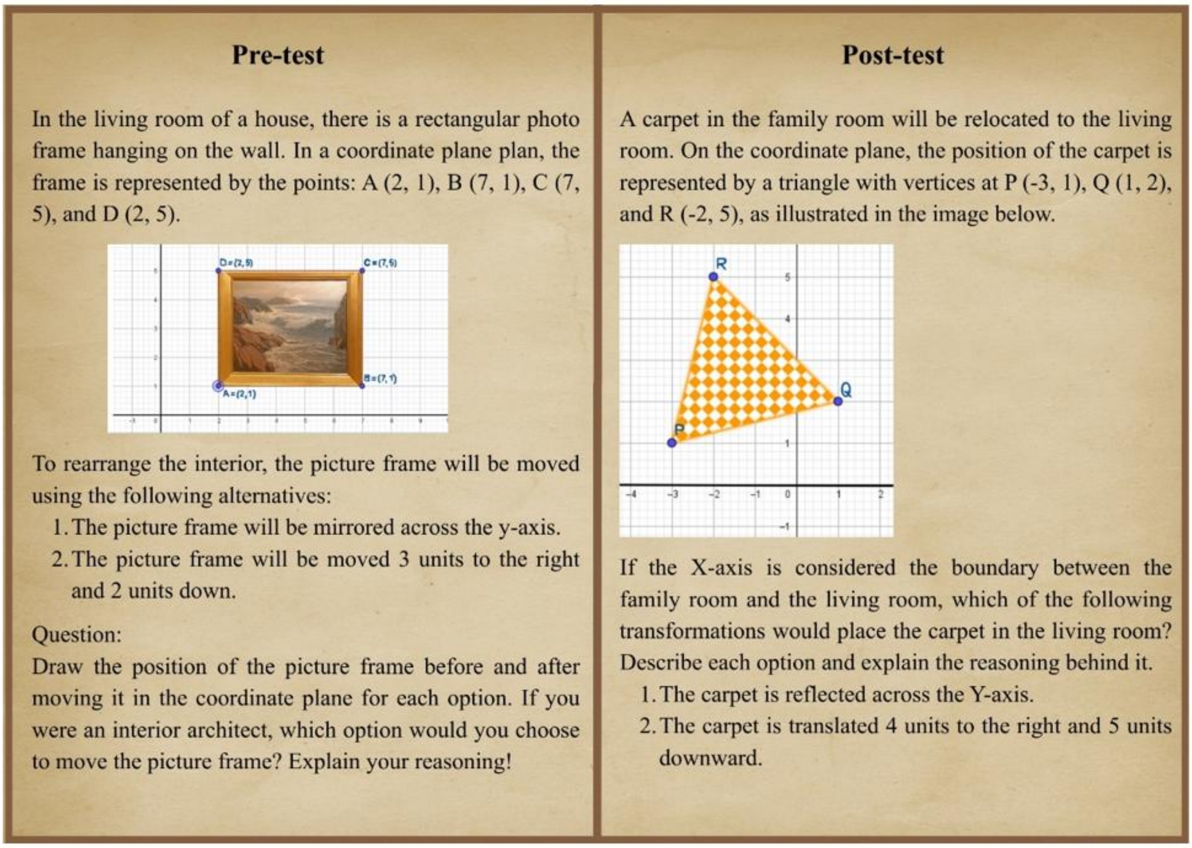
Meanwhile, the mathematical representation ability test instrument refers to the mathematical representation indicators proposed by Utomo and Syarifah (2021):

(1) in visual representation, students present problems in the form of images to solve them;

(2) in symbolic representation, students use mathematical expressions using symbols or numbers to solve problems; and

(3) in verbal representation, students write interpretations of the problems presented.

Figure 2 presents the mathematical representation of the pre- and post-test questions used for data collection. The instrument was then tested for validity and reliability. Validity refers to a trial of research questions with the aim of determining the extent to which respondents understand the questions posed by the researcher, while reliability is the test of the consistency of respondents' answers (Sahir, 2021). The validity of the mathematical communication ability observation sheet and the mathematical representation ability test was tested through assessments by mathematics education lecturers.



Pre-test

In the living room of a house, there is a rectangular photo frame hanging on the wall. In a coordinate plane plan, the frame is represented by the points: A (2, 1), B (7, 1), C (7, 5), and D (2, 5).

To rearrange the interior, the picture frame will be moved using the following alternatives:

1. The picture frame will be mirrored across the y-axis.
2. The picture frame will be moved 3 units to the right and 2 units down.

Question:

Draw the position of the picture frame before and after moving it in the coordinate plane for each option. If you were an interior architect, which option would you choose to move the picture frame? Explain your reasoning!

Post-test

A carpet in the family room will be relocated to the living room. On the coordinate plane, the position of the carpet is represented by a triangle with vertices at P (-3, 1), Q (1, 2), and R (-2, 5), as illustrated in the image below.

If the X-axis is considered the boundary between the family room and the living room, which of the following transformations would place the carpet in the living room? Describe each option and explain the reasoning behind it.

1. The carpet is reflected across the Y-axis.
2. The carpet is translated 4 units to the right and 5 units downward.

Figure 2. Mathematical representation pre- and post-test questions (created by the authors)

Table 3. Cronbach's alpha test

	Cronbach's alpha	N
Pre-test	0.710	2
Post-test	0.842	2

The validation process examined both content validity and construct validity to ensure the alignment of the instruments with the transformation of geometry material and the indicators of mathematical communication and mathematical representation skills. Based on the experts' feedback, several revisions were made, including improving the clarity and effectiveness of sentence structures, refining the appropriateness of questions and supporting images, and ensuring the alignment of each item with the corresponding assessment indicators. To provide additional evidence of instrument quality, the reliability of the mathematical representation ability test was evaluated using Cronbach's alpha. The analysis yielded coefficients of 0.710 for the pre-test and 0.842 for the post-test, indicating acceptable and high levels of internal consistency, as shown in **Table 3**.

Furthermore, classroom observations were conducted by a single observer using a structured observation rubric. Therefore, inter-rater reliability was not applicable in the study. To enhance the consistency and trustworthiness of the observation data, the observer followed standardized observation procedures and applied clearly defined assessment criteria throughout the implementation of the study.

Furthermore, each indicator of mathematical communication and mathematical representation was coded to facilitate identification. Coding was performed by manually writing the code on the subject's answer sheet after completing the first test. The step aimed to classify students' mathematical communication and mathematical representation skills based on the established indicators. The coding results are presented in **Table 4** and **Table 5**, which serve as the basis for drawing conclusions regarding the characteristics of students' mathematical communication and mathematical representation skills.

Table 4. Aspects and indicators of mathematical communication

Aspects of mathematical communication	Mathematical communication indicators	Code
Mathematical vocabulary	Able to understand mathematical problems in the form of questions, texts, or everyday life contexts by using appropriate mathematical vocabulary.	MV1
	Able to change or rewrite a story problem into a sentence or appropriate mathematical symbol using correct mathematical language.	MV2
Representation	Able to understand and determine the right way to represent a mathematical problem in visual, symbolic, or verbal form.	R1
	Able to represent mathematical problems in various forms, such as pictures, graphs, tables, or relevant mathematical models to obtain solutions.	R2
Explanation	Able to understand the steps in explaining the process of solving a mathematical problem in a sequential and logical manner.	E1
	Able to provide explanations of the results or mathematical answers obtained, both verbally and in writing, using appropriate mathematical terms.	E2

Table 5. Types and indicators of mathematical representation

Types of representation	Indicator	Code
Visual	Able to present mathematical problems in visual form, such as diagrams, pictures, or graphs, to help the process of understanding and solving problems.	RVi
Symbolic	Able to use mathematical expressions or models in the form of symbols, equations, or notation to represent and solve given problems.	RSi
Verbal	Able to write or express an interpretation of a mathematical problem and the results of its solution using clear and systematic sentences.	RVe

Research Stages

The research was conducted in four stages: analysis, model design, implementation, and evaluation. The analysis stage identified classroom learning conditions and opportunities to integrate GeoGebra into contextual mathematics learning. These findings were used to design learning tools that were implemented in the experimental class, while the control class received conventional instruction. Finally, pre-intervention tests, post-intervention tests, and classroom observations were conducted to evaluate the effectiveness of the intervention on students' mathematical communication and representation skills. The overall research stages are presented in **Figure 3**.

Data Analysis

Quantitative data from the pre-test and post-test results of students' mathematical communication skills were analyzed using the statistical package for the social sciences (Karamurugan & Govindaraja, 2022). The analysis began with descriptive analysis to obtain a general overview of the scores in each group. Before conducting the hypothesis test, the data were tested for normality using the Shapiro-Wilk test and for homogeneity of variance using Levene's Test to ensure the feasibility of using parametric tests.

Furthermore, a paired sample t-test was used to determine whether there was a significant increase in mathematical communication and mathematical representation skills in each group. Then, an independent two-sample t-test was used to examine the differences in post-test results between the GE using GeoGebra in contextual learning and the GC using conventional methods. In addition, as the study has two dependent variables, namely mathematical communication skills and mathematical representation skills, the analysis was continued with multivariate analysis of covariance (MANCOVA) with pre-test scores as covariates. The use of MANCOVA was intended to determine the effect of GeoGebra implementation in contextual learning on both students' mathematical abilities simultaneously by controlling differences in initial abilities.

Hypothesis

Several previous studies have applied a contextual approach to improve students' mathematical communication and mathematical representation, such as Tupamahu et al. (2023). Furthermore, several previous studies have also integrated GeoGebra to improve students' mathematical communication and mathematical representation (Kholid et al., 2022; Kusumah et al., 2020; Septian et al., 2023). Although several previous studies have demonstrated effectiveness, it is hypothesized that the integration of GeoGebra with

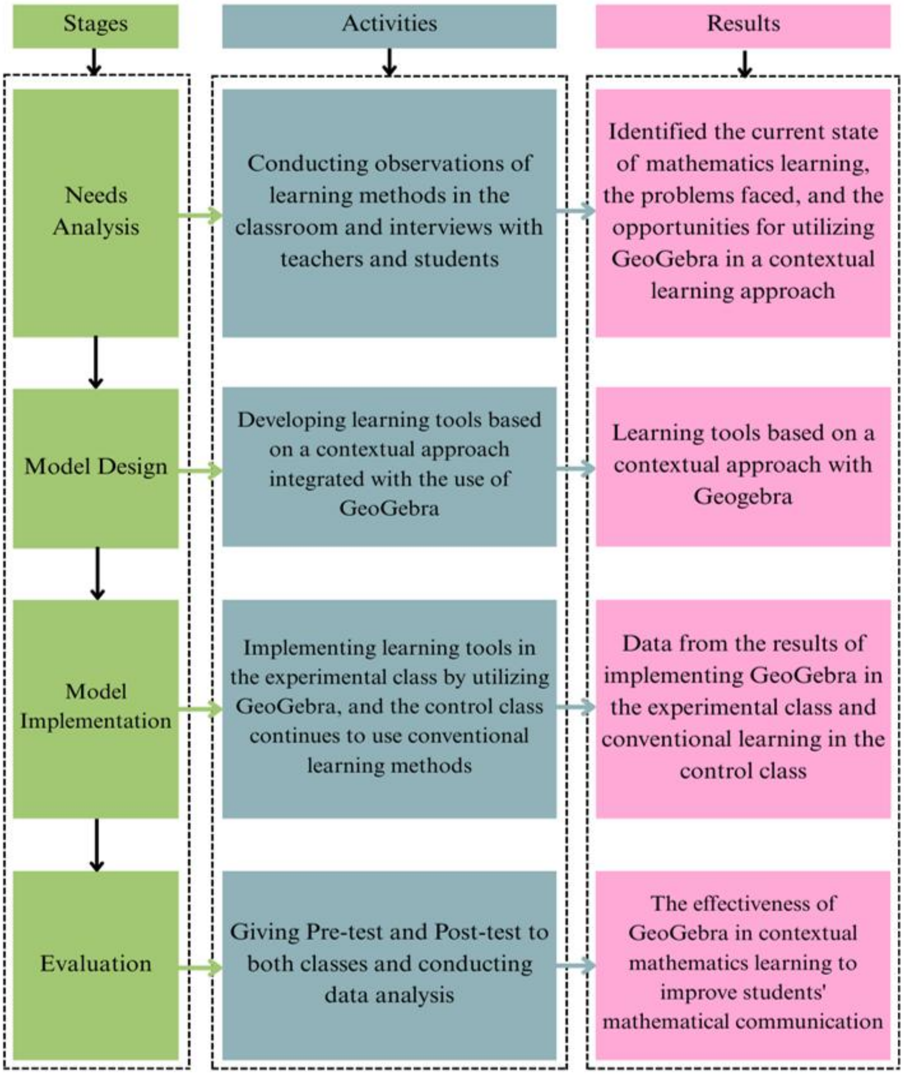


Figure 3. Research stages (created by the authors)

contextual learning can enhance mathematical communication and representation. Therefore, the study hypothesizes that the implementation of GeoGebra in contextual mathematics learning significantly improves students' mathematical communication and representation.

RESULT

GeoGebra-Based Learning Media in Contextual Mathematics Learning

In the study, GeoGebra is used as a learning tool that students can use to explore the concept of transformation geometry in everyday life contexts. GeoGebra is not the primary learning resource but serves as a tool for exploration that allows students to directly transform objects through features such as drag, sliders, and moving visualizations. In this way, students can observe changes in position, shape, and relationships between objects in simple contexts, such as changing the position of an object in a room or the reflection of an object's image in a plane mirror.

After using GeoGebra, students recorded their findings in the Student Worksheet, such as the pairs of starting points and transformation results, patterns of coordinate changes, and initial predictions about transformation rules. The information obtained was then used to draw conclusions and formulate transformation formulas as a group. Thus, GeoGebra not only provides an interactive learning experience but also reinforces contextual-based mathematics learning methods by encouraging students to connect visual exploration results with symbolic representations and their own mathematical thinking skills.

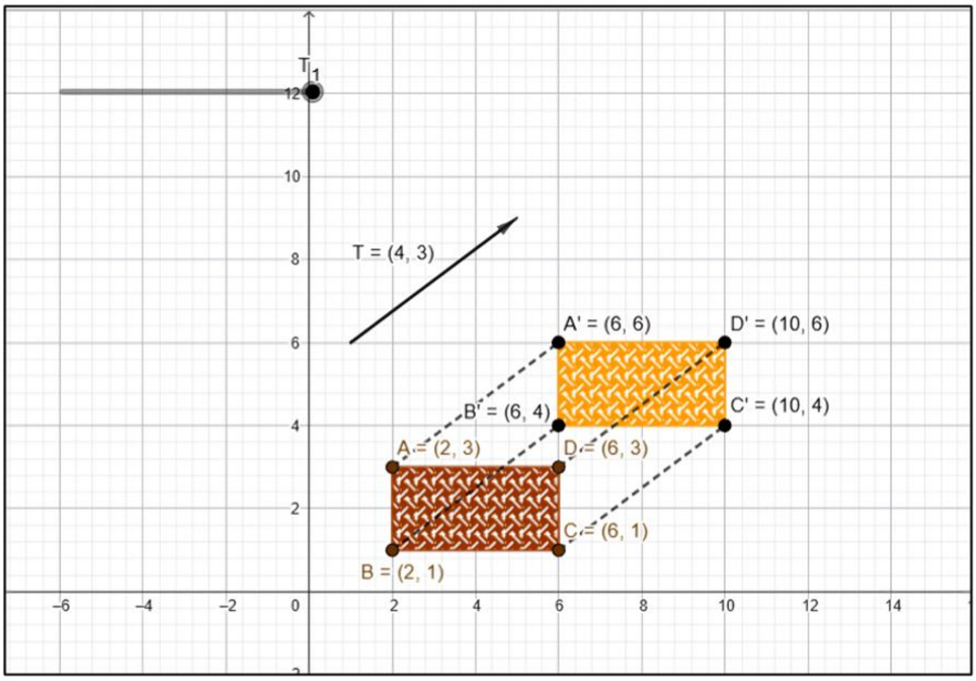


Figure 4. GeoGebra activity (created by the authors)

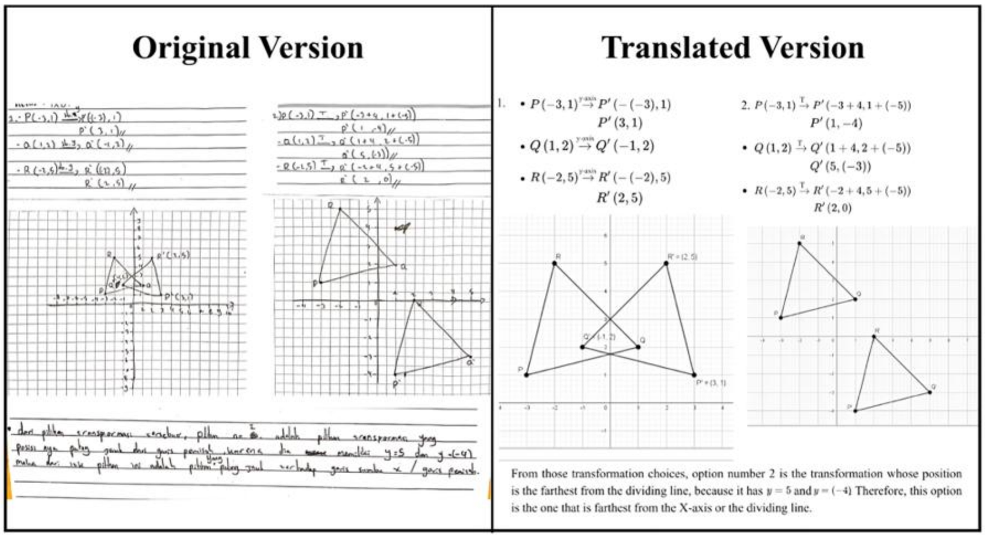


Figure 5. Students' answers (created by the authors)

To clarify how learning media were used in the study, **Figure 4** shows one of the GeoGebra activities used by students. In the activity, students made changes to objects in GeoGebra, then wrote the resulting transformation patterns in a worksheet as a basis for drawing conclusions. These activities serve as the main foundation for using GeoGebra to strengthen mathematical communication and representation skills within a contextual learning approach.

The implementation of GeoGebra-assisted learning provides opportunities for students to be actively involved in the process of constructing concepts, communicating understanding, and constructing mathematical representations based on exploratory experiences. The findings that emerged during the process were then reflected in student learning outcomes as measured through pre- and post-tests for mathematical representation and observation results for mathematical communication. Therefore, quantitative data analysis in the study was conducted to measure the effectiveness of GeoGebra implementation in improving students' mathematical communication and representation skills. **Figure 5** shows the students' answers.

Table 6. Results of the Shapiro-Wilk normality test

Sample	Statistics	df	Sig.	Criteria
GE communication pre-test	0.931	23	0.114	Normal
GE communication post-test	0.948	23	0.260	Normal
GE representation pre-test	0.921	23	0.069	Normal
GE representation post-test	0.934	23	0.136	Normal
GC communication pre-test	0.965	23	0.577	Normal
GC communication post-test	0.943	23	0.206	Normal
GC representation pre-test	0.980	23	0.899	Normal
GC representation post-test	0.959	23	0.440	Normal

Table 7. Results of Levene's homogeneity test

Sample	Levene statistic	df1	df2	Sig.	Criteria
Communication and representation pre-test results	2.721	1	99	0.102	Homogeneity
Post-test results of communication and representation	1.725	1	103	0.192	Homogeneity

Table 8. Results of the paired sample t-test

Sample	Mean	95% confidence interval of the difference		t	df	Sig. (2-tailed)	Criteria
		Lower	Upper				
GE communication pre-test - GE communication post-test	-45.52538	-50.63041	-40.42036	-18.366	25	0.000	There is a difference.
GE representation pre-test - GE representation post-test	-70.86538	-76.29148	-65.43929	-26.898	25	0.000	There is a difference.
GC communication pre-test - GC communication post-test	-40.43185	-48.16038	-32.70333	-10.754	26	0.000	There is a difference.
GC representation pre-test - GC representation post-test	-42.50000	-51.36683	-33.63317	-9.852	26	0.000	There is a difference.

Data Analysis Results

Table 6 shows the results of the normality test for the observation data of mathematical communication and mathematical representation tests, where the significance value in the Shapiro-Wilk test is above 0.05 (sig. > 0.05). Therefore, the data is normally distributed. Furthermore, **Table 7** shows the results of the homogeneity of variance test with a significance value of 0.102 for the pre-test and 0.192 for the post-test. Since both values were greater than 0.05 (sig. > 0.05), the assumption of homogeneity of variance was satisfied. Because the data is normally distributed and homogeneous, the data in the study can be further tested using a paired sample t-test to see improvements in each group, an independent sample t-test to compare differences between the GE and GC, and MANCOVA to analyze multivariate differences by considering relevant covariates.

Table 8 depicts the results of the paired sample t-test used to determine whether there was an increase in ability in each group. In the GE, the significance value for mathematical communication and mathematical representation skills was below 0.05 (sig. 2-tailed < 0.05), demonstrating significant differences between the pre- and post-test scores. These findings suggest that both skills improved following the implementation of GeoGebra-supported contextual learning. Similar results were observed in the GC, where the significance values for both variables were also below 0.05 (sig. 2-tailed < 0.05). The finding shows that students in the GC also demonstrated improvement in mathematical communication and representation skills. Although both groups exhibited gains, the relative effectiveness of the intervention was further examined through between-group analyses.

Table 9 illustrates the results of the independent sample t-test used to compare the differences in abilities between GE and GC. Based on the analysis, the significance value for mathematical communication ability showed a value of 0.001 (sig. 2-tailed < 0.05). The result indicates that there is a significant difference between GE and GC in mathematical communication ability in the post-test results. Furthermore, the test results for mathematical representation ability also showed a value of 0.000 (sig. 2-tailed < 0.05). Thus, it can be concluded that there is a significant difference between the two groups in mathematical representation ability. Overall, these results confirm that the learning treatment given to GE resulted in a significant difference in ability when compared to GC. To determine the magnitude of the treatment effect, Cohen's d

Table 9. Results of the independent sample t-test assume equal variances

Sample	F	t	df	Sig. (2-tailed)	95% confidence interval of the difference		Cohen's d	Criteria
					Lower	Upper		
Communication	10.350	1.458	51	0.001	-2.56213	16.16586	0.402	There is a difference.
Representation	18.993	5.841	51	0.000	19.93003	40.80359	1.61	There is a difference.

Table 10. Test results of between-subjects effects

Dependent variable	df	F	Sig.	Criteria
Communication	1	1.316	0.025	There is a difference.
Representation	1	30.647	0.000	There is a difference.

Table 11. Results of multivariate tests

Effect		Value	F	Sig.	Criteria
Class	Wilks' lambda	0.383	39.547^b	0.000	H_0 rejected

effect size was calculated. The effect size for mathematical communication ability was d = 0.402, indicating a small effect, while the effect size for mathematical representation ability was d = 1.61, indicating a large effect. These results suggest that GeoGebra-supported contextual learning had a stronger impact on students' mathematical representation skills than on their mathematical communication skills.

The MANCOVA test results were used to determine the effect of GeoGebra implementation in contextual learning on both students' mathematical skills simultaneously by controlling differences in initial abilities. Based on the analysis results in **Table 10** through the test of between-subjects effects test, the significance value for mathematical communication is 0.025 (sig. < 0.05) and mathematical representation is 0.000 (sig. < 0.05). These findings indicate that the intervention significantly influenced both outcome variables after controlling pre-existing differences between groups.

Furthermore, **Table 11**, which contains the results of the Multivariate Tests, shows a significance value of 0.000 (sig. < 0.05), providing evidence of a significant overall effect of GeoGebra-supported contextual learning on students' mathematical communication and representation skills.

DISCUSSION

The study aims to examine the effect of GeoGebra implementation in contextual mathematics learning on improving students' mathematical communication and mathematical representation skills. These two skills are important parts of mathematical competencies that must be developed in today's learning. They emphasize not only the mastery of procedural steps but also students' ability to convey mathematical ideas both orally and in writing. Additionally, students should be able to represent mathematical concepts in various forms, such as symbols, graphs, diagrams, and visual models (Anwar et al., 2025; Rahmi & Chrisdiyanto, 2024). To achieve the research objective, the study formulates one hypothesis, that the implementation of GeoGebra in contextual mathematics learning has a significant effect on improving students' mathematical communication and mathematical representation skills.

The results of the statistical analysis showed that both groups, namely the GE and the GC, experienced an increase in mathematical communication and mathematical representation skills after participating in the learning process. This is evidenced by the results of the paired sample t-test presented in **Table 8**, which shows that there is a significant difference between the initial test scores (pre-test) and the final test (post-test) in the two groups. These findings suggest that both instructional approaches contributed to the development of students' mathematical abilities. One possible explanation is that the contextual approach helped students connect mathematical concepts with real-life situations, thereby facilitating conceptual understanding.

However, after further comparison between the two groups, the results of the independent sample t-test with the assumption of homogeneous variance in **Table 9** indicate a significant difference in post-test scores between GE and GC. GE, who received contextual mathematics learning with the help of GeoGebra, showed significantly better results than GC. These results indicate that the use of GeoGebra provides significant benefits in contextual mathematics learning, especially in improving students' mathematical communication and mathematical representation skills. GeoGebra allows students to explore mathematical concepts dynamically, manipulate mathematical objects, and see the relationship between symbolic, graphic, and visual forms directly.

Furthermore, to ensure that the observed differences in results were attributable to the method employed rather than variations in students' initial abilities, the study conducted a MANCOVA test, controlling for the pre-test score as a covariate variable, as illustrated in **Table 10** and **Table 11**. The results of the MANCOVA test showed that GeoGebra implementation still had a significant effect on students' mathematical communication and mathematical representation skills, even after initial abilities were controlled. The finding supports empirical evidence that the improvement of students' mathematical abilities in GE is not only caused by initial factors, but also due to the use of GeoGebra in mathematics learning based on contextual mathematics learning. Accordingly, the findings support the proposed hypothesis. Therefore, GeoGebra implementation in contextual mathematics learning significantly influences students' mathematical communication and mathematical representation skills.

The findings of the study align with the results of several previous studies showing that GeoGebra is highly effective as a technology-based mathematics learning medium. Several studies have shown that GeoGebra can improve students' understanding of mathematical concepts due to its dynamic and interactive visualizations, enabling students to understand not only the procedures but also the meaning of the concepts (Aliu, 2025; Arbain & Shukor, 2015). Furthermore, the use of GeoGebra also stimulates students' creative thinking, enhances practical and effective learning processes, and helps develop mathematical problem-solving skills (Azis & Rohaeti, 2025; Bilgin & Serin, 2022; Mollakuqe, 2025). GeoGebra's unique visualization and interactivity enable students to explore independently, test assumptions, and build deeper conceptual understanding. Therefore, the results of the study do not contradict previous research but instead provide additional evidence that the integration of GeoGebra and contextual learning can effectively improve students' mathematical abilities.

Bach et al. (2024) stated that GeoGebra-based learning had a positive impact on students' mathematical communication and representation skills. The is because GeoGebra has characteristics that allow students to express mathematical ideas through various forms of representation, such as graphs, animations, and visual models (Azis & Rohaeti, 2025). In addition, students can also discuss the results of their explorations with friends and teachers. These findings are consistent with the results of the study, which showed that students in GE had a better ability to convey mathematical ideas clearly, using appropriate representations, and connecting various forms of representation to solve contextual problems.

On the other hand, the contextual learning approach used in the study also plays a significant role in improving students' mathematical abilities. The approach emphasizes the relationship between the material taught and students' real-life experiences, making the learning process more relevant and meaningful (Spooner, 2024). Several studies have shown that the approach can increase student engagement, deepen students' understanding of concepts, and help students construct knowledge constructively (Dewi et al., 2021; Mahmuti & Thaqi, 2025; Seloane et al., 2023; Suryawati & Osman, 2018). In the study, the use of problems related to students' daily lives encouraged them to communicate, discuss, and convey mathematical ideas more actively.

The combination of GeoGebra and contextual learning, as implemented in the study, has been shown to enhance the effectiveness of mathematics learning. GeoGebra acts as a visual and exploratory tool that helps students understand abstract mathematical concepts (Ardina & Boholano, 2024). Meanwhile, the contextual approach provides meaning and relevance to these concepts (Sukasno et al., 2024). By combining these two approaches, students not only understand mathematical concepts conceptually but are also able to communicate and represent mathematical ideas in various forms according to the context of the problem. The results of the study not only support the findings of previous studies but also provide empirical evidence regarding the effectiveness of integrating visual technology with a contextual learning approach in improving students' mathematical communication and representation skills. From the perspective of constructivist theory, the finding can be explained by the active role of students in constructing knowledge through direct interaction with mathematical objects. Through the drag-and-drop feature in GeoGebra, students can manipulate geometric objects and immediately observe the resulting changes in position, shape, and coordinates. The process enables students to identify patterns, test conjectures, and connect visual information with symbolic and verbal representations. Because students can directly observe how a transformation changes an object, they develop stronger representational thinking and are better able to represent mathematical concepts accurately. Therefore, GeoGebra not only facilitates procedural understanding but also supports the construction of conceptual understanding through multiple representations.

The findings can also be interpreted from a sociocultural perspective, which emphasizes the role of social interaction in knowledge construction. During GeoGebra-supported contextual learning, students were encouraged to discuss problem-solving strategies, explain their reasoning, and negotiate mathematical meanings with peers and teachers. These collaborative activities provided opportunities for students to externalize their thinking and refine their understanding through dialogue. From the perspective, mathematical communication develops not only through individual cognitive processes but also through participation in socially mediated learning activities. Therefore, the interaction between contextual tasks, collaborative discussion, and GeoGebra-assisted exploration may have contributed to the observed improvements in students' communication and representation skills.

An important finding of the study is the substantial difference in the magnitude of the intervention effects on mathematical representation and mathematical communication. While GeoGebra-supported contextual learning produced a large effect on students' mathematical representation skills ($d = 1.61$), the effect on mathematical communication was comparatively smaller ($d = 0.402$). The difference may be explained by the nature of GeoGebra as a dynamic visualization tool. Through interactive manipulation of geometric objects, students can directly observe transformations, identify patterns, and connect visual, symbolic, and graphical representations. Such features provide immediate support for the development of representational competence, which may explain the large improvement observed in the study. In contrast, mathematical communication involves more complex processes, including the use of mathematical language, argumentation, explanation, and participation in discussion. These competencies often require sustained opportunities for interaction, feedback, and reflective discourse over a longer period of time (Asmawati et al., 2023; Kholid et al., 2024c). Therefore, although GeoGebra-supported contextual learning contributed positively to students' mathematical communication skills, the observed effect should be interpreted as small to moderate. The finding suggests that dynamic technology may have a more direct influence on representational development, whereas communication skills may require longer-term instructional support to achieve more substantial gains.

CONCLUSION

The study addressed two research questions concerning the effects of GeoGebra-supported contextual learning on students' mathematical communication and representation skills in transformation geometry. Regarding the first research question, the findings indicate that GeoGebra-supported contextual learning contributed positively to students' mathematical communication skills, although the magnitude of the effect was relatively modest ($d = 0.402$). Regarding the second research question, the intervention demonstrated a substantial positive effect on students' mathematical representation skills ($d = 1.61$), suggesting that the integration of contextual learning and dynamic visualization is particularly effective for supporting students' representational competence.

The study contributes to the growing body of research on technology-enhanced mathematics education by providing empirical evidence that the combination of contextual learning and GeoGebra can simultaneously support the development of mathematical communication and representation skills. The findings further suggest that dynamic visualization tools may have a more direct impact on representational development, while communication skills may require longer and more sustained instructional support.

From a practical perspective, the findings suggest that mathematics teachers should integrate dynamic visualization tools such as GeoGebra within contextual learning activities rather than using technology solely for demonstration purposes. Learning experiences that connect mathematical concepts with real-world situations can provide opportunities for students to explore, represent, discuss, and communicate mathematical ideas more effectively. For curriculum designers, the results highlight the importance of incorporating technology-enhanced contextual tasks into mathematics curricula, particularly in topics that require visualization and multiple representations, such as transformation geometry.

Several limitations should be acknowledged. The study employed a quasi-experimental design without random assignment and was conducted within a single school context, which may limit the generalizability of the findings. In addition, the intervention was implemented over a relatively short period, and the assessment of mathematical communication relied partly on classroom observation, which may be influenced by observer subjectivity. Future research should involve larger and more diverse samples, longer intervention periods, and additional mathematical topics to further examine the effectiveness and sustainability of GeoGebra-supported contextual learning across different educational contexts.

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